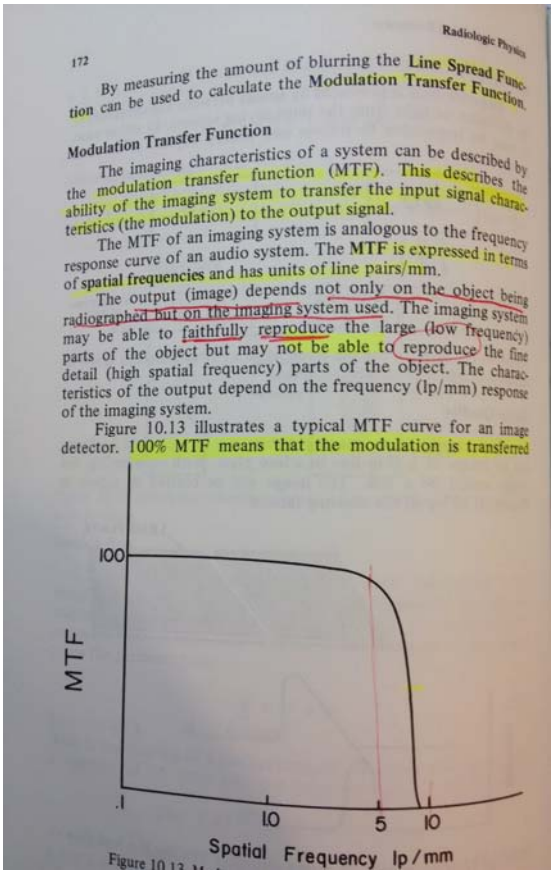
C3- Image Acquisition, Processing and Display

Principles of and techniques for image acquisition; image formation; digital imaging; computer-based image reconstruction; methods for image display; image analysis; image processing, image enhancement, fusion and segmentation; image artifacts; modulation transfer function; signal to noise ratio; and related subjects.

Wepassed ()
Image registration (+1)
MRI: MRI Note (+1) question (+1)
PET: question (+1) read wepassed (PET Attenuation Correction)
CT: CT dose note (+1) TG66(+1)
Film: (+1)
Ultrasound: Kahn (238-239)
EPID (+1)
Scout&DRR (+1)

(Essential of radiology physics p165 & p172 has good explanation)
Spatial resolution of an imaging sys is defined as the separation at which 2 objects can just be distinguished as 2 distinct objects rather than 1. Spatial resolution is measured as lp/mm.

MTF describes the ability of the imaging sys to transfer the input signal characteristics (such as spatial resolution) to the output signal



C3-A (MRI, PET/CT)

(Registration & fusion)

- How does fusion work? Image fusion and image registration: what is the difference?

  Basically, there are 2 steps one is the image registration and then is the image fusion;

  The image registration builds the geometric transformation that connects the coordinates of the 2 image data sets.

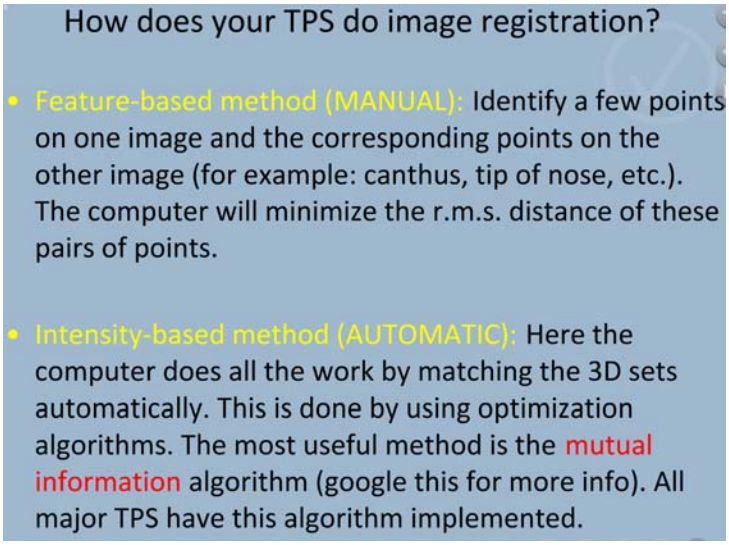
  The image fusion bases on the information of the transformation obtained from the registration and maps the structure or the image feature from one to another / or combines the grayscale data of the 2 imaging sets (that's what we usually do)

  Registration finds the correlation between 2 image sets and fusion adds the 2 image set together.

  - How do you do fusion? What ways exists to do fusion?

1. (Alignment) First, I will manually fuse 2 images by using the features of the 2 data sets such as bony anatomy. Also depending on the VOI, I will emphasize aligning the 2 images correctly on that VOI.
2. Then, I will let the TPS do the automatic registration, and at some case, I will open the VOI box, and ask the TPS focus on the registration with in the VOI.
3. After the automatic registration is done, I will then double check and possibly fine tune (translational & rotational adjust) the image registration in case the registration algorithm missed.
4. We can use image overlay, split window, checkerboard display…etc to check the fusion accuracy. (If we use point-by-point method, it will provide the max distance (tolerance is 2 mm) among the point pairs and the mean distance of point pairs, so we will know how good is our image registration,(Eclipse image registration manual 8.9 p28 -29))

- Identify a few fusion algorithms; briefly describe the math behind them. Describe in detail mutual information.



They are all rigid registration:

1. Feature-based method
   - Point-by-point method: Manually identify the point at one image and the corresponding point on another. The algorithm will minimize the r.m.s. dist. of these images (Eclipse has this feature as well)
   - Surface based method: this method extract the surface from one or more anatomic structure and algorithm will compute and minimize the mismatching between the 2 data sets.

2. Intensity-based method:
   - Such as Mutual information (MI) used in Eclipse: The concept is that it measures the amount of information that one image contains about another image set. During the image registration, the mutual information is maximal if the images are geometrically accurately aligned.

(Ref: Eclipse algorithm guide, and Image registration document, AAPM summer school document)

Eclipse registration procedure: Eclipse algorithm guide p358:

1. Pre-align 2 images using central points of the images
2. Translates & rotates the target images (ex: MRI) and register it to the reference image which is static won't move (ex: CT). At this point, both images are set in low resolution to increase the registration speed. Then Eclipse evaluates the image using mutual information method
3. Once the mutual information is maximal. Eclipse will increase the image resolution and then fine tune the registration to further get better registration result.

The following images show a schematic representation of the method. Figure 50 on page 359 shows two images of the same patient, representing different organs with different shades of gray, and histograms computed from the pixel data in the images.

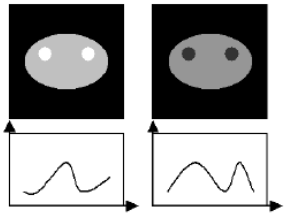
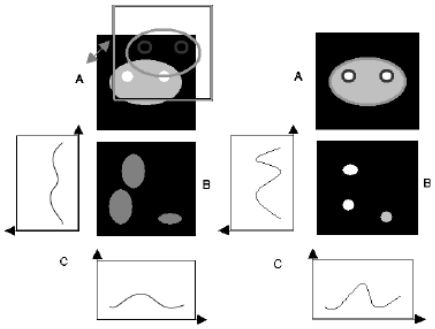


Figure 50 Images of Different Modalities and Histograms

Figure 51 on page 359 shows how the images are registered using their pixel data.



A. Registered images **B.** Two-dimensional representation of the joint histograms **C.** Image histograms

Figure 51 Registered Images and Joint Histograms

First, the images are geometrically aligned, and the registration procedure is started. At this point, the joint histogram is shallow, and the histogram points found are dispersed to large areas in the 2D representation. When

the registration procedure is completed, the joint histogram is highly peaked, and the mutual information values fall into smaller areas in the 2D representation.

- What are typical problems with fusion?
  Setup variation and the patient anatomy deformation are the major limitation for image fusion, which can induce the uncertainty of the target and OAR delineation. (Red journal **71**, S33, 2008) Poor resolution of the PET image can also lead the target delineation uncertainty.

- Image registration and fusion. Why? Give example cases when fusion of CT/MRI, CT/PET are needed. Do you fuse ultrasound images?
  The goal of image fusion is to effectively overlap the strength of one imaging modality over the weakness of another.

  CT/MRI: H&N, prostate
  CT/PET: Lung case (PET provide lung functional image)

  Ultrasound fused with CT/MRI is still under research development not used in routine clinical environment yet. The difficulty is the

  1. Different FOV between US and CT/MRI
  2. Noisy image of US (low image quality)
  3. Low image quality especially to bony structure
  4. Anatomic distortion due to transducer pressure
  5. US is real-time image, and the image quality is very operator dependent. The image registration with CT/MRI needs to be performed each time when US is taken.

     The above issues make the automatic registration difficult, and need extensive manual work to register US with other image modality.

  (IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION, VOL. 12, NO. 3, JUNE 2008)
  (Medical Image Analysis 12 (2008) 577–585)

- (2008) Fusion question. How much does the brain move? (less than resolution of CT -- less than 1mm) What kind of scan is PET? (he was looking for "functional" -- I said it reflected metabolic activity so he said I was on the right track)

- Discuss Image Fusion (Given a picture of CT/MRI fused axial. Identify which is CT which is MRI. Know what types of fusion techniques there are (most likely it's rigid registration).

- Image fusion. How does mutual information work? Seemed to want the mathematical relationships. What are other methods and how do they work? Is there a difference between multi-modality and same modality fusion?
  Same modality will have similar image features such as bony landmark is bright in CT, so CT-CT is easier compared to CT-MRI and CT-PET

For the same modality, it should be easy for system to find common feature to do the fusion. e.g, CT/CT, gray scale of the image can be reset to similar level and used to find featured structures or point for fusion. But for multi-modality, the easiest way is to match the outer body surface.

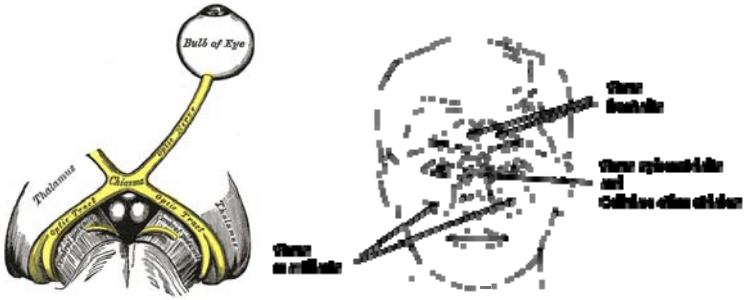
- What accuracy in fusion do you accept?
  MR/CT fusion: 2 mm
  PET/CT: 2 - 4mm, can be higher at other areas other than GTV

- How many different studies can you fuse for one patient?

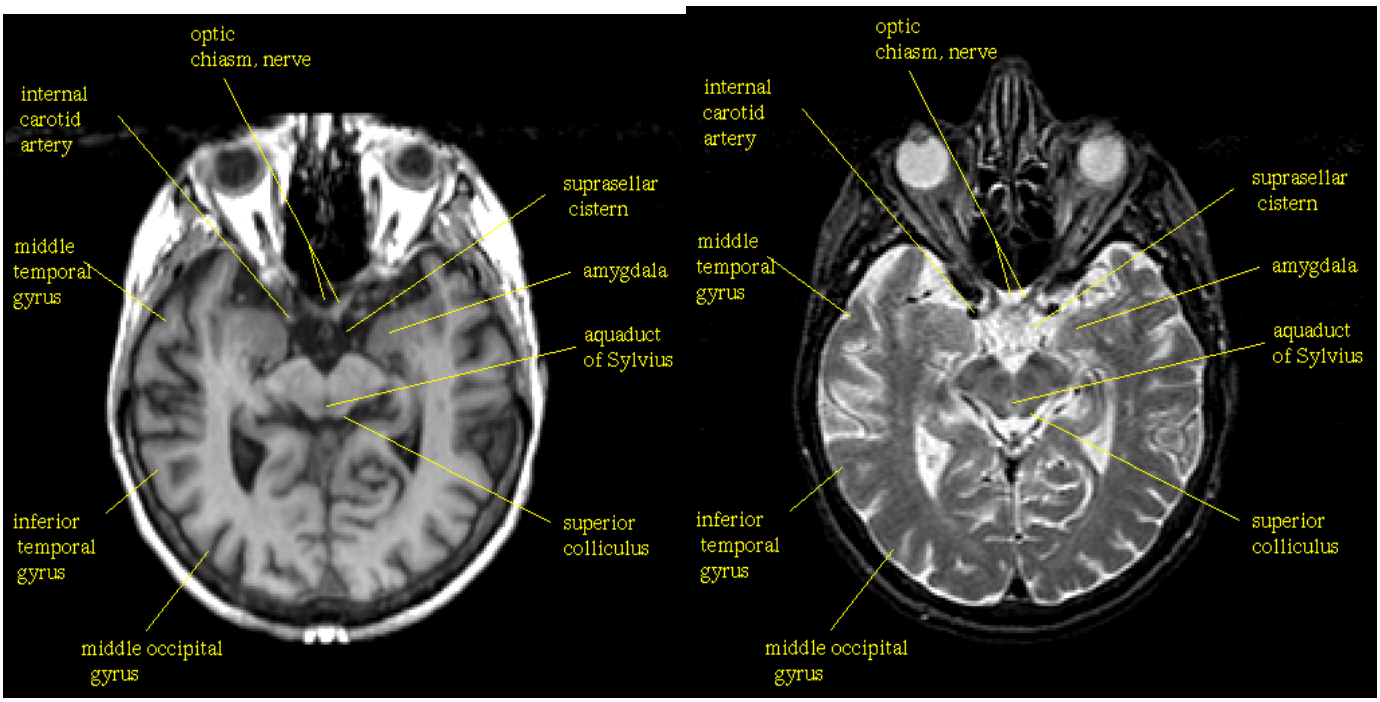
As many as u want

MRI:

- Two MRI (axial) slices of brain T1 or T2? Point out the structures ethmoid sinus, lens, optic chiasm, optic nerves. What type of MRI is this (T2) – how do you know that? T1 T2 MR images, which one is which? What type of MR images used in RT? (T1-axial, T2-axial, T1 contrast & T2-FLAIR), Know why you tell this one is T1.

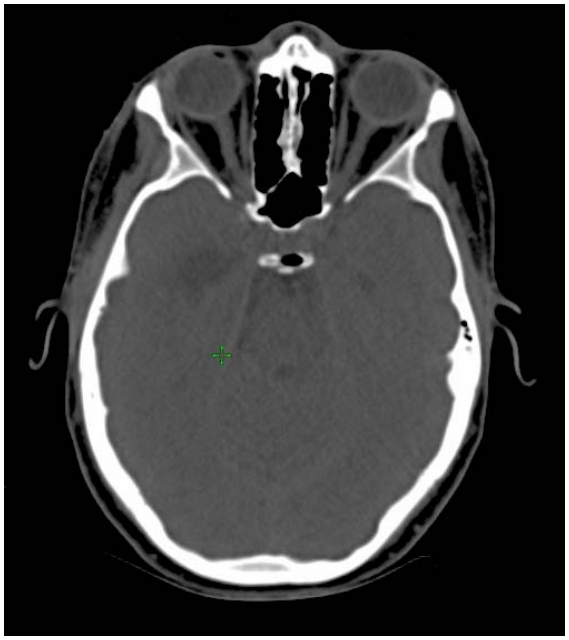


The **ethmoid sinuses** of the ethmoid bone are two of the four paired paranasal sinuses.



T1 **T2**

http://www.med.harvard.edu/AANLIB/cases/caseM/mr1_t/023.html



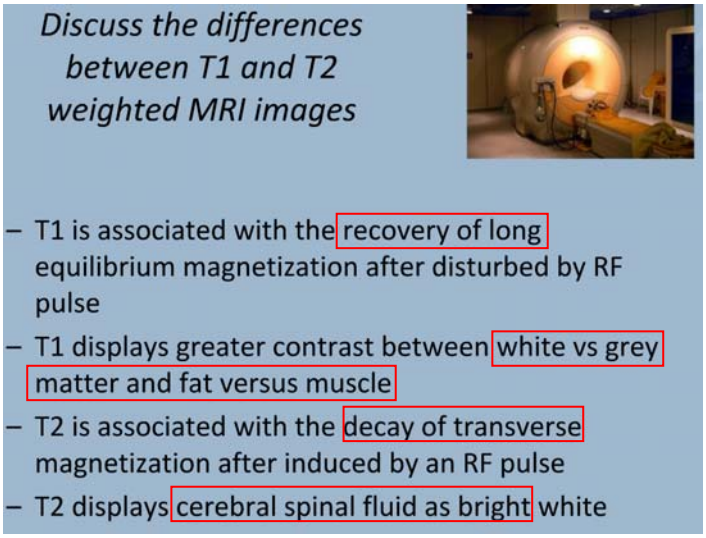
CT not from the same patient

T2 fluid is bright, and fat is dark.

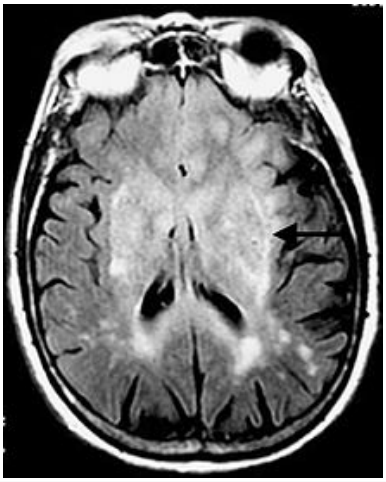
- Why would we need to see T2? T1 or T2 benefits of each? How is this image generated and what information does it give? Are there other types?

T_1-weighted image usually has excellent contrast: fluids are dark, and water-based tissue/organs are grey, and fat-tissues are very bright → so called "anatomy scan", as they show clearly the boundaries between tissues.

T_2-weitghted image has the highest intensity for fluid, and is often thought as "pathology" scan. Because it shows the abnormal fluid bright against the darker normal tissue, such as tumor.



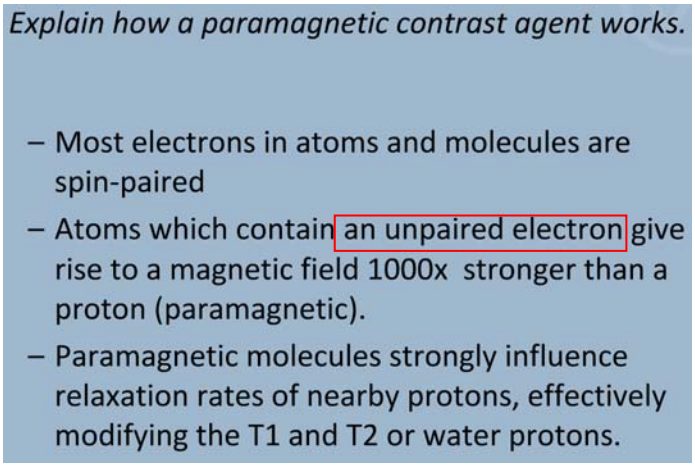
Yes, such as an improvement in T2-weighted image known as FLAIR (Fluid Attenuated Inversion Recovery) has become popular for being able to visualize the periventricular (腦室周圍) tissues without interference from bright cerebrospinal fluid (CSF).



Axial fluid-attenuated inversion recovery (Flair) MRI image demonstrating tumor-related infiltration involving lenticular nuclei (Arrow). http://en.wikipedia.org/wiki/Fluid_attenuated_inversion_recovery

The pulse sequence is an inversion recovery technique that nulls fluids. For example, it can be used in brain imaging to suppress cerebrospinal fluid (CSF) effects on the image, so as to bring out the periventricular hyperintense lesions, such as multiple sclerosis (MS) plaques.[1]

- Is contrast used in MRI? What material? Explain the workings of contrast mechanisms in MRI?
  Yes, gadolinium (Gd) compound.



Paramagnetic (順) materials have slightly positive susceptibility & enhance the local B field ex: O_2 or Gd based contrast agent.

Gd is an IV-injected MR contrast agent which **shortens the T1 of surrounding protons**, making the corresponding tissue appearing brighter. Because Gd normally stays in blood vessels it makes vessels, highly vascular tissues (such as tumor), and areas of blood leakage appear brighter.

- How do you use this image in treatment planning? What MR images are typically transferred into TPS?
  For treatment planning, the MR image is used for soft tissue contouring, as well as identifying tumor location. Due to tumor has abnormal fluid content/blood, it is clear in the T2 image. T2 axial is the images typically transferred into TPS for tumor outline, and T1-contrast can be used to delineate the organ and tumor as well.

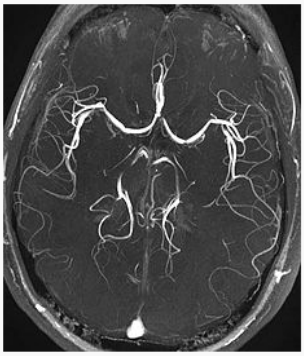
- Typical field strengths in an MRI? Smallest field strength used in imaging?
  1.5T, Typically clinical operation in the range from 0.2 – 3T. Philips has 0.23 T using permanent magnets C-shaped MRI (MRI from picture to proton p168 – 169).

- (2010/11): Head neck case: One is CT and another one MRI angiography (I guess). I was asked how do you get it?
  Magnetic resonance angiography (**MRA**) is a group of techniques based on magnetic resonance imaging (MRI) to image blood vessels. Magnetic resonance angiography is used to generate images of the arteries in order to evaluate them for stenosis (abnormal narrowing), occlusion or aneurysms (vessel wall dilatations, at risk of rupture). MRA is often used to evaluate the arteries of the neck and brain, the thoracic and abdominal aorta, the renal arteries, and the legs (called a "run-off").

  based on flow effects or on contrast (inherent or pharmacologically generated). These images, unlike conventional or CT angiography do not display the lumen of the vessel, but rather the blood flowing through the vessel. The most popular methods now use IV contrast agents (Gadolinium-DTPA) to shorten the T1 of blood to about 250 ms, shorter than the T1 of all other tissues (save fat). Short-TR sequences produce bright images of the blood.

Magnetic resonance angiography

Intervention



Time-of-flight MRA showing the circle of Willis in the brain. Note the "venetian blinds" artifact visible as the multiple pseudo-stenosis on both the left and right middle cerebral artery

- There was a picture of an atom with a potential well shown below it. Question was what is this? There was no indication of whether the nucleons were protons or neutrons, but some looked like they might have had very fuzzy '+' in the middle. Discussion then went on to whether this would make a good MRI agent.

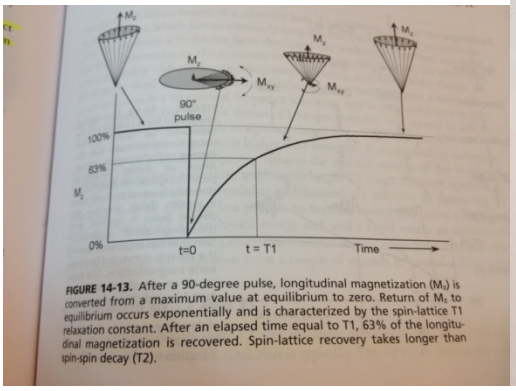


FIGURE 14-13. After a 90-degree pulse, longitudinal magnetization (M_z) is converted from a maximum value at equilibrium to zero. Return of M_z to equilibrium occurs exponentially and is characterized by the spin-lattice T1 relaxation constant. After an elapsed time equal to T1, 63% of the longitudinal magnetization is recovered. Spin-lattice recovery takes longer than spin-spin decay (T2).

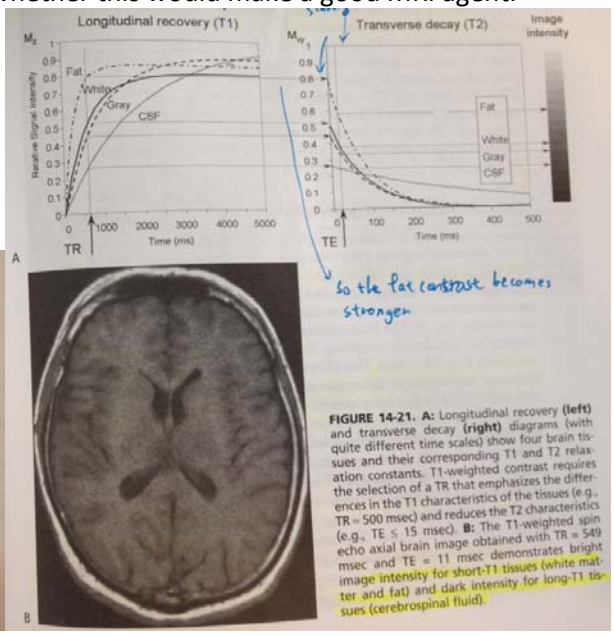


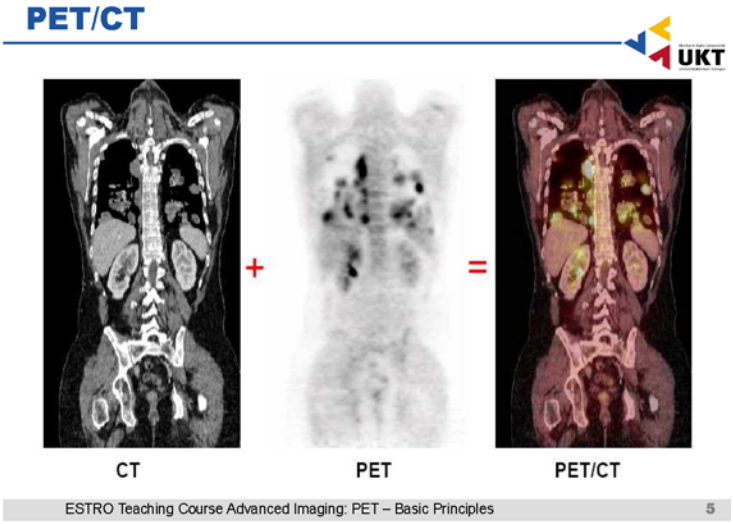
FIGURE 14-21. A: Longitudinal recovery **(left)** and transverse decay **(right)** diagrams (with quite different time scales) show four brain tissues and their corresponding T1 and T2 relaxation constants. T1-weighted contrast requires the selection of a TR that emphasizes the differences in the T1 characteristics of the tissues (e.g., TR = 500 msec) and reduces the T2 characteristics (e.g., TE ≤ 15 msec). **B:** The T1-weighted spin echo axial brain image obtained with TR = 549 msec and TE = 11 msec demonstrates bright image intensity for short-T1 tissues (white matter and fat) and dark intensity for long-T1 tissues (cerebrospinal fluid).

This question most likely asking why Gd can make a good contrast agent but looking at the signal recovery curve. A good T1-contrast will be able to shorten the T1 of the substrate so we will get good signal and the recovery curve will be leveled up so does the T1 signal.

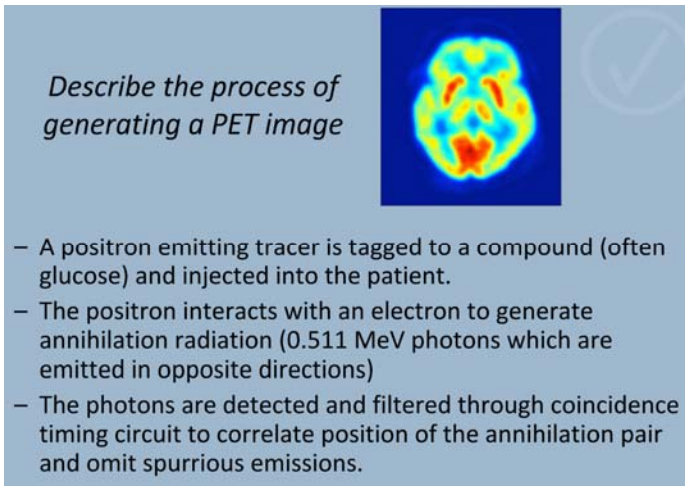
Note: no MR agent for pregnant women at any pregnancy stage. No MR agent for people with reduced renal function

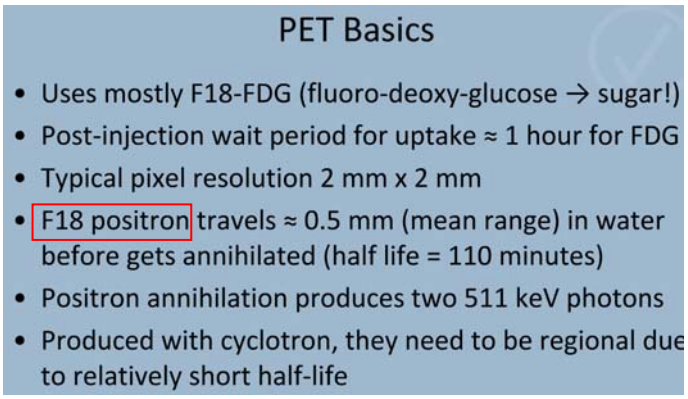
(PET)

- Picture of whole body PET and CT images. What image modalities are shown? What are typical resolutions in these images? He asked a lot of follow-ups on details of PET image acquisition (resolution, what limits resolution, etc).

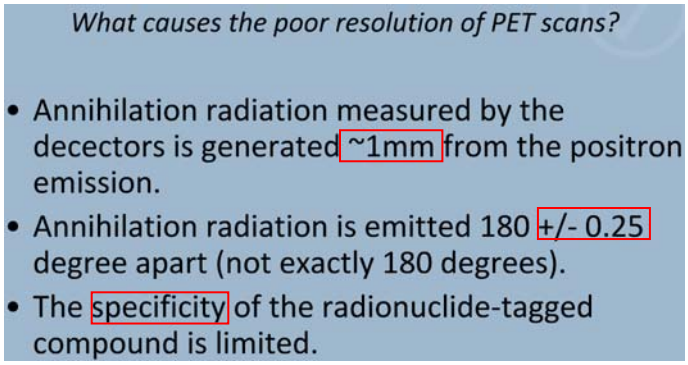


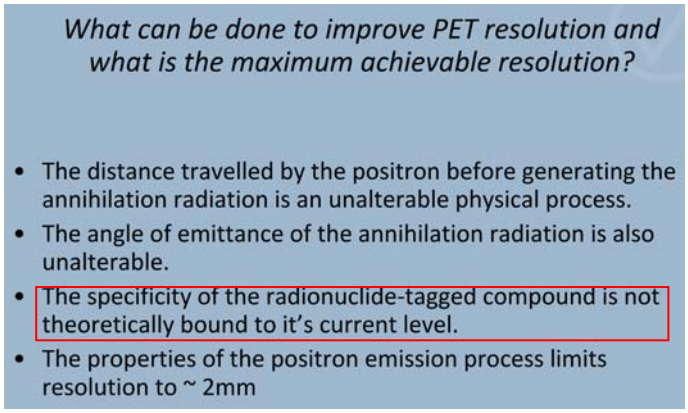
PET(3-4 mm) → MRI (1 mm) → CT/Ultrasound(0.4 mm) → film (0.1 mm) (Bushberg Ch1)
CT/US/Film are **sub mm** image modalities





Annihilation: positron (e^+) + electron(e^-) → 2 photons





- Why do you need PET? What's being imaged in PET? What tracer is used?

  PET image can provide the physiology information; in clinic, most use tracer for PET is the 18-FDG(18 fluoro-deoxyglucose) which is a glucose analog which can be used to distinguish the malignant neoplasm from benign lesions. (Bushberg p719)

  F-18 FDG is a nonspecific tracer for glucose metabolism that is taken up normally in the brain, heart, bone marrow, bowel, kidneys, and activated muscles. It also concentrates in many metabolically active tumors, making it a powerful diagnostic agent for a large number of cancers (TG108)

- Describe the overall PET scanning procedure with patient walking in;
  1. Bring in the patient to the uptake room, and , IV in 18FDG 10 – 20 mCi, (370 – 740 MBq)
  2. Wait for 1 hour uptake time to reduce the uptake in skeletal muscles
  3. Image the patient
  4. Because the half life for FDG is about 2 hrs, patient can be released right after the scan. (TG108)

- What are the advantages and disadvantages of PET images?

  Advantage: PET image can provide the physiology information and it is a functional image; in clinic, most use tracer for PET is the 18-FDG(18 fluoro-deoxyglucose) which is a glucose analog and it can be used to distinguish the malignant neoplasm from benign lesions. (Bushberg p719)

  Disadvantage of PET: it doesn't not provide anatomical info as provided by CT or MRI, and the spatial resolution is not as good as CT and MRI. It also didn't not provide the e density info for dose calculation in RT.

- PET: What are typical doses to patient? Safety issues related to PET patients?

  The typical FDG dose to patient is about 10 – 20 mCi, (370 – 740 MBq)
  1. Dose from injection procedure: Tungsten syringe can be used to reduce hand dose by 88%, and divide injection responsibility among staffs
  2. Dose during pt. positioning for imaging: have enough staff so the dose will be diluted among staffs
  3. Dose during pt. imaging: console should be more 2 m away from the scanner, & the additional wall partition can be placed in between to reduce the dose.

  (TG108)

SAFETY: How much dose do you get?

- Typical dose: 10-20 mCi = 370-740 MBq
- For radiation safety and shielding calculation, use effective dose equivalent dose rate constant (TG-108)
- Γ_H = 0.143 μSv.m^2/MBq.h
- This is instantaneous rate. It will ↓ as the F18 decays
- Data from practical experience give about 25 μSv per simulation (about 15 minutes at <50 cm to patient) effective dose equivalent to staff

- PET/CT fusion. Why to do this? How do you register it, how do you know it is good registration? (tolerance 2 – 4 mm, other location than GTV can be bigger), Where is the tumor on the graph?

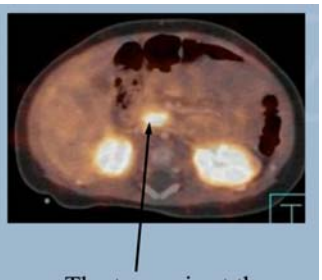
  PET image can provide the physiology information and it is a functional image; in clinic, most use tracer for PET is the 18-FDG (18 fluoro-deoxyglucose) which is a glucose analog and can be used to distinguish the malignant neoplasm from benign lesions. (Bushberg p719)

  CT can provide the (1) anatomy information and electron density information for planning and dose calculation purpose.

  In additional, CT information obtained from the PET/CT can be used to provide the attenuation correction for the PET image.

What kind of image is this and where is the tumor?

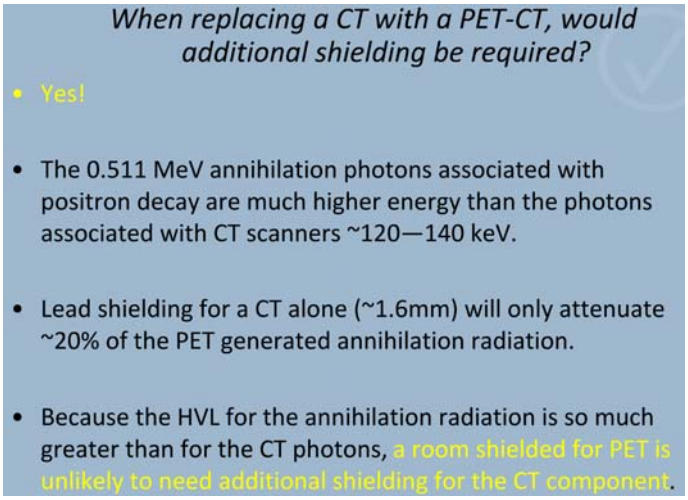
- This is a PET-CT image
- F-18 is a common radioisotope tagged to glucose to highlight areas of high metabolic activity.
- Tumors are typically regions of high metabolic activity, however the F-18 tagged cocktail will be present in normal tissues as well so PET images should only be interpreted by those trained to do so.



The tumor is at the head of the pancreas. The other two hot spots are the kidneys where the F-18 is excreted.

If the tumor is visible on PET, why would a CT be necessary for radiation therapy?

- CT numbers are used to correct the PET image for differential attenuation occurring along the path of the annihilation radiation.
- PET provides only a map of metabolic activity, therefore a CT anatomical overlay is necessary to identify critical structures.
- A PET alone would not provide a body contour or any electron density data necessary to account for heterogeneities within a dose calculation.



- Why is CT the standard for radiation therapy planning? Discuss pro's and con's of CT, MRI, PET, SPECT?

	CT (0.4 mm)	MRI (1 mm)	PET (3-4 mm)	SPECT (7 mm)
Pros	o Good spatial resolution (0.4 mm) o Good visualization for large tumor o Provide e density for heterogeneity correction in TPS o Generate DRRs correlating to treatment portal images o Provide bony landmark for pt. setup o Provide well-enough soft tissue and good bony anatomy for planning purpose	o Great differential ability for soft tissue, largely used for brain and pelvis case o Wide variety pulse sequence can be used to improve image contrast o Non-ionizing radiation	o provide the physiology information, such as o tumor metabolism, o differentiation between tumor recurrence and radiation necrosis, evaluation of regional lung function, o detection of hypoxic areas of the tumor o Provide functional image for brain and heart	
Cons	o Limited soft tissue contrast o Ionizing radiation	o Lack of signal from cortical bone o No info for e density o MR signal easily influenced by the external factor, such as RF interference o Great care for the scanning procedure, no ferromagnetic material should be presented. o Long scanning time o Spatial distortion, especially around edges o DRR won't be able to used in MV x-ray	o Coarse spatial resolution (3-4mm) o Radiation dose to the staff o No anatomy and e density information	o Coarse spatial resolution (7 mm) o Radiation dose to staff o No anatomy and e density info

Why does CT remain the standard modality for radiation therapy treatment planning?

- Images are spatially robust
- Provide good visualization for a large range of tumors
- Electron density information permits heterogeneity-corrected dose distributions by treatment planning algorithms.
- generates DRRs which correlate well with treatment portal images

What scan for what site?

- CT is needed for treatment planning (because it has the electron density information).
- MR is useful for differentiating soft tissues. Each kind of tissue has different local molecular structure that makes it respond differently to MR fields. MR is commonly used for brain and prostate, among others.
- PET is useful for identifying tissue with high metabolic activity such as tumors (tumor needs a lot of energy to fuel its rapid growth).

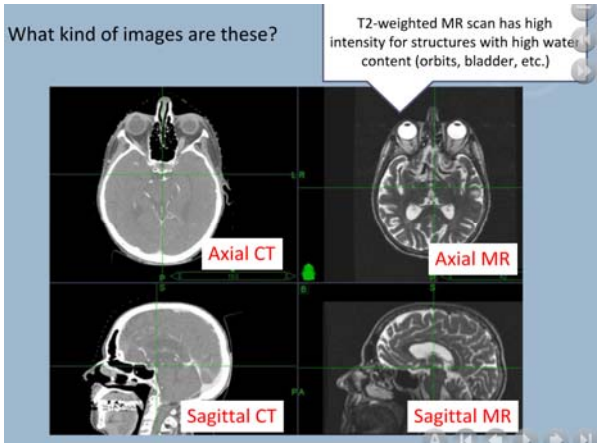
Why have MRI simulators not become commonplace in radiation therapy departments?

- Spatial distortion, especially around edges
- No electron density information
- DRR's do not correlate with MV X-rays
- Higher cost of device
- Longer scan times
- Perhaps most especially because the benefits of MRI (visualization) can be acquired through fusion of MRI image with base CT image

(CT & MR)

- (2006) fusion of CT & MR & fused CT/MRI advantages of each (CT, MR, Fused), which image set is base
  CT is the primary image set because we use the CT image for planning.

- MRI and CT slice of brain at different levels. Can you fuse these two images? Various follow up questions on advantages/disadvantages of image fusion. How do you do it (talk about the different methods)?



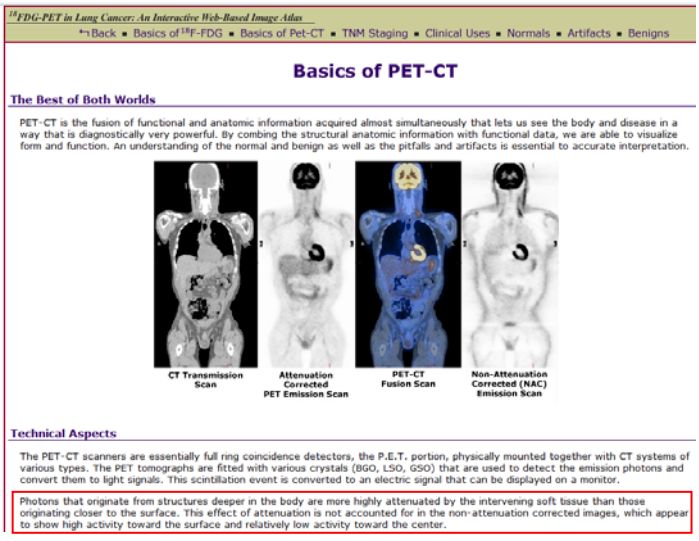
Advantage: CT provided great bony anatomy and MR provide great soft tissue contrast
Disadvantage: Setup variation and the patient anatomy deformation are the major limitation for image fusion, which can induce the uncertainty of the target and OAR delineation.

- Ct & MRI images shown: What are these images? What modality? How do you know? What are the characteristics of these images? What software do you use?
- CT/MRI pictures of brain. what are these 2 pictures? Identify various parts (5 of them; cavity, optical nerve, etc). (review the 1st MRI question, and Grey's anatomy p448 has more detail)

- Brain axial MRI and CT images; Identify anatomical structures. How do you use them? Why use them? What accuracy in fusion do you accept? Can you plan using MRI?
  Literature shows the MRI and CT for brain case can be 2 mm. (Kessler BJR, **79** s99 (2006) & J Purdy, **51**, 255, (2001))
  If we don't use heterogeneity correction for dose calculation, such as Gamma knife and T&O case, we can use MRI for planning.

- (2011): Shown side by side pictures of images. The quality was terrible. One appeared to be CT and the other MR, but it was very tough to tell what was what because the bone appeared very bright in both images – in retrospect, I think it was a T2 FLAIR image. We had a long discussion on CT vs MR, how does MR work, what are they used for, why use both, etc.

- (2006) Picture of a lung PET- CT image. What's this? How is it used in RT? Why is there uptake in the lung? FU: What determines the metabolism? What are some problems with PET and PET/CT fusion?



PET provides the physiology information, such as tumor metabolism, differentiation between tumor recurrence and radiation necrosis, evaluation of regional lung function.

^{18}F-FDG, as a glucose analog, is taken up by high-glucose-using cells such as brain, kidney, and cancer cells. Because tumor is highly metabolically active (use a lot of glucose), the location with high FDG level can represent the extent and staging of the cancer.

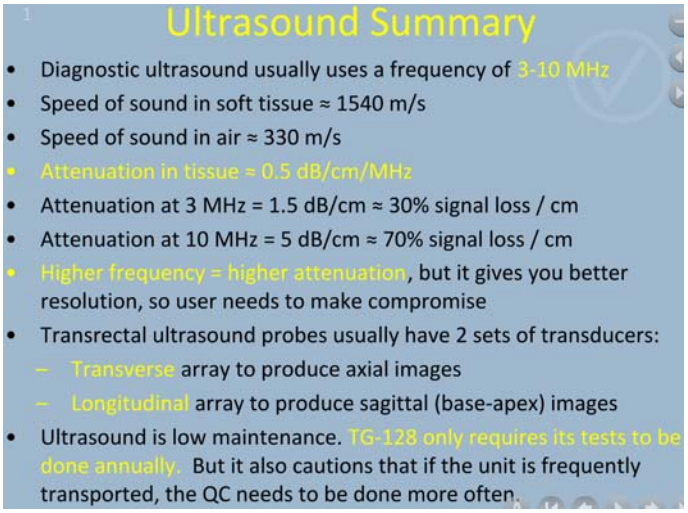
(Just as glucose, FDG is actively transported into the cell mediated by a group of structurally related glucose transport proteins (GLUT). Tumor cells display increased number of glucose transporters, GLUT. Tumor cells are highly metabolically active (high mitotic rates), and favor the more inefficient anaerobic pathway adding to the already increased glucose demands. These combined mechanisms allow for tumor cells to uptake and retain higher levels of FDG when compared to normal tissues.)

FDG is not cancer specific and will accumulate in areas with high levels of metabolism.

PET/CT fusion due to large spatial resolution, setup uncertainty during imaging, and the anatomy deformation can decrease the fusion accuracy.

(Ultrasound)

- (2008) MRI and CT fused image of brain site shown and asked to talk about it.
  - Follow up:
    - Electron density-CT, Proton density MRI
    - More Stereotactic questions- slice thickness (1mm)
    - Touched upon PET, Ultrasound (Read wepassed ultrasound)
  - Ultrasound is generally do not use for fusion with other images due to: bad image quality, totally different FOV, no bony information, distortion due to transducer
  -

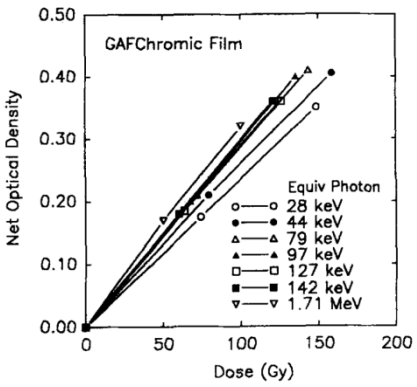


Decibel (dB) = 10 log (I_2/I_1) I is the wave intensity (power per unit area)
-1.5 dB = 30% loss
-3 dB = 50% loss ← like HVL
-5 dB = 70% loss

C3-B (Film)

(Radiochromic film)

- H&D curves for radiochromic film (plot on right). Discuss radiochromic films.
  The principle of the Radiochromic film is due to the absorption of radiation or UV light that the energy of the photon or particle is

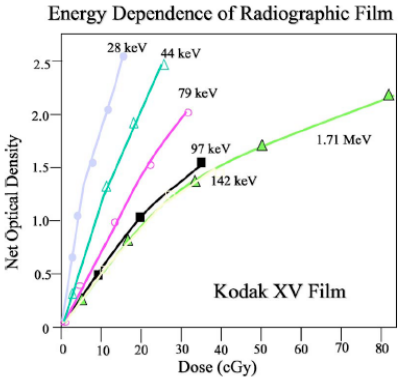


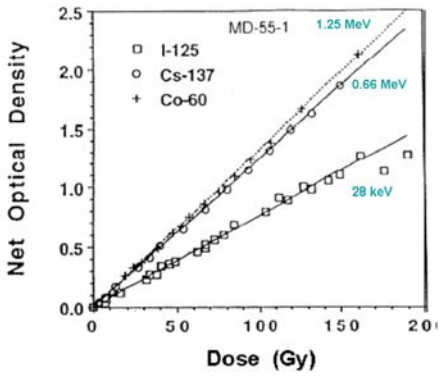
transferred to (leuko) colorless dye and the dye will show **color** and therefore, we can see the radiation pattern on the radiochromic film. This process is called the dye-forming or polymerization process.

- How about radiographic films?
  A radiographic film consists of a transparent polyester base coated with an emulsion containing with Silver Bormide (AgBr). When the film is exposed by the radiation or light, a chemical reaction within the AgBr crystal to form the **latent image**. When the film is developed (by the developer), the **affected crystal** will react with chemical to form metallic silver, and unaffected granules are removed by the fixer solution. The metallic silver left on the film will cause the darkness of the film. The degree of the film depends on the radiation dose.

  Chemical reaction within the AgBr crystal (TG69)
  the loosely bound electrons are freed by radiation and combine with the Ag+ ion to form a metallic silver:
  Br^- + radiation → Br + e-
  ⇨ Ag^+ + e- → Ag then add developer to form metallic silver

- Differences between radiochromic and radiographic films, advantages and its disadvantages.
  (From Kahn sec. 8.9)
  Compared to the radiographic film
  The advantage of Gafchromic:
  1. No need for chemical process to develop the film
  2. insensitive to visible light
  3. Made by tissue equivalent material
  4. Large dynamic range (0.05 – 10 Gy EBT or 1-100 MD55-2) compared to (0.08 – 5 Gy) EDR2 radiographic film. (Our is EBT2, 0.05- 10 Gy in red channel, and 10 – 40 Gy in green channel)
  5. Less energy and dose rate dependence *(For the Radiochromic and radiographic film, the energy dependence trend is in opposite direction see the following figure)

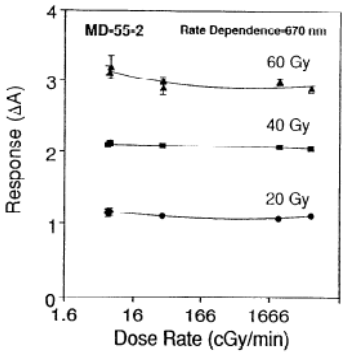




(TG69 & 55)

To what extent is radiochromic film energy and dose-rate dependent?

- Energy: Energy dependency varies between film types however the commonly used GAFCHROMIC EBT film claims energy independence from 30 kV to 18 MV.
- Dose Rate: In general, radiochromic film is independent of doses rate effects at the clinically relevant dose rates of 2-4 Gy per minute.



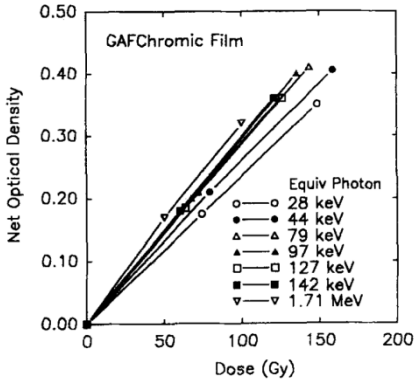
Disadvantages:

1. MD-55-2 film readout time should be at least 24 h after radiation
2. GafChromic EBT should be at least 1 h
3. Reader system is important; calibration linearity is instrument dependent

Since no wet processing is necessary, can radiochromic film be analyzed immediately after exposure?

- Again, this answer is film dependent.
  - TG-55 (1998) indicates that MD-55-1 and MD-55-2 films should not be quantitatively analyzed for a period of 24 hours.
  - The manufacturer of GAFCHROMIC EBT recommends a wait time of ~1 hour.

- Explain the energy dependence seen on the plot – why does it look like that?



The OD increases as the increase of dose due to the darkness of the film determined by the amount of the radiation dose. For a given dose, high energy photon also induced stronger OD. The reason for that is the mass energy absorption coefficients for the Gafchromic film increase along with the energy between **0.01 – 2 MeV** (following figures), (by taking the reciprocal of the $(\mu_{en}/\rho)^{water}_{GAF}$, and moreover, the collision stopping power ratio is about 1, so only the mass energy absorption coeff. maters)

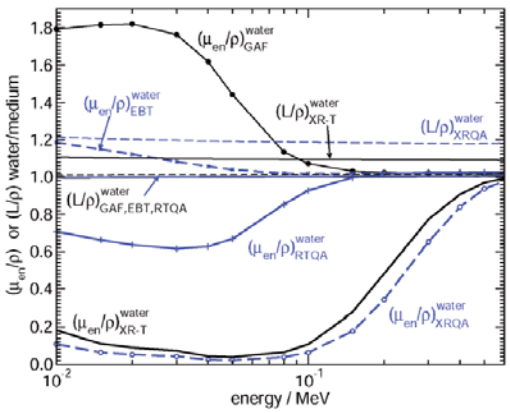


Figure A-4. As in figure A-3 but including lower energies.

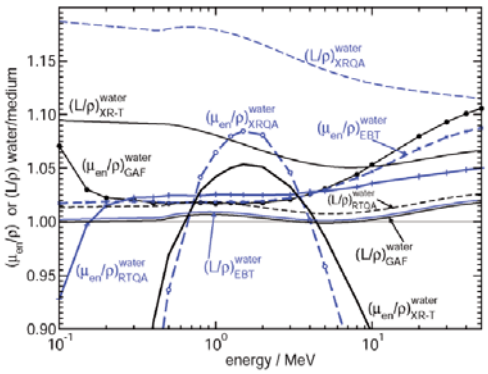


Figure A-3. Restricted mass collision stopping-power ratios and ratios of mass-energy absorption coefficients for the sensitive materials in radiochromic films relative to water. Compositions defined in table A-1.

Table 23-2. Composition of GAFCHROMIC Detector Materials

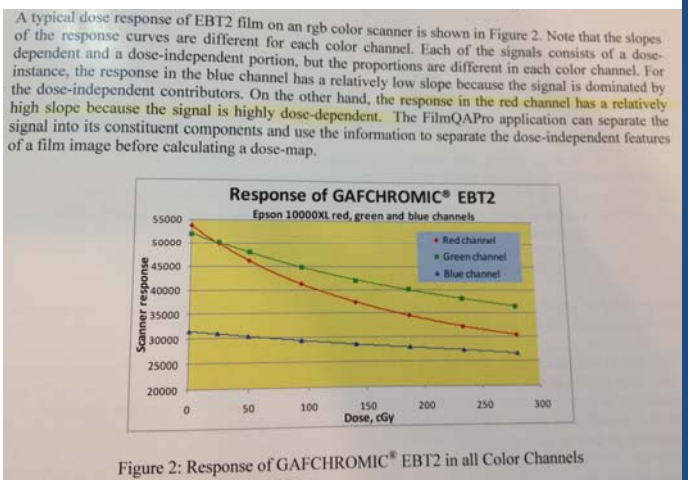
Material	Density g/cm³	Effective Z	Number of electrons per unit volume 10^{27}/m³	Elemental composition (percentage by mass) H	C	N	O	Others
GAFCHROMIC emulsion	1.08	6.27	328	9.3	56.6	15.7	18.4	
GAFCHROMIC EBT emulsion	1.1	7.05	328	9.4	57.4	13.2	16.4	0.8 Li; 2.9 Cl
GAFCHROMIC XRQA emulsion	1.2	32.6	303	6.4	38.1	5.5	13.8	0.4 Li; 13.4 Br; 22.3 Cs
GAFCHROMIC RTQA emulsion[a]	~1.1	8.29	326	9.1	53.7	12.7	14.2	1.9 Li; 8.4 Cl
GAFCHROMIC XR-T emulsion[b]	~1.2	26.6	315	7.8	46.2	11.5	14.3	7.6 Br; 12.6 Cs
Surface layer[c]	~1.2	9.90	317	6.5	32.3	21.6	20.5	2.3 Li; 16.8 Cl
Transparent and yellow polyester[d]	1.35	6.64	313	4.2	62.5		33.3	
Adhesive[d]	~1.2	6.26	329	9.4	65.6		24.9	3.5 S; 15.1 Ba
Opaque white polyester[d]	~1.6	27.6	302	3.1	46.6		31.7	
Water[e]	1.00	7.42	334	11.2			88.8	

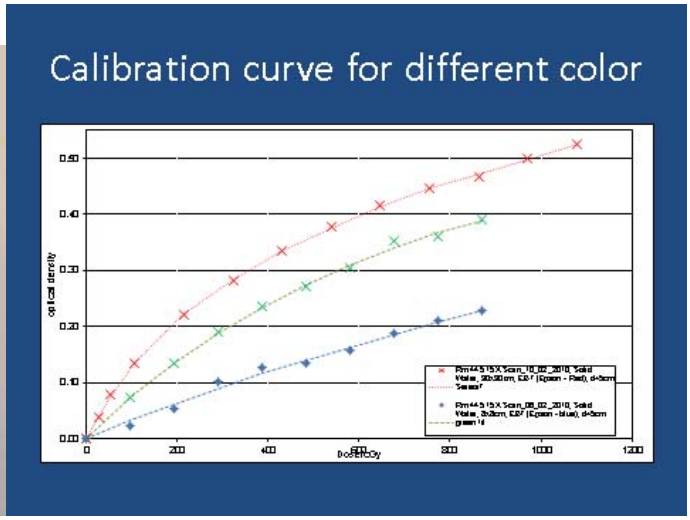
(2009 Summer school Fig. A-3, and A-4, Table 23-2)

- What elements are the radiochromic films are made of?
  Radiochromic film consists of 7 – 23 um thick, colorless radiosensitive leuco (=colorless) dye bonded onto a polyster base. (TG55 p2097 Kahn p153, 3rd).

- Radiochromic Film graph. Which energy range is it most effective. Know the definition of OD and Write it down. Questions on scanner calibration.
  From the general radiochromic OD curve, the higher energy induces faster OD change.
  OD = $\log(I_0/I_t)$ where I_0 is the incident light intensity, and I_t is the transmitted light intensity.

  Radiochromic film is different than the XV film, because the Radiochromic film radiation pattern depends on the "darkness of the color". To read the dose correctly, we will need to calibrate the readout channel (RGB) in the scanner (red, green, blue) because for each channel, the scanner response to the dose is different;





http://www.filmqapro.com/FilmQA_Pro_files/Calibration.htm

The **Calibration** process uses patches of film that have been irradiated with known doses to generate a "Calibration Table" and calculate a set of 3 calibration functions (one for each the red, green, and blue color channels). These calibration functions correlate the dose values of the exposed film patches with the color values in the scan images.

The films for calibration should include a piece of blank film (zero exposure) and 4 to 7 film patches with doses assigned in geometric progression, i.e. each dose value is greater by a fixed percentage (40% – 60%) than the previous value. E. g. 25, 40, 70, 120, 210, 350cGy, plus zero.

---- scanner calibration (from AO) ----

The idea of scanner calibration is just to linking the scanner output (photon count) to the known OD, so next time when we scan the film, we will have OD vs. dose rather than the scanner response vs dose;

The calibration of any film dosimetry system is a 2 step process.

First, the scanner performance output is calibrated with the use of the strip of film with known OD values (OD strip) which is supplied by the manufacturer of the system. This strip is scanned and the scanner is characterized in terms of scanner output vs. known OD. (scanner calibration)

Next, the film which will be used is calibrated in terms of OD vs MU (or dose delivered). This is done by irradiating of the film at depth 10x10 fs to known doses and reading out the OD values corresponding to the doses delivered. Different steps of MU values are chosen, it is necessary to choose a few points in the shoulder and heel portion of the HD curve in order to get a decent calibration. I know in RIT software a minimum of 17 different points are required between 1 and 700 cGy (for EDR film) (film calibration).

For the Gafchromic film the story is very similar but 3 different curves are obtained for different light colors because response of the 3 is different.

The first step of the process varies as a function of scanner resolution and stability of light source so it is done when the scanner is first purchased and it does not significantly change from that point forward. Note that the OD strip does get old and so it is recommended that a new strip is ordered from the company if recalibration is

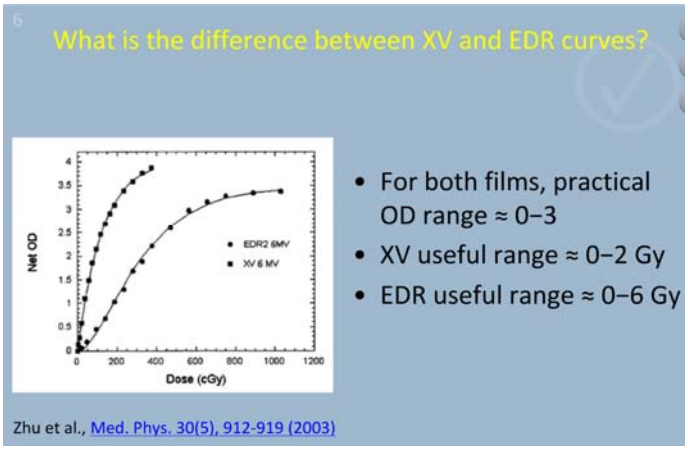
necessary. In my experience the old OD strip can lead to error in OD read vs specified of as much as 10%. But the scanner calibration does not change significantly with time, so that this is only necessary to do once.

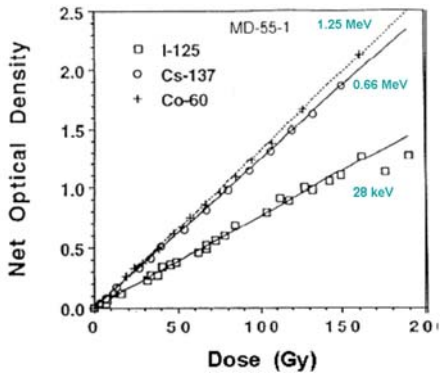
The HD curve has been shown to change as much as 5% from one batch of the film to the next, when I used to do film IMRT QA I always ordered a few boxes of film from the same batch and do the HD curve for that batch.

- Do you use radiochromic film in your institution? Radiographic film? What type? What's different between XV and EDR film? How would this plot (energy dependence) look for EDR film as compared to radiochromic?
  We use radiochromic (GafChromicEBT2 for verifying the brachytherapy source location & Cyberknife QA due to large dose range)
  Radiographic film (Kodak XV2 and EDR2)
  The major difference between the XV2 and EDR2 is the dynamic range difference
  Dynamic dose range is
  XV2 : 0.1 – 1 Gy, and EDR2: 0.1 – 5 Gy. Practical OD range is 0-3, OD to 1 (0.4 Gy for XV & 2 Gy for EDR2) → XV is faster
  (TG69)A good optical density for visualization in radiology is **2**; however, the useful OD range in radiation oncology typically ranges from 0 to 3.

TABLE I. Physical properties of Kodak films.

Description	XV2	EDR2
Grain crystal	AgBr and AgI	AgBr
Total silver density (g/cm^2) (both sides of the film)	4.2	2.3
Effective thickness (μm)	0.4	0.2
Grain size distribution	Variation in size and shape	Monodisperse
Base thickness (μm)	180	180
Gelatin coating thickness (g/cm^2) (per side)	3	5
Double sided	Yes	Yes
Dynamic range	0.05–0.80 Gy	0.1–5.0 Gy
Dynamic OD range	0–4	0–4
Approximate Dose (Gy) for OD 1	0.4	2.0
Maximum recommended dose (Gy)	0.8	5.0



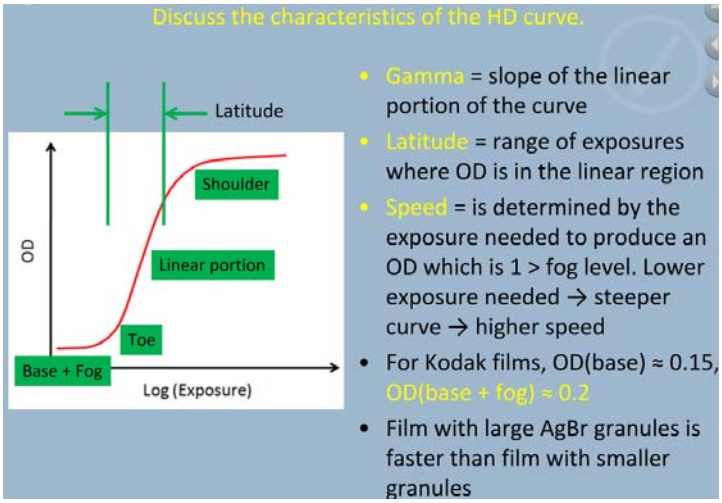


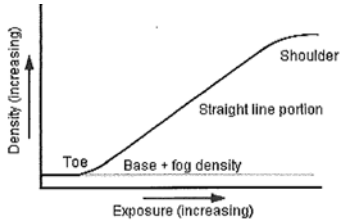
Radiochromic OD vs. dose is straight line.

- Radiochromic Film graph.
  a. what is it made up of. I answered that base with polymer coating

b. How is it processed. I answered that it does not require any processing as conventional films
c. question about the graph. Which energy range is it most effective.
d. Asked me questions on scanner calibration and I replied that I would calibrate by exposing films with different doses and making a OD curve.

- Film dosimetry
  - a H&D graph is showing, define the terms





Base+Fog: The optical density of the unexposed film plus any chemical fogging that may occur during processing.

Inertia point: The point at which the film has absorbed sufficient light energy to start forming a latent image.

Toe: The non-linear region of the curve where compression of optical density differences produces poor contrast.

Latitude: The range of exposures where OD is in the linear range.

Gamma: The slope of the linear portion of the curve, or:

$$\gamma = \frac{OD_2 - OD_1}{\log(X_2) - \log(X_1)} = \frac{OD_2 - OD_1}{D_2 - D_1}$$

Speed: The film characteristic determined by the exposure needed to produce an optical density of 1 greater than the "base+fog" optical density. For Kodak film, OD(base) = 0.15 and OD(base+fog) = 0.2. These are typical values for most films.

The main characteristics that are considered for selecting a film are "speed" and "linearity".

Basically, speed is the dose or exposure needed to produce the net optical density = 1 or optical density = 1 + base + fog

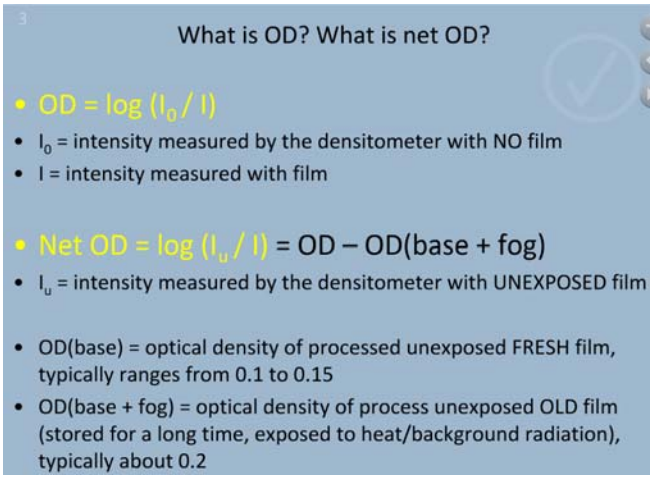
Speed & linearity, dose range are the mainly character to choose the film;

- OD vs dose, what kind of films do you use at work

Kodak XV2 and EDR2

Gafchromic EBT2

- what is fog? What does fog include (noise, ..)
- What is net optical density?



- Where do you use the film in the clinic, monthly machine QA, electron PDD, etc.?

Monthly and annual QA for light-to-rad field size consistency check, MLC QA, as well as the star shot for gantry collimator, MLC collimator and collimator radiation star check.

- Do you use XV film in IMRT QA? Why not? What other film do you use for IMRT QA?

We don't use XV film for IMRT, because the dynamic dose range is from 0.05 – 1 Gy which is not enough for IMRT QA dose range, which can be larger than 3 Gy at high dose regions. EDR2 is with the dose range from 0.1 to 5 Gy can be a better choice.

- What affects the film image? What are the disadvantages of using film?

OD is sensitive with many factors such as, and following TG69 eq. (5) and DABR p253

$$\mathrm{OD} = f(D, D_r, E, \gamma, d, \mathrm{FS}, \theta, \tau)$$

1. Dose & FS
2. Energy dependence, E
3. Dose rate dependence for high dose region (TG69)

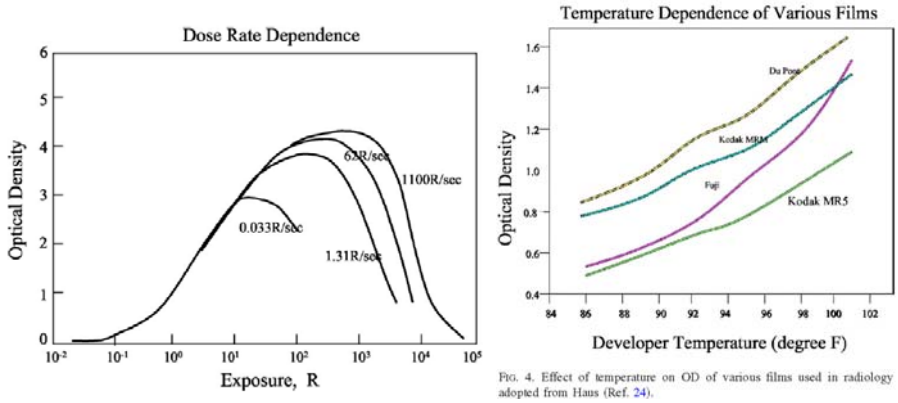
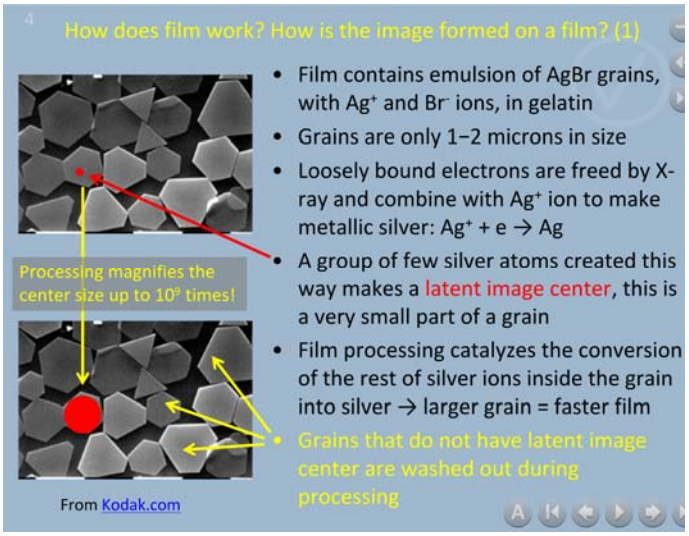


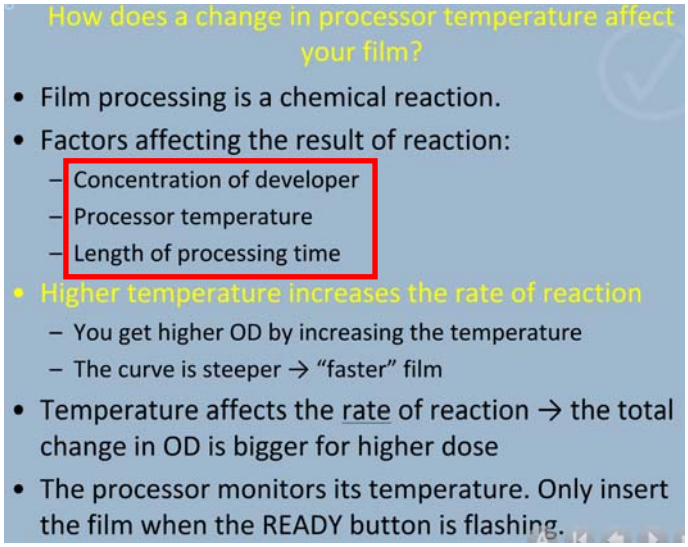
FIG. 4. Effect of temperature on OD of various films used in radiology adopted from Haus (Ref. 24).

4. Air pockets effect (If there is air pocket, in the film, it will affect the response of the film. study shows that air pocket can induce 10% over response of the XV film mentioned in TG69 P2247)
5. Emulsion difference among film with different batches,
6. Processor condition (such as developer temperature) {need to be consistent}
7. Densitometer/scanner condition
8. Film plane orientation with respect to the beam

- Explain how you obtain calibration curve for film dosimetry?
  TG69 (Perpendicular calibration method)
  1. 13 dose points are enough to fully characterize the calibration curve
  2. Choose the depth and field size we want to deliver the dose to the film. We can choose the calibration depth and field size, such as d_{max} or d= 10 cm (setup at Penn) and 10 x 10 field size
  3. Remove the air pocket from the film
  4. Deliver the known dose. I will also do the monthly QA to check the output variation so I know the exact output at the time I irradiate the film
  5. Expose one dose to each film
  6. We will also need to include one film with the delivered dose level exceed the maximum level expected to be analysis, as well as an unexposed film, so we can build the calibration curve including the maximum dose we are interested and the base + fog level.

- (2008) Film questions: Contents (AgBr), size of the grains (1-2 μm) and what affect the speed (temperature, energy, developer concentration, processing time)?





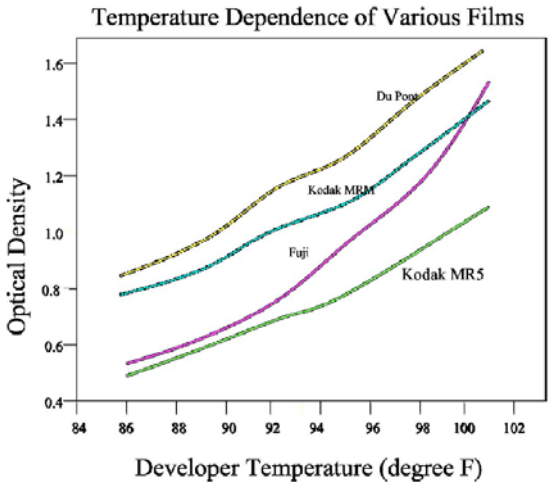
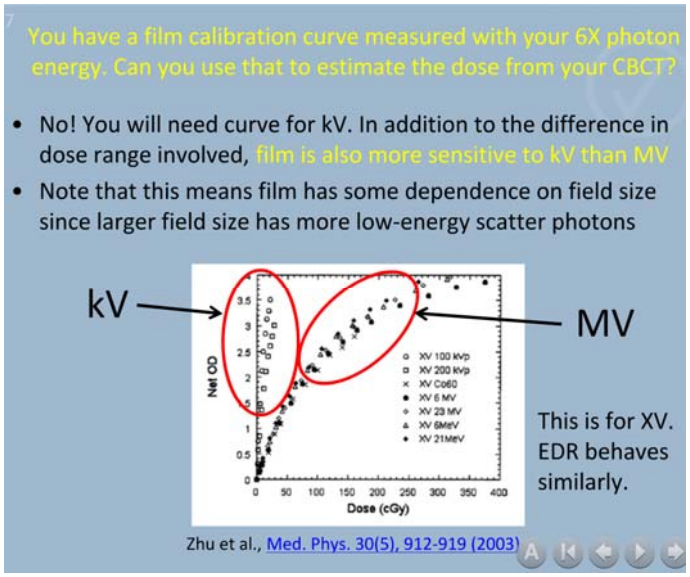
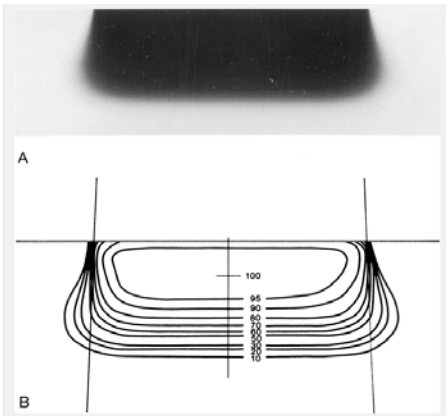


FIG. 4. Effect of temperature on OD of various films used in radiology adopted from Haus (Ref. 24).

- Explain net O.D. H-D curves for multiple beams (50kV all the way to Co-60) were shown. Explain the difference between them and which one we should use for LINAC (use the one for MV)?
- Discuss film H&D curves. Which one faster? (Low energy is faster for XV) Which one you'd use for portal verification, localization? Which one has higher contrast, what is speed of a film?
  (Important!) Radiographic contrast (Bushberg p261) = OD1 – OD2, so steeper curve shows high contrast. The contrast curve can also be obtained by taking derivative of the OD curve.



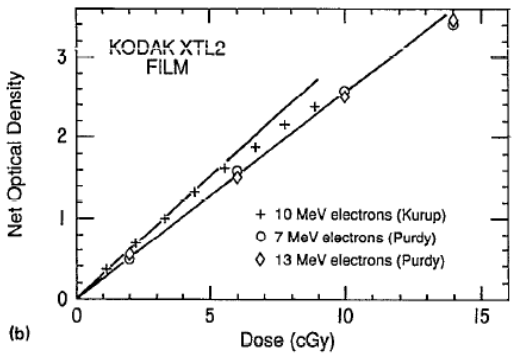
- (Film dosimetry for electron beam) Discuss Electron depth dose (Kahn Figure 14.7a). What is it? Film vs. chamber.



(Kahn p304-306)

Advantage of using film for electron dosimetry:

1. Convenient and rapid way to obtain a complete set of iso dose or PDD. For chamber, we need to scan the tank
2. Due to the ratio of collision stopping power between emulsion & water varies slowly with electron energy, radiographic film (XV) shows electron energy independence, BUT not EDR2 (TG25 & TG70).
3. Great spatial resolution compared to ion chamber



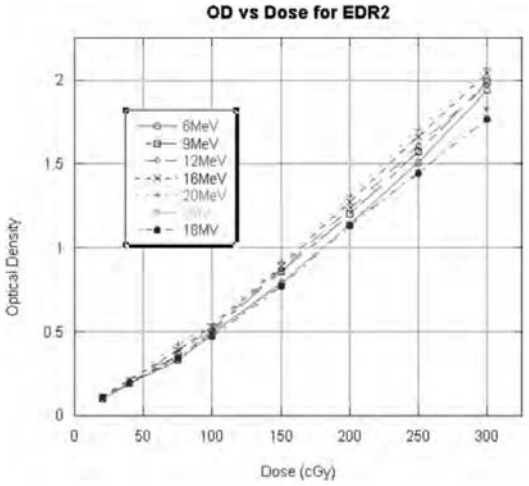


FIG. 3. The response of Kodak EDR2 film to high-energy electrons. The top curve shows the increase in response of the film with increase in electron beam energy. [Reprinted with permission from B. J. Gerbi and D. A. Dimitroyannis, Med. Phys. 30, 2702 (2003). Copyright 2003, American Association of Physicists in Medicine.].

Compared to IC, film used for electron dosimetry is limited to relative dosimetry rather than absolute dosimetry because the OD of a film exposed to e depends on many variables such as emulsion, processing conditions, magnitude of dose, measurement conditions. Great care is needed for using film for e dosimetry.

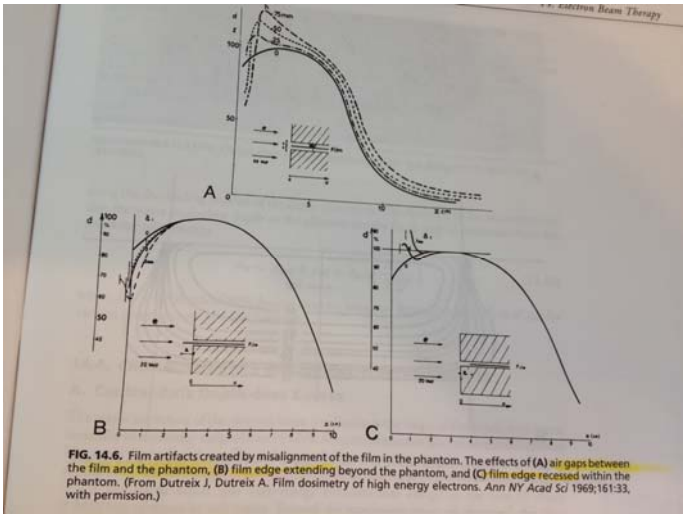


FIG. 14.6. Film artifacts created by misalignment of the film in the phantom. The effects of **(A)** air gaps between the film and the phantom, **(B)** film edge extending beyond the phantom, and **(C)** film edge recessed within the phantom. (From Dutreix J, Dutreix A. Film dosimetry of high energy electrons. *Ann NY Acad Sci* 1969;161:33, with permission.)

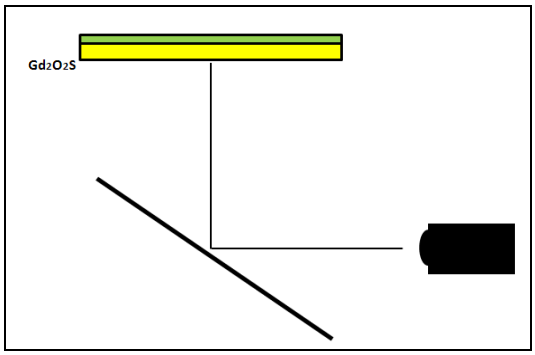
- (2008) Two images -- what are they? (one was double exposure image, one was single exposure.)
  Double exposure for setup, UCLA: just look at the field CIAO (completed irradiated aperture outline)

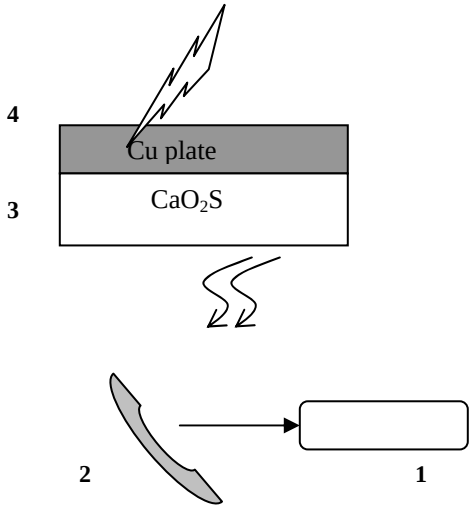
  First shot the open field, then close down the mlc, so you see the field shape
  Fuse with DRR, the field shape will also show on DRR and you will see two outline in different color
  you can tell if the field match well and you also see if the structure within the field is correct
  so the open field to get the overall structure

  so it's pretty much bony structure or marker for kv

- (2008) Film calibration curves by energy for XV film. Why do we use this film? Describe the curves you would need if you were going to use film for profiles
  I will choose the curve with large dose range within the linear region because the dose at the penumbra regime can drop pretty fast.

C3-C (portal Imaging)





- Diagram of a camera-based portal imager shown on right. Point to several parts of the diagram and know what they are? Why use a mirror? What are the two purposes of metal layer? Can you remove it? What does phosphor do? What material is it made of?
- Picture of EPID. Shown was a figure of EPID with a Cu plate and a GDso4 plate beneath it. Show a incident beam and one photon which went through it and one electron which scattered and that was reflected in the mirror and detected by a camera. What is this? What are the things labeled as 1, 2, 3 and 4. What is the function of each? Can you get an image without copper plate?

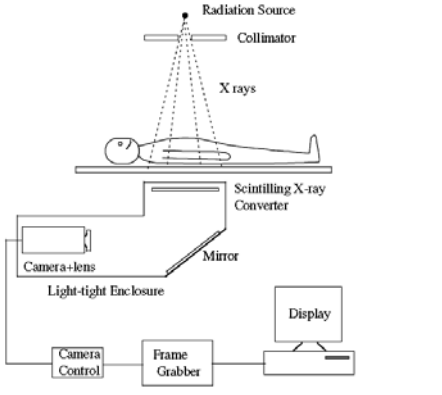


Figure 4. Schematic illustration of a camera-based EPID with the x-ray detector (a phosphor screen) optically coupled to the camera using a mirror and lens.

Phosphor 磷光 = phosphoresce (is an adj. just meaning light emitting layer)

PMB 2002, 47 R31-R65
As illustrated in figure 4 (Vedio-Based EPID sys), the approach involves the use of an x-ray converter that is optically coupled to a camera by means of a mirror and a lens. The converter consists of a flat metal plate (typically an ~ 1 - 1.5 mm copper, steel or brass plate) and a gadolinium oxysulfide (Gd_2O_2S:Tb) phosphor screen. The metal plate (x-ray converter) serves to (1).converts incident primary x-rays into high energy

Compton electrons, some of which escape the plate into the phosphor layer, as well as to (2). block low-energy, scattered radiation which would otherwise reduce the contrast of the imaging system. The phosphor layer (Gd_2O_2S:Tb) serves to convert electrons into optical photons. Some of the light (optical photon) diffuses through the screen, exiting on the mirror side. The camera and lens serve to capture a fraction of this emerging light and transform it into a video signal that is then sent to other hardware for digitization, processing, display and archiving. It is estimated that, depending on the thickness of the phosphor and the energy of the radiotherapy beam, on the order of only ~2–4% of the incident x-rays interact and generate measurable signal in such systems.

Can you get an image without copper plate? (TG58)

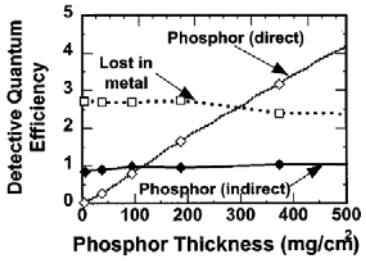


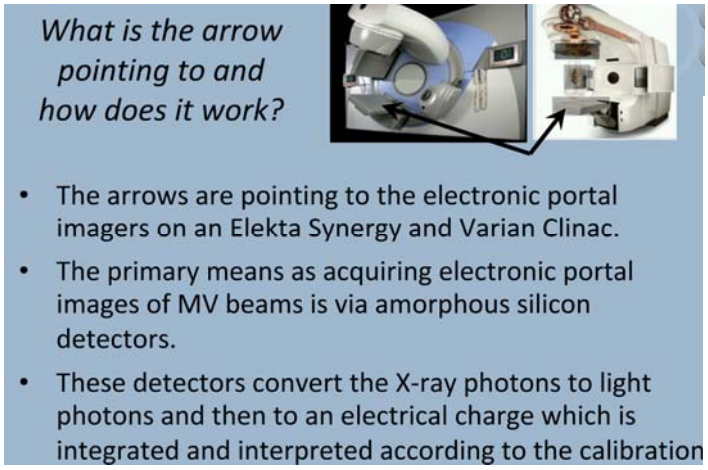
FIG. 2. The percentage of incident x-ray quanta that deposit energy in the phosphor layer of an x-ray detector consisting of a 1 mm copper plate and different thicknesses of Gd_2O_2S phosphor screens. The "phosphor (indirect)" curve represents those quanta that first interact in the copper plate and deposit energy in the phosphor screen. The "lost in metal" curve represents those quanta that interact in the metal plate but do not deposit energy in the phosphor screen. These quanta do not contribute to the image. As the phosphor thickness increases the number of x-ray quanta that deposit energy directly in the phosphor layer also increases.

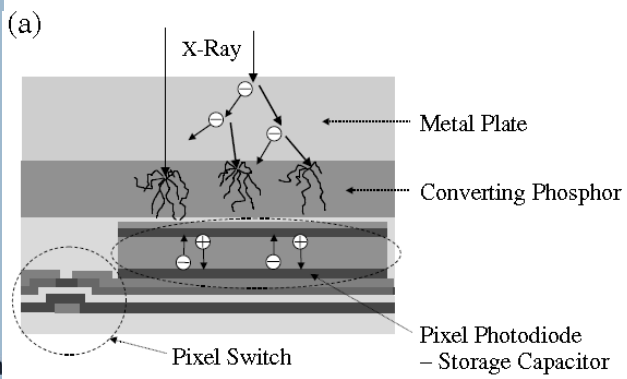
The incident x-ray can also directly react with phosphor screen and generate the optical photon (TG58, p715). The detective quantum efficiency (DQE) is actually higher when we increase the phosphor thickness. However, in addition to the loss of spatial resolution & optical light transmission, thick screens are prone to nonuniformity in phosphor content and thus add to the structure noise of the imaging sys. It is unlikely that increasing the thickness of the phosphor screens will yield further benefits.

You can still get image without copper however, practically, we should not remove the copper plate because it will deteriorate the image quality.

DQE is a measure of how efficient the imaging sys is at transferring the info contained in the radiation beam incident upon the detector, expressed as SNR(input)/SNR(output)

- What type of EPID do you use in your clinic? What is Si layer for? What resolution is desirable for EPID? Does that vendor produce a different kind of EPID? What are the differences?





We use Varian PortalVision aS500. (Kahn 3rd p244). The Varian PortalVision based on Amorphous Silicon detector array. The sensitive area is 40 x 30 cm with 512 x 384 pixels, spatial resolution is (~1 mm) 0.78 mm, and the read out is about 200,000 pixels. aSi (like the (Gd_2O_2S:Tb) is the converting phosphor layer) after the metal plate transfers the e to the light. A photodiode detector layer, placed after the Phosphor layer (aSi), which convert incident light signal to electrical current, and the generated charge is stored in the **capacitor**. After the radiation, the electronic will read out the accumulated charge stored in the capacitor and produce images. (PMB 2002, 47 R31-R65 & Bushberg p300))

(PMB 2002, 47 R31-R65) Before aS500, Varian PortalVision is based on Matrix liquid Ion Chamber device, formed by 2 planes of electrodes separated by a 0.8 mm gap. The gap is filled with a fluid (2,2,4-trimethylpentane) which acts as an ionization medium when the chamber is irradiated. Each electrode plane consists of 256 parallel wires spaced 1.27 mm apart. The electrodes on the two planes are oriented perpendicularly to each other thereby forming a matrix of 256 ×256 ionization cells that provide a detection area of 32.5 × 32.5 cm^2. The ionization medium serves to convert primary x-rays into high-energy electrons and, analogous to the phosphor screen in some camera-based systems, transforms a fraction of the energy of the high-energy electrons passing through it into a measurable (ion) signal. A high-voltage supply is used to apply a 300 V bias to each electrode individually on one of the planes (the high voltage plane).

Important advantages: include the compactness of the detector approaching that of a film cassette, and the lack of geometric distortions in the image.

The most significant disadvantage: the utilization of incident x-ray quanta is inferior to that of a true area detector since, for full-resolution readout, only a single electrode on the high voltage plane is switched on at a time.

Table 2. Specifications of commercial imagers based on indirect detection, active matrix flat-panel imaging technology. Information not available at the time of publication is so indicated. For the Varian system, the asterisk refers to the fact that the pixel format and pixel-to-pixel pitch of the array are actually 1024 × 768 pixels and 392 μm, respectively, while the system is presently configured to provide readout at a lower resolution.

Company	Varian Medical Systems	Elekta Oncology Systems
Product	PortalVision aS500	*i*ViewGT
Commercial availability	2000	2001
Detector area	40.14 × 30.11 cm^2	40.96 × 40.96 cm^2
Array format	Monolithic array	Monolithic array
Pixel format	512 × 384*	512 × 512
Pixel pitch	784 μm*	800 μm
Maximum image acquisition rate	10 frames per second (frames averaged in hardware)	3 frames per second
Image display and storage rate	2 seconds per image	~0.3 seconds per image
Digitization	14 bits	16 bits
Metal plate	1 mm Cu	1 mm Cu
Scintillator	133 mg cm^{-2} Gd_2O_2S:Tb	Gd_2O_2S:Tb
Miscellaneous	Neutral density filter	n/a

(PMB 2002, 47 R31-R65)

TABLE II. Features of the five commercially available EPIDs.

Supplier	Elekta-Philips	Eliav	Infimed[a]	Siemens	Varian
Name	SRI 100	PortPro	Theraview	Beamview Plus	PortalVision
Type	CCD camera	CCD camera	Plumbicon camera	Newvicon camera	Matrix ion chamber
Detector pixels	512×512	512×512	512×512	512×512	256×256
Digitization	8 bit frame-grabber	8 bit frame-grabber	8 bit frame-grabber	8 bit frame-grabber	14 bit A/D converter
Max frequency of acquisition	7 frames/s	30 frames/s	2 monitor units	30 frames/s	Mark 1: 5.5 s Mark 2: 1.25 s
X-ray detector	1.5 mm steel plate +411 mg/cm^2 Gd_2O_2S screen	1.5 mm steel plate +411 mg/cm^2 Gd_2O_2S screen	1.5 mm brass plate +400 mg/cm^2 Gd_2O_2S screen	1.2 mm brass plate +160 mg/cm^2 Gd_2O_2S screen	1.0 mm platoferrite plate +0.8 mm 2.24-trimethyl-pentane + wire electrodes
Mechanical assembly	Dismountable	Portable	Partly retractable and partly dismountable	Fully retractable	Fully retractable; portable if used with retractable arm
Mounting	Philips only	Any accelerator	Any accelerator (GE, Varian, Scanditronix)	Siemens only	Any accelerator (attached by customer)
Collision interlock	Yes	No	Yes (connect to accelerator motion interlocks)	No (interlock activated during deployment only)	Yes
Field of view at isocenter (cm×cm)	Fixed 19×24	Variable	Adjustable 31.8 diam Varian 31.5 diam Sanditronix 31.6 diam G.E.	Fixed 24×30	Adjustable 25×25
Detector area (cm×cm)	30×38	Variable	40×40 (detector)	35×44 (detector)	32.5×32.5 (detector)
Detector to isocenter (cm)	60	Not applicable	30–60 (Varian) 26–67 (G.E.) 27–78 (Scanditronix)	39	5–80
Display center accuracy	±1 mm		±5 mm	±2 mm	±5 mm
Prototype descriptions	Ref. 49		Ref. 51	Ref. 53	Refs. 46,47
Resolution lp/mm (Sec. IV)	0.180	0.305	0.223	0.204	0.258

[a]The Infimed system is now marketed by Cablon Medical.

TG58

- Schematic (I think from Varian) of an EPID. What are the different layers for, what is a TET.
  (Bushber p301-302)
  TFT (thin-film transistor)
  A **transistor** is a semiconductor device manufactured by thin-film deposition used to amplify and switch electronic signals from the detector.

  A transistor has 3 connections, gate, source, and drain. In the flat panel detector, each detector element has a transistor associated with it; the source line is connected to the capacitor that stores the charge accumulated during exposure, the drain is connected to the readout line, and the gate is connected to a wire. During

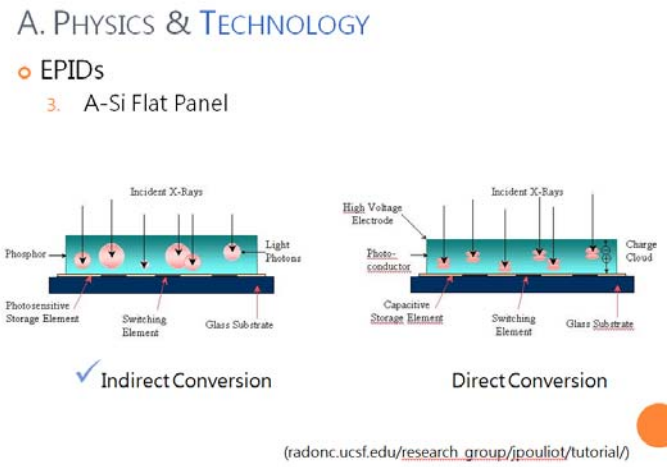
exposure, negative voltage is applied to the gate line, and the transistor switches are turned off. After exposure, a positive voltage is applied to each transistor to turn it on and read the accumulated charge.

Because each detector element has a transistor and the device is manufactured using thin-film deposition technology, these flat panel systems are called thin-film transistor (TFT) image receptors.

- EPID: Differences between direct and indirect.

(Bushberg p300 – 304)
The direct detection flat panel system different than the indirect detection panel system, as the aS500 Varian system (the big3 vendor, Varian, Elekta, Siemens are using the indirect detection system) is the phosphor layer transferring the electron to light photon not used in the direct detection panel, but instead the electron is directly detected in the Amorphous Selenium photoconductor layer, and form the image.

Direct sys has no phosphor (aSi) layer, and when the radiation react with the photoconductor layer (the first layer), it generates electron-hole pair and after applying an e field, the electron-hole will be separated, we will get the signal from electron or hole, and the signal will be amplified in TFT, and then we get the amplified signal.



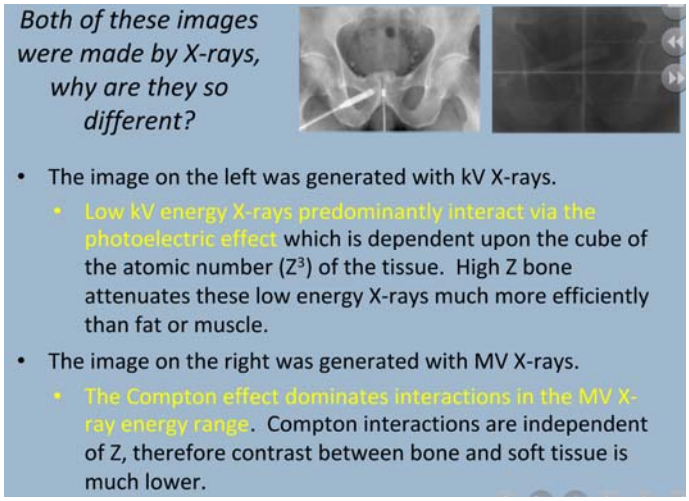
Indirect: kV radiation →(grid take out scattering, grid needs to be thin, otherwise it will reduce the primary photon) → primary photon get into aSi (aSi orbital e excited and decay back)→ light → (photodiode)→ electron → TFT → amplified the signal
(kV doesn't have copper because it will attenuate a lot primary photon signal)

Indirect: MV radiation →(copper get rid of the scattered radiation) → electron get into aSi (aSi orbital e excited and decay back)→ light → (photodiode)→ electron → TFT → amplified the signal

Direct: radiation →generate electron-hole pair in photoconductor (Amorphous Selenium) → apply e field → get charge → TFT → amplified the signal

- EPID. Draw a diagram of an EPID and explain its parts. What's the difference between MV and kV OBI imaging? (TG58, p714 - 715)

MV image: Compton scattering is the dominate interaction for the MV beam, so the contrast and SNR between the bone and soft tissue is not as good as we see in the KV OBI imaging.



- QA for EPID.

  (TG58)

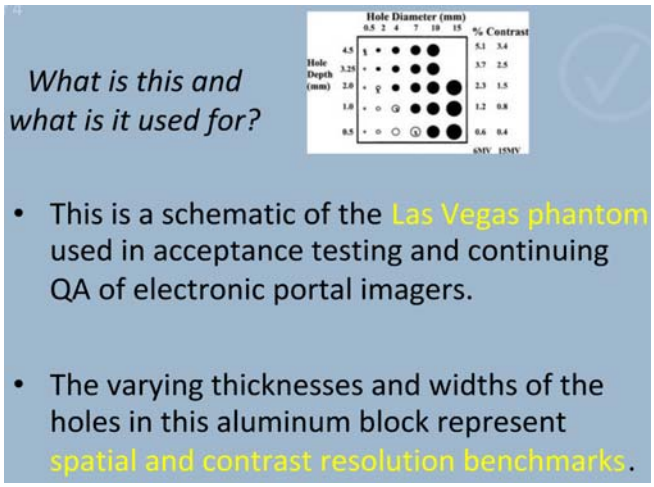
  Daily:

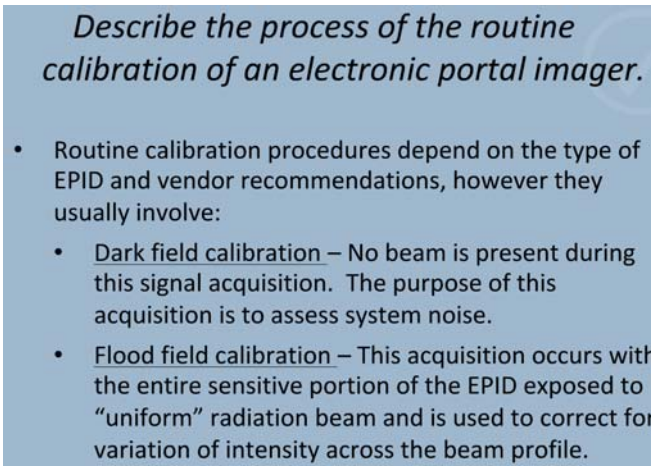
  1. Collision Interlocks
  2. EPID Position Verification (x, y, and z position), out of tolerance, mechanical recalibrate
  3. Image quality check (Contrast and special resolution) Vegas phantom monthly

  Monthly:

  with all the daily +

  4. Review daily QA log
  5. We also check the image center coincidence with the machine Isocenter.
  6. Perform image statistics test (flood field test), if value exceed tolerance, repeat again, if still off, recalibrate



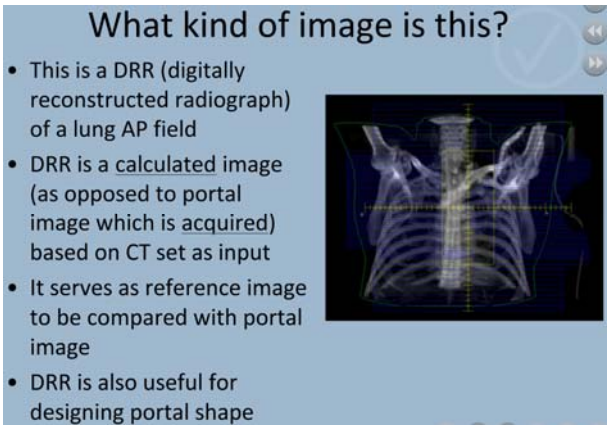


Dark field calibration: to assess the background (noise) signal.

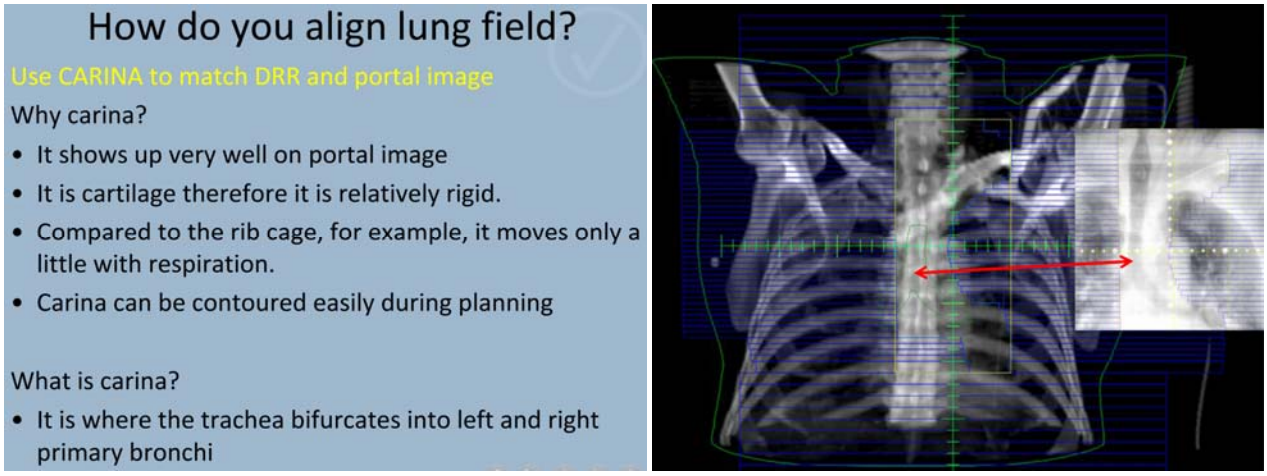
Flood field calibration: uniform field to calibrate the detector response.

- Two images a DRR and a portal image of a lung/Mediastinum Tx. Which one is DRR and which one is portal? How do we obtain each image and which one is the reference? Which image is better (quality wise) and why? Is

there an anatomical site in both images that you can reference to see if they are matched or not. If not matched, what do you do? What if they are not compatible? Shift patient to left or right?



DRR has better image contrast because it was reconstructed using CT data set. The CT data set is obtained from kV energy range so it has higher contrast difference between the soft tissue and bone, compared to the portal image.



- (2008) Shown a PORT film v.s. DRR of prostate. How do you improve the contrast for both types of films? What type of material has twice amount of electron density than water? Later on the other examiner asked me a DRR and Port film of a lung case. I was asked whether I can see any shift between the two.
  (TG58) The contrast can be improve by increase the attenuation difference (changing energy) or reduce scattering fraction.

$$C = \frac{2(1-e^{-\Delta})}{1+e^{-\Delta}+\frac{2\,\mathrm{SF}}{1-\mathrm{SF}}}, \qquad (2)$$

where Δ is the difference in attenuation between the object and the background (i.e., $\Delta = L_x|\mu_{\mathrm{bone}} - \mu_{\mathrm{water}}|$), μ_{bone} and μ_{water} are the x-ray attenuation coefficients for bone and water, respectively, L_x is the thickness of the anatomic structure, and SF is the scatter fraction $\{\mathrm{SF} = \phi_s(\phi_s + \phi_p)\}$. Equation (1) shows that the contrast is increased by increasing the difference in attenuation along the x-ray path and is decreased by the addition of a scatter fluence.

For portal image: the contrast can be increased by reducing field size to reduce the unnecessary scattering effect

For DRR: The contrast can be increased by changing the CT scanning protocol such as adjusting kV to the PE dominate region, and increase mAs increasing SNR and consequently contrast.

How would you improve DRR resolution?

- The input data for DRR are the pixel data from CT
- Coarse CT voxel → coarse DRR
- To improve DRR resolution along the longitudinal direction, scan with thin slices
- To improve DRR resolution along transverse direction, use small FOV along this direction (reduce pixel size)
- CT image usually has fixed 512 x 512 resolution, thus smaller FOV means smaller pixel size (in mm)
- Different X-ray parameters (kV, mAs) will give different contrast (better for different purposes)

(TG58) The bone electron density is around 5.81 x 10^{23} e/cm^3 compared to water 3.34 X 10^{23} e/cm^3, which is approximately 1.74 fold higher.

- Portal film What is port film? (film exposure to the linac MV beam) Why use port film? (to check patient alignment with treatment field compared with DRR) Which type of film do you use? (XV-2) How much MU do you give for this type of film? (1 MU open 1MU close to treatment field, 2 + 2 MU for big pt.) What is the patient dose due to port film? (<5cGy) Should we include this dose in chart? (No, because it's not prescription dose) What is CR (computer radiography see below)? What is EPID? (Electronic portal image device) Do they require more MU or less MU (EPID is more sensitive than port film because the DQE is higher, in general, MU is the same for normal size pt. but for bigger pt, the MU can be less for EPID)?

A. PHYSICS & TECHNOLOGY

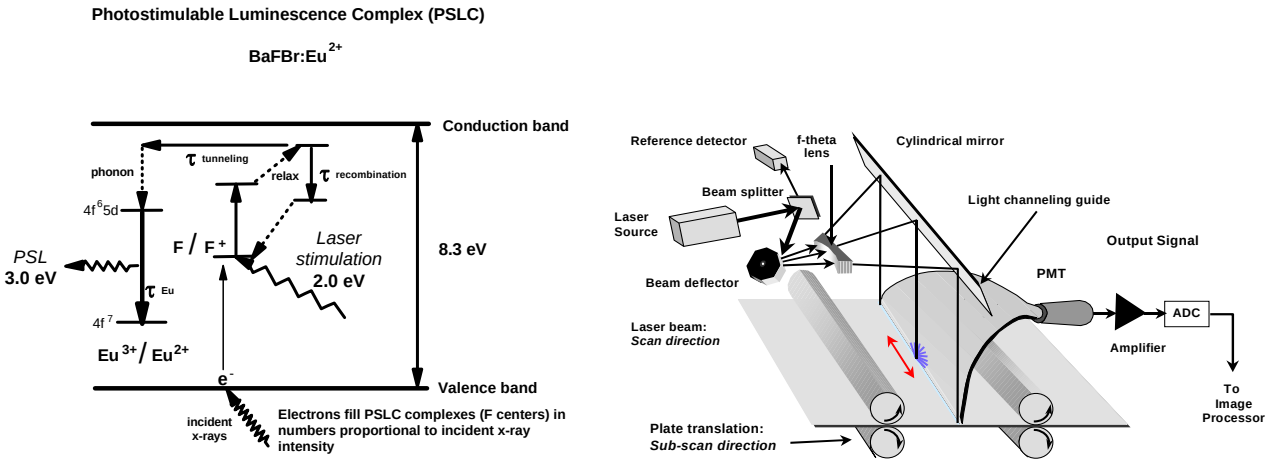
- EPIDs
  3. a-Si Flat Panel

Elekta iView GT system	Siemens OptiVue 500/1000	Varian a-Si PortalVision aS500 (Varian 2100 Linac)
• Source-detector distance 160cm fixed •Active area: 41x41 cm^2 •1024x1024 •0.4 mm pixel size •1 MU Image	•Active area: 41x41 cm^2 •1024x1024 or 512x512 •0.4 or 0.8 mm pixel size •1 MU Image	•Varian aS500 imager •Active area: 40 x 30 cm^2 •512x384 •0.784 mm pixel size •1-2 MU Image

What is the difference in patient dose for a single kV versus MV image?

Room-mounted	CyberKnife and Novalis	kV	0.25 – 0.5 mGy
Gantry-mounted	OBI and Synergy	kV	1 – 3 mGy
EPID	Multiple vendors	MV	10 – 50 mGy
Film	All vendors	MV	50 – 100 mGy

TG-75



CR is the portal imaging sys between the evolutions from portal film to EPID; CR uses a portable cassette; and the radiation directly interact with phosphor material, and the e of the phosphor will be excited into the intermediate energy state and trapped there. Therapist will bring the cassette to the reader, and the reader use laser bring the trapped e to higher excited state from which these e can jump back to the valence band and emit visible light and read by PMT. The advantage of CR is low cost and the 1 cassette can be shared in multiple linac rooms.

The phosphor material used in CR & EPID is different, because the phosphor in EPID emits the light immediately and for CR, the electron is trapped until laser excites it.

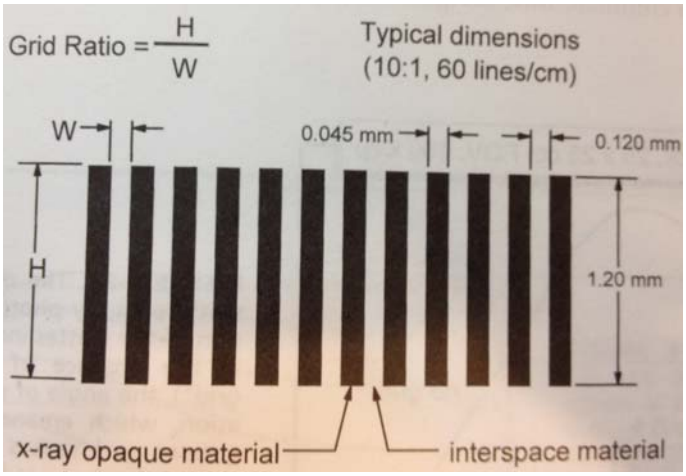
- Discuss Grid for radiological image. Why do you need one? (to reduce scattering) Where do you place it? (above the kV detector) Explain about anti-scatter grid, grid ratio and materials. Can we use the grid for film based simulation, fluoroscopy based setup with simulator, film portal imaging and EPID?

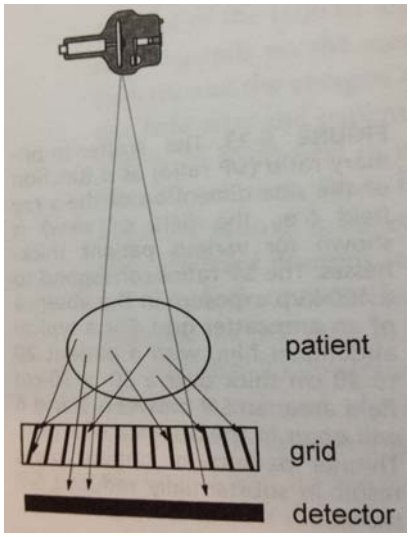
  Grid only works for kv image. Due to the thin width of the grid, it will not work for MV.

  (Bushberg p169)

The grid ratio is simply the ratio of the height to the width of the inter spaces (not the grid bars) in the grid. Grid ratios of 8: 1, 10: 1, and 12: 1 are most common in general radiography and a grid ratio of 5: 1 is typical in mammography. The grid is essentially a one-dimensional collimator, and increasing the grid ratio increases the degree of collimation. Higher grid ratios provide better scatter cleanup, but they also result in greater radiation doses to the patient. A grid is quite effective at attenuating scatter that strikes the grid at large angles (where 0 degrees is the angle normal to the grid), but grids are less effective for smaller-angle scatter.

Grid is made in lead and the open space can be carbon fiber, Al, or even paper





- Showing a pic with KV setup field and MV portal. What are they, why are they different? (PE and Compton)What can you do to help visualizing esophagus? (use contrast agent)

Barium sulfate, an insoluble white powder is typically used for enhancing contrast in the GI tract.

- Shown a DRR and a port film side by side of a prostate plan. Asked to identify the images. How do I know if the second image is a port film or an EPID? I said it was an EPID because it had a window and level control. He said it could be a digitized film… Asked about the function of the port film. What is it called when you leave a film in for the whole treatment instead of just delivering a few MU?

Verification film; set up film

http://www.ncbi.nlm.nih.gov/pubmed/10897254
The use of modern irradiation techniques requires better verification films for determining "set-up deviations and patient movements during the course of radiation treatment". This is an investigation of the image quality and time requirement of a new verification film system compared to a conventional portal film system.

The conclusion is verification film = the "V" film you called before.

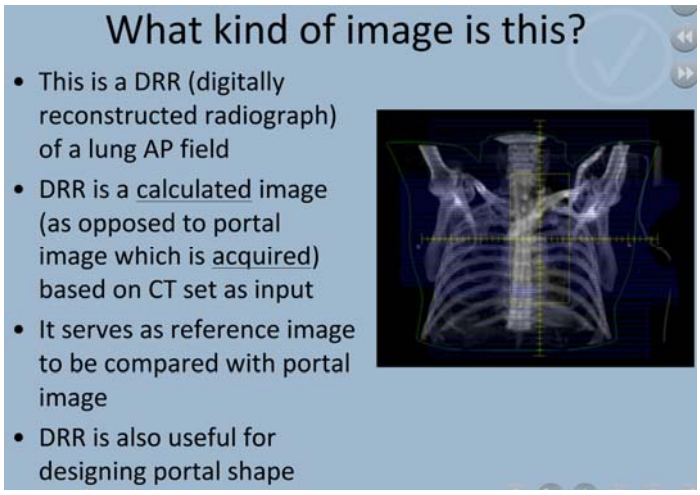
It is used to verify the pt. movement during treatment not the dose.

(Scout & DRR)

- How do you use portal images in clinic? What do you compare to? What's the resolution on DRRs? What are the differences?

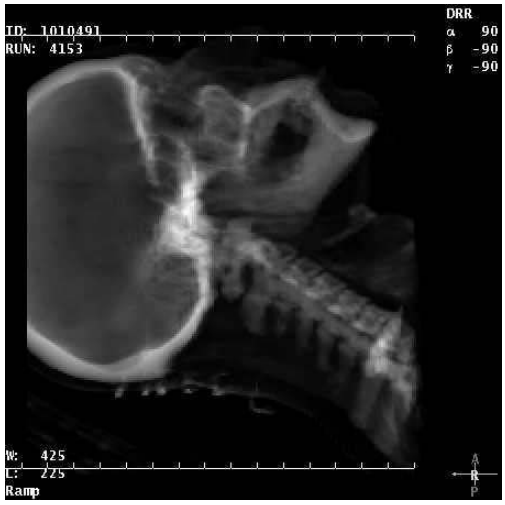
  (Podgorsak Ch12)

Portal images are compared with reference images during treatment, which can either be (orthogonal) simulator images, digitally reconstructed radiographs (DRR) or the first portal image made during a treatment series. A double exposure technique can be useful if only limited anatomical information is present in the treatment field.



(Podgorsak Ch12, p193)

DRRs are produced by ray tracing from a virtual source position through the CT data of the patient to a virtual film plane. The sum of the attenuation coefficients along any one ray-line gives a quantity analogous to optical density on a radiographic film. If the sums along all ray-lines from a single virtual source position are then displayed onto their appropriate positions on the virtual film plane, the result is a synthetic radiographic image based wholly on the 3-D CT data set that can be used for treatment planning.



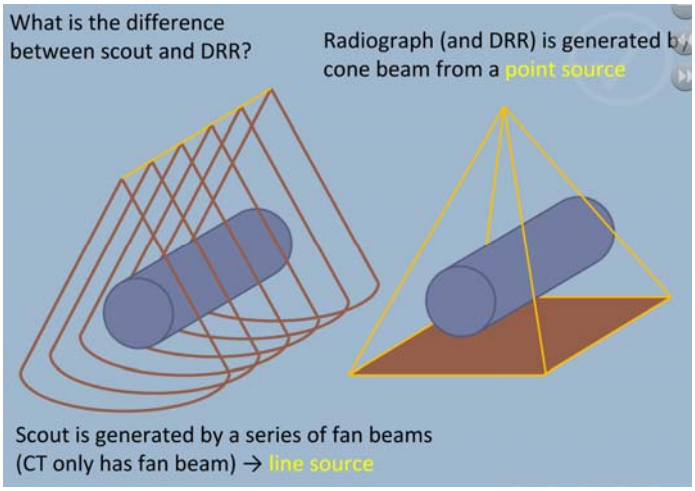


FIG. 7.10. A digitally reconstructed radiograph (DRR). Note that gray levels, brightness, and contrast can be adjusted to provide an optimal image.

The DRR resolution is based on the CT image since it is calculated from the CT set. The DRR resolution can be sub-mm order CT image resolution is about 0.4 mm.

The DRR is calculated based on the attenuation coefficient from the CT image, so basically the calculation dimension is the same as the pixel size of the CT. The DRR can be sub mm resolution. (My opinion)

- (2006) DRR ? quality issues, electron density, HU

How is DRR generated?

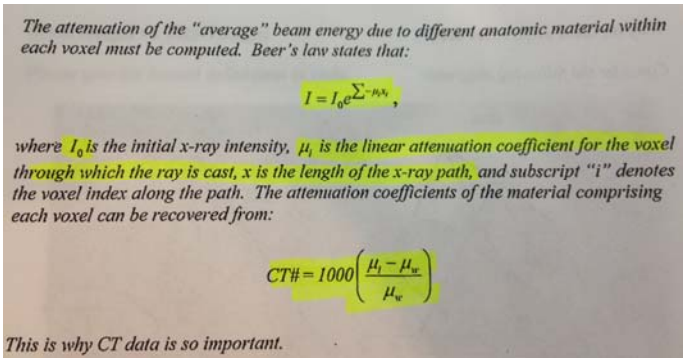
- DRR is calculated from 3D data from CT
- CT → HU numbers → electron density → attenuation
- Follow each ray from the point source to the image plane and attenuate its intensity according to the electron density it encounters on its path
- The attenuation coefficient depends on the beam quality used for calculation

How would you improve DRR resolution?

- The input data for DRR are the pixel data from CT
- Coarse CT voxel → coarse DRR
- To improve DRR resolution along the longitudinal direction, scan with thin slices
- To improve DRR resolution along transverse direction, use small FOV along this direction (reduce pixel size)
- CT image usually has fixed 512 x 512 resolution, thus smaller FOV means smaller pixel size (in mm)
- Different X-ray parameters (kV, mAs) will give different contrast (better for different purposes)

- If given a radiograph and DRR of same anatomy. Know to explain what they are, what a DRR is, how it is made, limits of resolution (depends on CT), and which of the two images are better to use and why.
- If Given 2 DRR's which were of the same site, but with different quality. How are they formed? Why is one better quality than the other? (also get into slice thickness of CT's, mAs, Energy, and small FOV)

- (2008) Shown a picture of DRR and Scout image with image slice selections on it
  - Follow up:
    - How you generate a DRR, Name the Algorithm (Ray-tracing) used.



The attenuation of the "average" beam energy due to different anatomic material within each voxel must be computed. Beer's law states that:

$$I = I_0 e^{\sum -\mu_i x_i},$$

where I_0 is the initial x-ray intensity, μ_i is the linear attenuation coefficient for the voxel through which the ray is cast, x is the length of the x-ray path, and subscript "i" denotes the voxel index along the path. The attenuation coefficients of the material comprising each voxel can be recovered from:

$$CT\# = 1000\left(\frac{\mu_i - \mu_w}{\mu_w}\right)$$

This is why CT data is so important.

    - Why can't you use a Scout image as a DRR?
    - Can you use a scout image for block cutting etc?
      Can you use a scout film for planning?

No, the SAD is different scout 60 cm and linac is 100 cm.

C3-D (Algorithm)

- **DQE** graph vs spatial frequency with 4 different curves (video, ion chamber, amorphous silicon, and amorphous selenium) explain spatial frequency and how the curve is related to what you use in the clinic. What Detector Quantum Efficiency stands for, and what the graph relates for what is stated to be 3 types of flat panel detectors for portal imaging. What is resolution (lp/m)? What does this mean? Which system is better?
  DQE is a measure of how efficient the imaging sys is at transferring the info contained in the radiation beam incident upon the detector, expressed as SNR^2(input)/SNR^2(output).

  DQE: aSelenium > aSi > video > IC

1. the maximum DQEs achieved for camera–mirror–lens-based EPID systems using a metal plate/phosphor screen are reported to be as high as ~1%.

2. the DQE of the scanning matrix IC is, at best, only on the order of 0.5% due to the signal loss in sampling. Consequently, the total dose required to generate an image is larger than that for EPIDs incorporating true area detection. In addition, the sampling frequency of the detection elements of this system is lower than that for the other commercially-available EPIDs.

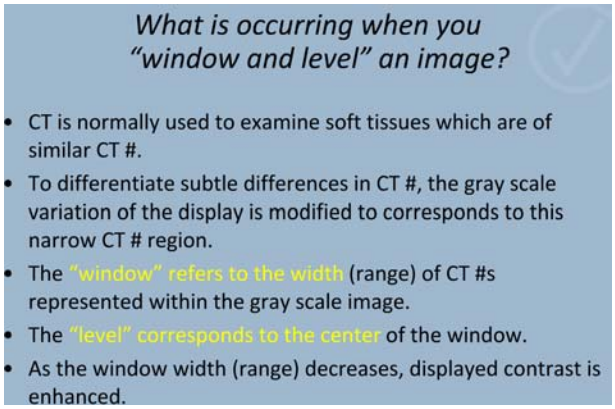
3. the DQE of indirect flat panel when operated with an ~133 mg cm^{-2} phosphor screen is anticipated to be slightly greater than 1% at 6 MV.

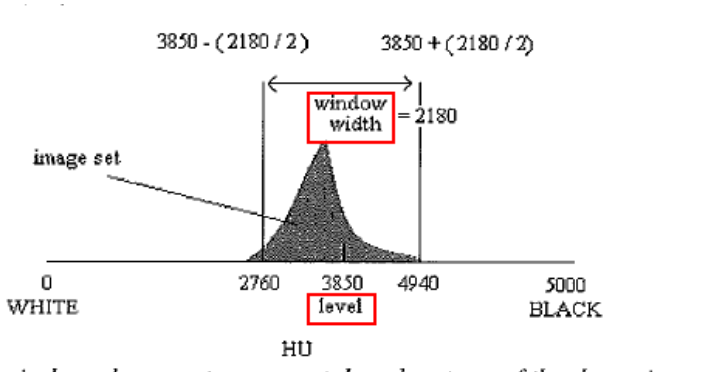
4. in TG 58, there is figure showing that direct flat panel has high DQE than indirect

Spatial resolution of an imaging sys is defined as the separation at which 2 objects can just be distinguished as 2 distinct objects rather than 1. Spatial resolution is measured as lp/mm.

(windows & leveling) (DABR 448-451)

- Definition of window/leveling. Two CT image with different window/leveling. Discuss the algorithm associated with window and leveling (linear, log, and inverse hyperbolic scaling DABR P451). Image resolution/depth.
- Showing a CT of thoracic region with different window/leveling, one in the lung window, one in the soft-tissue window. What are they? What is window/level? What typical window/level do you use? Why use different window/level? (increase contrast to better visualizing different type of organ/tissue such as bone, spinal cord, soft tissue) How HU is defined?



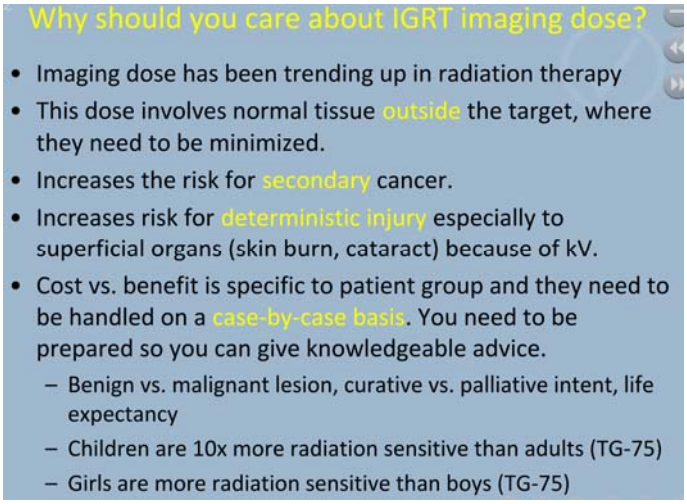


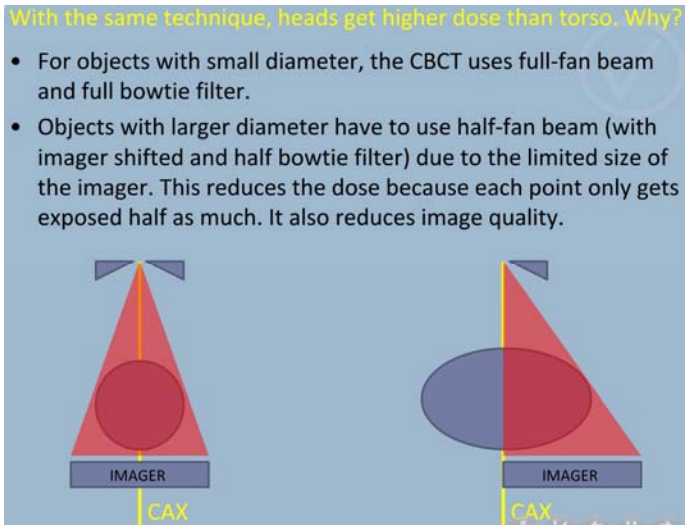
http://rsbweb.nih.gov/ij/plugins/ct-window-level/index.html
(HU) Body window (400) level center (40) → -160 to 240
Lung window (1600) level center (-600) → -1000 to 600
Bone window (2000) level center (300) → -700 to 1300

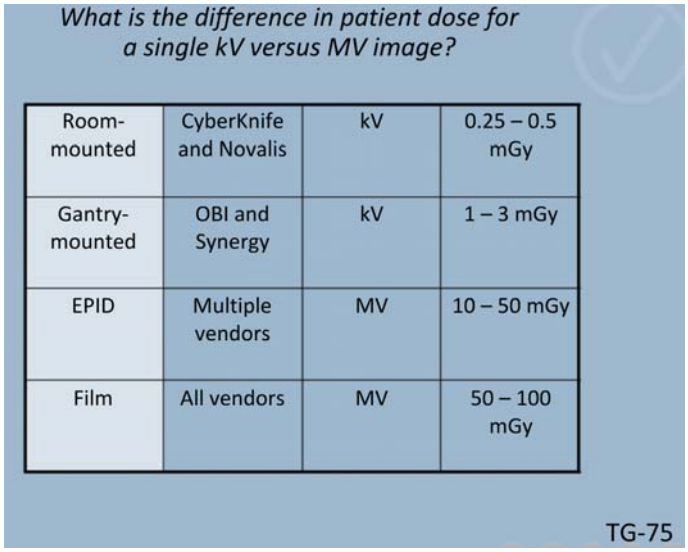
Image depth is a computer graphics term describing the scope or # of bits used to represent the colors or gray-tones of a single pixel in a medical image. If we have 16 bit CT scanner and 512 x 512 pixels, we have 2^{16} bits (image depth) per pixel to resolve the gray scale.

16 bit CT map to 12 or 16 bit display and then 32 gray level for our human eyes (not sure if Varian Eclipse do that for human eye visualization).

- Image dose:







CT, CBCT: 30 – 50 mGy, higher dose at surface.
4DCT: 250 mGy
Fluoroscopy: 45 mGy/min, for 10 mins fluoro, 450 mGy at skin entrance (we passed Fluoroscopy Dose)

C3-E (CT sim)

- How do you obtain CT images? Explain (filtered back projection algorithm).

(Bushberg p346 - 355):

1. Raw data acquired by CT x-ray source sending photon, attenuated by patient, and detected by the detector at the different angle form a sinogram
2. After preprocessing the data to calibrate the geometric efficiency and other preprocessing steps, the data can be reconstructed as the CT image using backprojection algorithm. The algorithm smeared or backprojected the linear attenuation coeff. detected by each detector to each matrix pixel. For each pixel, the attenuation measured from each detector is added up and form the CT image.
3. The popular reconstruction algorithm is filter backprojection algorithm. The algorithm basically convolve the detector data with a specified filter to eliminate the image blurring effect.

- (wepassed in CT simulator) The scanning field of view (sFOV) is that region completely within the CT fan beam throughout an entire rotation. Anatomy outside the sFOV produces artifacts and incomplete image information. Expanded field of view (Efov, 80cm are of our case) reduces artifacts and provides missing anatomical information; however the HU may be suspect for the purpose of dose computation.

- Discuss CT use in radiation therapy.

  Mainly 1. For anatomy countering & 2. Heterogeneity calculation (Kahn)

- What are the differences between diagnostic (conventional) and therapy CT (CT simulator)?

The major difference between the CT and CT-Simulator is that the CT-Simulator typically has additional hardware and software components. (wepassed)

- Linked platform for anatomy contouring, beam placement and aperture design;
- external laser system to setup the treatment iso; QA criteria < 2 mm
- CT-sim may have a larger physical bore (70 cm) and field of view to accommodate the use of immobilization devices and the need for full axial view of patient anatomy.
- A hard flat, carbon fiber table top, as does the linac treatment couch. Diagnostic CT has a curved tabletop.

- Picture of a CT-sim. What is its characteristic compared with conventional Simulator? (Laser, Table).

Simulator CT is a conventional simulator that is equipped with hardware/software necessary to perform 3D CT scan (with cone-beam acquisition), such as Varian Acuity.
Advantage: larger clearance, can accommodate larger patients, and breast board.
Downside: poor image quality and smaller reconstruction circle (40-55 cm diameter) than CT. Also slower scan because it is limited to 1 rotation/minute.

- How do you generate DRR (from CT data set), can you get from conventional simulator?

  I think we can not get the DRR except we have HU and electron density curve for our acuity

- CT-sim, image intensifier, field wires (These thing should be in the simulator CT)

  Image intensifier-- There are four principal components: (a) a vacuum bottle to keep the air out, (b) an input layer that converts the x-ray signal to electrons, (c) electronic lenses that focus the electrons, and (d) an output phosphor that converts the accelerated electrons into visible light.

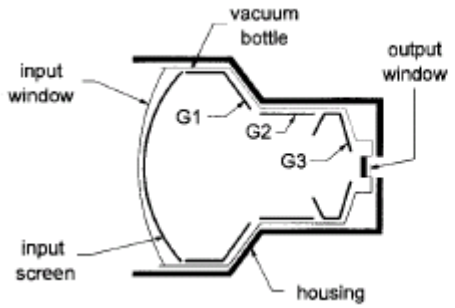


FIGURE 9-2. The internal structure of an image intensifier. The photocathode (in the input screen), the three focusing electrodes (G1, G2, and G3), and the anode (part of the output window) make up the five-element (pentode) electron optical system of the II.

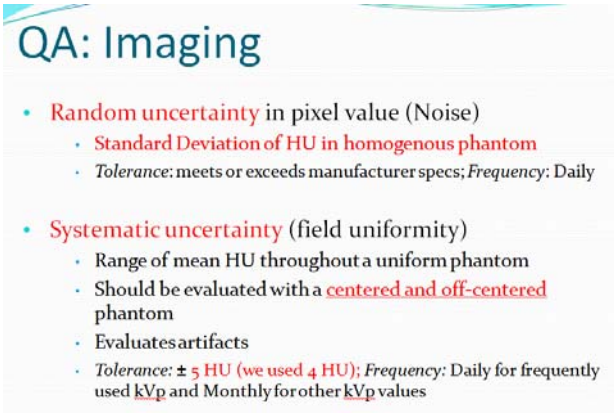
- Can you use any diagnostic scanner in a RT department?
  No, because the energy of a given diagnostic scanner can be different than the energy we used to build the CT calibration curve)

(CT QA):

- Low contrast resolution phantom for CT. Identify what this test is how often would you do the test (Monthly QA) and talk about the different test that you would do for image quality
- Photos of CT resolution test. What is this? Why is it important? What other tests done on CT?
- Image of a contrast resolution phantom. What is this? What is it for? Describe contrast resolution test. What is tolerance? What are you looking for? What if it fails? Any guidance document? (TG66)
- What tests do you perform for your monthly CT QA?
- CT image quality phantom. Several rod with different diameter. What is this test for?

(Daily QA)

1. Chk laser
2. Use Vendor provide phantom to check



(Monthly QA)
(monthly QA form):

1. Laser: (read wepassed CT End-to-End test)
    1. Align and level the wilki phantom to the wall laser at laser zero position
    2. Table moving the wiki phantom toward gantry 575 cm (the predefined position between gantry and wall laser). Here the gantry wall laser should be on the groove set in the wilki phantom. We can check the gantry laser here. Zero at this position.
    3. Scan the phantom
    4. Find the central slice of the wilki phantom, and put grid on. If our wall laser align well with the image plane, we should see the grid on the middle of the groove, and uniform intensity throughout the phantom (2mm)
    5. We send the scanning image to Aria and perform iso shift test (2mm)
2. Table movement vertical and longitudinal using ruler + laser (1mm)
   Table top orientation with respect to imaging plane (2mm)
3. Image quality test
    - HU reproducibility <|40HU| manufacture spec, compared to baseline, consistency test
    - In slice spatial linearity < 2 mm, check if there is spatial distortion which is important for anatomical structure for planning
    - Slice thickness < 1 mm
    - Low contrast resolution to evaluate the scanner ability to discern the small objects with only 0.5% contrast compared to background and the tolerance following the manufacturer spec is 7 disk
    - High contrast resolution is to evaluate the spatial frequency (resolution) lp/mm. manufactuer spec is 6 lp/mm.

- NOTE: We don't use this (HU uniformity test in Catphantom) layer for CT, since we already done it using Daily QA phantom. The|40HU| tolerance is for CBCT.

(Annual QA) (TG66)
All daily + monthly
- Check CT calibration curve by scanning the e density phantom
- Table indexing and positioning +/-1 mm
- Gantry tilt accuracy +/- 1 degree
- Gantry tilt position accuracy +/- 1 degree or 1 mm
- Scan localization (scout image) +/- 1mm
- Radiation profile width (film with different collimator opening) manufactuer spec
- Sensitivity profile width (act, it's slice thickness we do in monthly +/-1 mm)

X-ray generator test is in acceptance & commissioning or the replacement of major generator component.

- What would you do if you find the resolution is worse than commissioning?
  Check if the machine setting consistent with commissioning, such as slice thickness, pitch.

- Sometimes you have to do CT scan in an orientation that is different from the treatment geometry, How do you go about transferring the data correctly (3 BB, make a V shape placed under table TG66)?
- How does the CT image affect TPS? (contouring accuracy & dose calculation accuracy)
- Shown a picture of CT scanner. How I would do a QA for sending images to the TPS.
  We can scan a CATphantom with 3 BB, make a V shape and placed it at left, anterior side and point to superior direction, to record the orientation. We scan it and send to TPS.
  1. We can check orientation
  2. Image parameter and properties
     (Indiana Uni. CT commissioning report p23)

(Acceptance & commissioning)
- How do you do acceptance for a CT simulator. How do you verify spatial accuracy? While talking about couch motion checks, what setup do you use for that? With respect to lasers what kind of lasers are they, how you QA? Explain acceptance, lasers, TPS, etc.
  - (TG39) Safety & shielding(testing CT dose using CTDI);
  - Mechanical (electro-mechanical components, x-ray generator test);
  - Image quality (All our daily +monthly);

- (2008) Shown a figure of CT-simulation. Explain each device does in the room and how to commission CT-sim?
- Describe a complete CT sim solution (including workstations, DRR printer). What tests you do need to perform to commission the system? What are the limits? Does the workstation require input about your linac if you are only going to use that software to design fields? What info?

  CT sim commission:
  - Safety & shielding (testing CT dose using CTDI);
  - Mechanical (electro-mechanical components, X-ray generator test);
  - Image quality (spatial integrity; noise; resolution);
  - Data transfer (orientation, image parameters);
  - Acquire CT curve
  - End-to-end test (TG66)

(1) Scan phantom with a fiducial marker,
(2) Check scan indexing based on length of phantom,
(3) Transfer data to workstation,
(4) Check orientation,
(5) Outline external contour of phantom,
(6) Calculate area and volume to determine accuracy of structure outlining,
(7) Align isocenter to fiducial marker,
(8) Move CT couch to isocenter coordinates,
(9) Mark phantom insuring that lasers match fiducial mark,
(10) Set field size,
(11) Send data to RTP system,
(12) Check orientation and beam parameters,
(13) Check CT numbers if the phantom is heterogeneous,
(14) Send data to a treatment machine,
(15) Print DRRs and setup documentation,
(16) Setup and verify phantom treatment.

Our sys is sending scan to TPS directly and set beam parameter, so there is no intermediate step.

CT sim should have the same geometry orientation; geometry limit (TG66)

What is the purpose of commissioning?

- Acquire all necessary data from the equipment that are required to make it clinically useable.
- Define a baseline for routine QA down the line.
- This is to be done by the medical physicist.

What is the difference between acceptance and commissioning?

- Acceptance test is done by engineer from manufacturer.
- Preferably done in the presence of medical physicist.
- It checks that the equipment meets the specs provided by the manufacturer and agreed upon by purchaser.

What commissioning tests would you do for new CT?

- Safety and shielding (always the first!) This involves survey and testing CT-dose from various protocols.
- Accuracy of electro-mechanical components
- Image Quality: noise, resolution, spatial integrity
- Software and data-transfer accuracy
- Process: Evaluate the overall simulation process

- The guiding document you can use is TG-66, QA for CT simulators (2003)

What parameters for image quality would you test? And how would you test them?

- The best way is to do what diagnostic physicists do (the pros!).
  TG-66 recommends to team up with diagnostic physicists if you are not sure about CT QA.
- They would do the tests listed on ACR CT test instruction.
- If possible use ACR CT phantom so you kill two birds with one stone (commissioning and accreditation data). Otherwise, other CT phantoms are available for this purpose. Check:

1. CT# accuracy: Known materials must have the correct CT#
2. CT# uniformity: Uniform material → uniform CT# ± noise
3. Image noise: How much spread in CT# for uniform material
4. Low contrast resolution: Can you still distinguish adjacent objects with only a few CT# difference? How small an object?
5. High contrast (spatial) resolution: How many line pairs per cm (lp/cm) can you resolve?
6. Geometric accuracy: Is there any image distortion?

+ 7. Spatial integrity check

What would be the components of your CT QA program?

Highlights of QA recommendations from TG-66

- External alignment to within ±2 mm. This includes the laser on gantry, wall, ceiling. These are part of monthly QA, except for gantry laser alignment which should be done daily.
- Image should be accurate to within ±1 mm. So all components that affect image integrity should have the same or better accuracy. This includes table motion, table indexing, scan localization, in-plane spatial integrity.
- Image parameters should be accurate to within ±5 HU or manufacturer specifications. So CT# for water should be 0±5 HU and field uniformity should be within ±5 HU.

- TG-66 provides detailed QA goals, frequency, and tolerance limits for all aspects of CT-simulator QA. Mention this!

- CT/Sim picture. Define each part. What does the simulator software do? (TG66: is a set of software which recreates the treatment machine & which allows import, manipulate, & store image from CT or other modalities, in our case it is the Eclipse TPS)

  What are the limits for (1) lasers (2mm), (ii) anatomical data (1mm), (iii) DRR (Spatial & contrast should be compared to baseline & geometric spatial accuracy should be within 1 mm (TG66 P2778))

- CT image with an artifact due to the contrast media. How would it affect the treatment plan? Would it affect the dose calc? How would you approach this problem?
  It will produce artificial HU in the CT image, and further affect the electron density and affect the dose calculation if using heterogeneity correction. We can overwrite the HU based on the surrounding tissue HU.

- How to get electron density information from CT to TPS. Hounsfield units, write equation for conversion of them, how do you measure, etc.?
- Image of a low contrast resolution CT phantom that is very grainy in the image. Question: What is this, how was it produced, how is the CT# vs Electron density graph different for a CT unit and our Tomo unit.

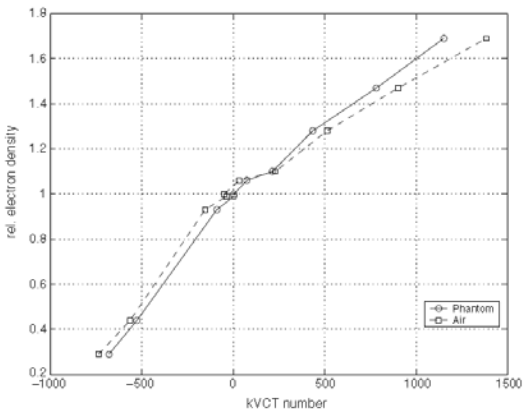


Figure 14. A kVCT to electron density calibration study. The kVCT to electron density curve was established from axial scans through the centre of the phantom and from axial scans just past the solid water slab. At this location, the test plugs are suspended in air.

2005 Phys. Med. Biol. 50 4259

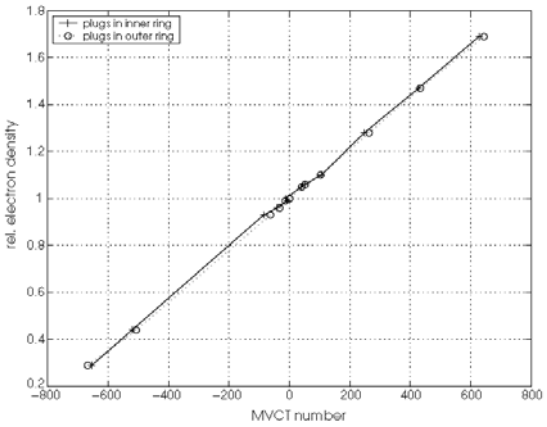


Figure 7. The variation of the MVCT number to relative electron density calibration curve to the placement of the test plugs. The positions of the inner and outer ring plugs were exchanged and the graph shows the effect of this for each plug.

*Note the above figure, axes are labeled in the opposite way as the normal CT calibration curve.
MV calibration curve is straighter because there is only Compton effect.
In kV ct, there is PE & Compton, so u can see the kink in the curve.

- Definition of CT#,

CT number is given by

$$CT\#(E) = k\frac{\mu(E) - \mu_w(E)}{\mu_w(E)}$$, k is the weighting constant. 1000 is used for HU.

- What could be done to improve the quality of the image, how would you know if it is acceptable.

Change kV to increase contrast,
Increase mAs to increase SNR (more Dose to the pt.),
Reduce slice thickness increase spatial resolution but SNR becomes lower
Reduce FOV to increase spatial resolution but SNR becomes lower
Small helical pitch to increase spatial resolution (large pitch, table wil move too fast)

Perform the Catphantom QA to assess the image quality.

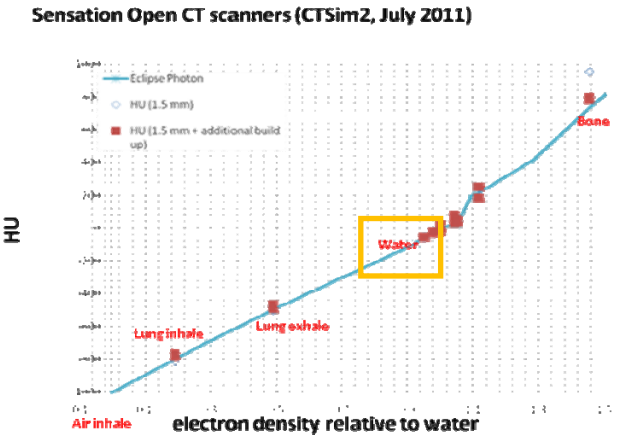
- Shown a picture of a CT scanner? Identify various parts.
  (scanner: x-ray tube, collimator & attenuator
  table, computer station
  external and internal laser)

- What is the distance between internal and external laser intersections (575 cm)?

- Cone-beam CT. How does it work? Does the couch move while scan? (No) What is the energy? (120keV)

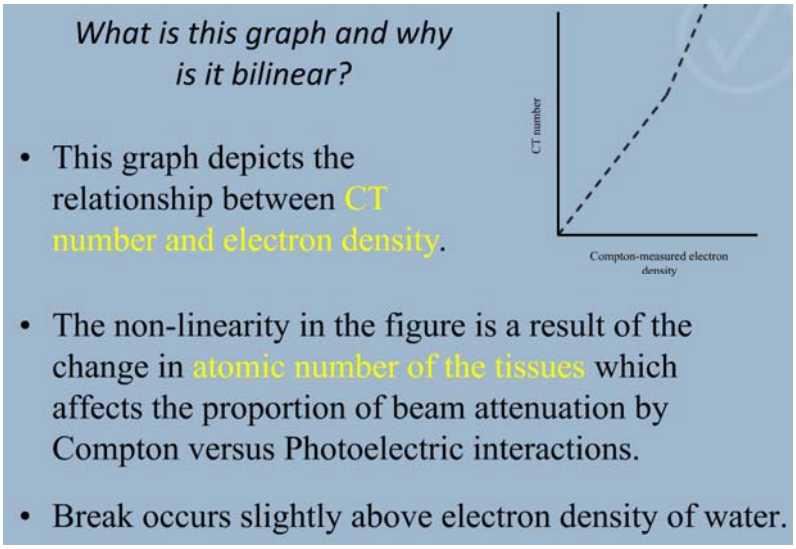
- CT image from Conventional simulator, and port image. I was asked about the underlying physicist for this.
- CT and portal images, difference and one or the other, difference between CBCT and CT
  (TG104, p9)
  CT fan beam geometry: Transmitted projections are taken either in helical or spiral form. The data are then interpolated or re-binned before reconstructing a set of slices that make up a vol.
  CBCT: cone beam geometry to obtain the large image volume within 1 rotation, and the 3D image was reconstructed.

- Graph of electron density vs. HU. Describe the graph. What is the E density of air, water, lung and bone.

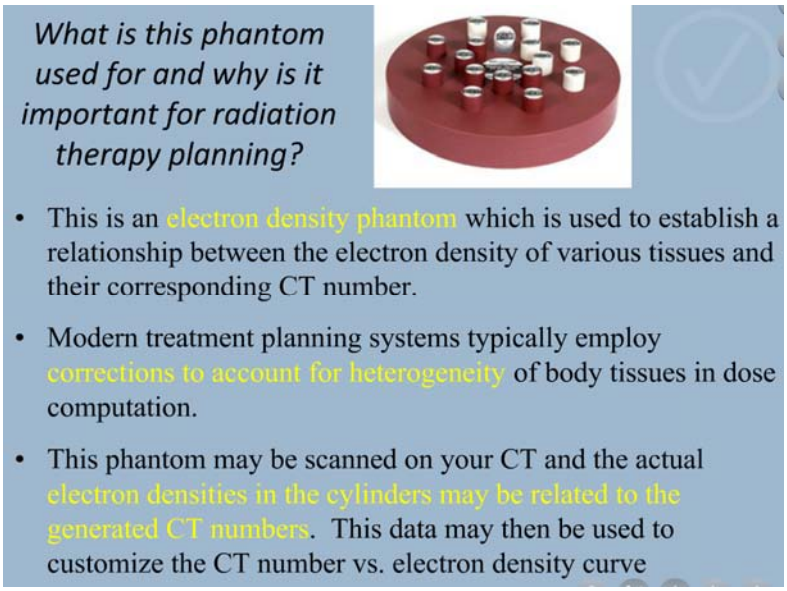


	Electron Density (relative to water)
Lung (Exhale)	0.489
Muscle	1.043
water	1.000
Travecular bone	1.117
Lung (Inhale)	0.190
Liver	1.052
Dense Bone	1.456
Breast 50/50	0.976

(From CIRS phantom)

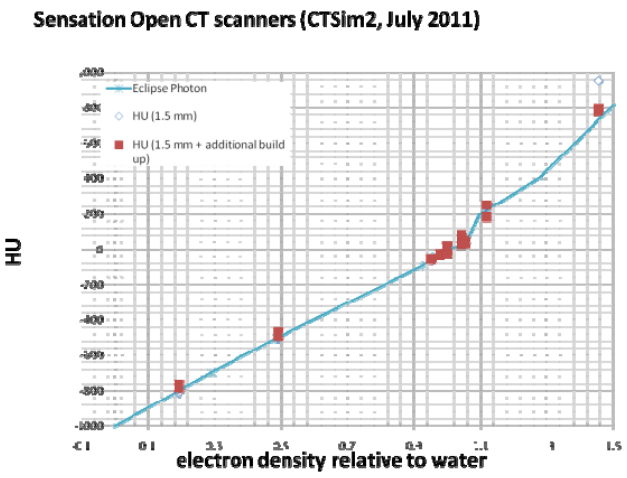


- Shown a thin circular phantom with 5 holes and lots of plugs beside the phantom. What is it and for what purpose? How do you calibrate CT # and electron density? Why is it important?
- (2008) Name of phantom used for CT to ED file
  We have CIRS electron density (tissue characteristic) phantom, and Gammex phantom



It's a Gammex phantom

Typical CT numbers: Metal > 2000 HU, Hard bone → 1000; Femoral Head → 400; Breast prosthesis → 70; Mediastinum → 50; Water → 0; Fat(adipose) → -100; Lung → -800; Air → -1000



What are some typical CT numbers for body tissues?

Tissue	CT Number
Water	0
Air	-1000
Dense bone	1000
Fat	-20 to -100
Muscle	45 to 60
Lung	-300
Brain matter	25 to 45

From Webster JG, ed. Encyclopedia of Medical Devices and Instrumentation. New York: Wiley, 1988, P. 834.

(CT Shielding):

Use (wepassed CT Suite Survey): **Bushberg p769**

- For a CT scanner, all walls in the room are secondary barriers, since the det. array provides the primary barrier already.
- TVL lead for 125 kVp is **1 mm**
- During survey:
  - Phantom in CT scanner
  - GM check possible shielding integrity (gap, door) + ion chamber to measure dose
  - Highest energy + largest slice thickness + high mAs to reach max exposure during shielding survey
  - X = W x T x (Instantaneous scatter & leakage exposure for a given distance)

CT Dose (my CT dose note + wepassed CT Dose)

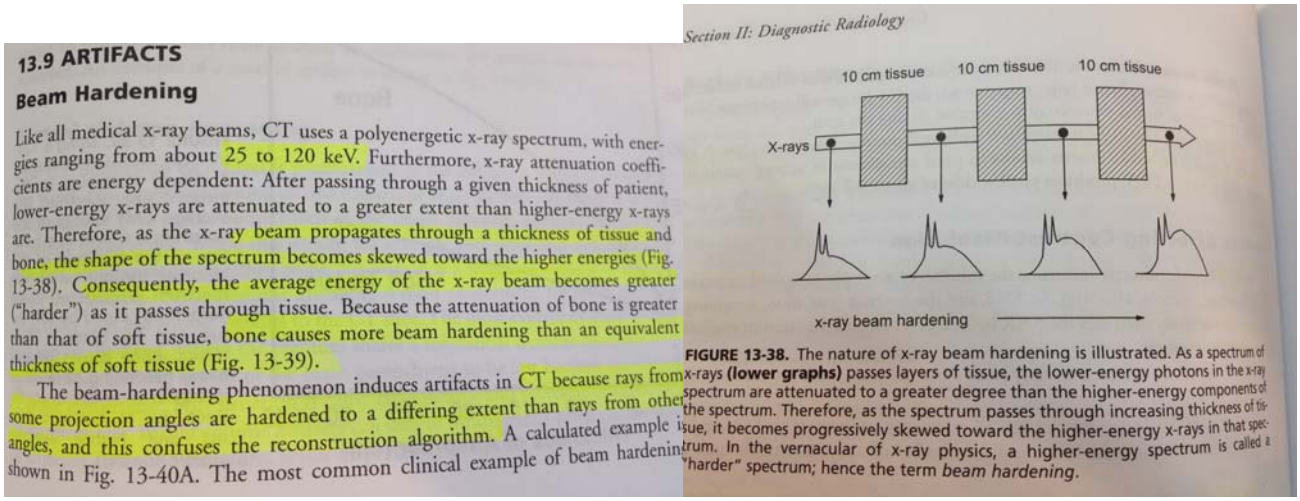
- Why there is no door interlock for CT? and when you open the door will the CT stop?

CT-scanners are typically equipped with connections for door interlocks. The use of door interlocks for CT-simulator can potentially be harmful for the patient. If the scan is interrupted during image acquisition, the entire scan may have to be repeated. This would expose the patient to unnecessary radiation. A more troublesome situation would be interruption of a scan while the patient is being injected with a contrast material. Exposure to a person accidentally entering a CT-scanner room during image acquisition is minimal and well below regulatory limits. The interruption of a scan acquisition therefore has a potential to be much more harmful to the patient than beneficial for a person entering the scanner room. Therefore, door interlocks should be avoided in CT-simulator installations, unless required by other regulations.

(CT Artifact)

- Transverse abdominal CT Image artifacts with contrast agent in the abdomen. Know what is happening? Why do we get streaks of white lines? (beam hardening effect)
- Shown a CT with beam-hardening artifact and asked what caused it, if it is usable for treatment planning (overwriting CT number etc…). Identify the contours in the axial and coronal slices (liver, kidney and bowels).

Bushberg

- 

13.9 ARTIFACTS

Beam Hardening

Like all medical x-ray beams, CT uses a polyenergetic x-ray spectrum, with energies ranging from about 25 to 120 keV. Furthermore, x-ray attenuation coefficients are energy dependent: After passing through a given thickness of patient, lower-energy x-rays are attenuated to a greater extent than higher-energy x-rays are. Therefore, as the x-ray beam propagates through a thickness of tissue and bone, the shape of the spectrum becomes skewed toward the higher energies (Fig. 13-38). Consequently, the average energy of the x-ray beam becomes greater ("harder") as it passes through tissue. Because the attenuation of bone is greater than that of soft tissue, bone causes more beam hardening than an equivalent thickness of soft tissue (Fig. 13-39).

The beam-hardening phenomenon induces artifacts in CT because rays from some projection angles are hardened to a differing extent than rays from other angles, and this confuses the reconstruction algorithm. A calculated example is shown in Fig. 13-40A. The most common clinical example of beam hardenin

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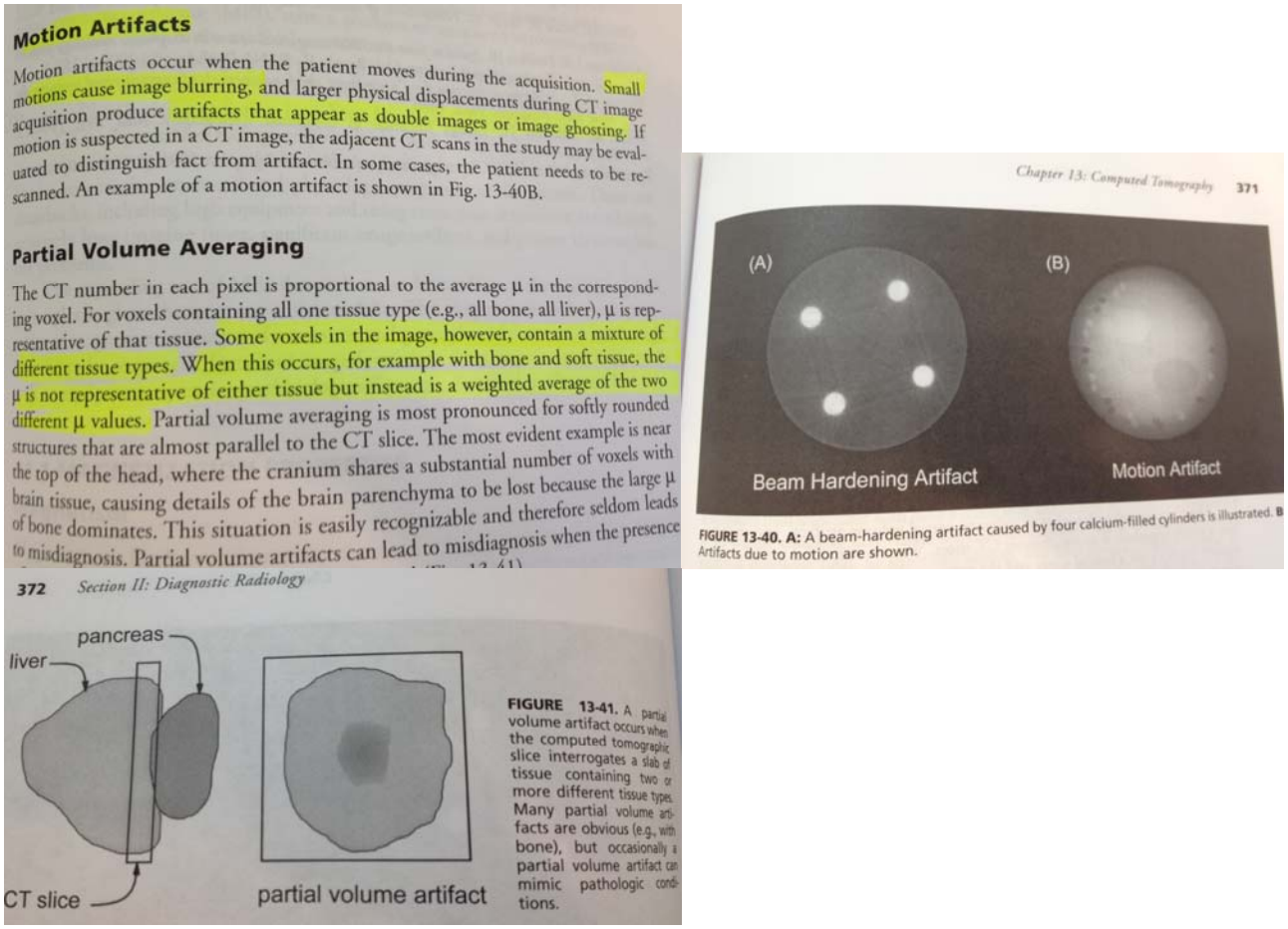
FIGURE 13-38. The nature of x-ray beam hardening is illustrated. As a spectrum of x-rays **(lower graphs)** passes layers of tissue, the lower-energy photons in the x-ray spectrum are attenuated to a greater degree than the higher-energy components of the spectrum. Therefore, as the spectrum passes through increasing thickness of tissue, it becomes progressively skewed toward the higher-energy x-rays in that spectrum. In the vernacular of x-ray physics, a higher-energy spectrum is called a "harder" spectrum; hence the term *beam hardening*.

- 

Motion Artifacts

Motion artifacts occur when the patient moves during the acquisition. Small motions cause image blurring, and larger physical displacements during CT image acquisition produce artifacts that appear as double images or image ghosting. If motion is suspected in a CT image, the adjacent CT scans in the study may be evaluated to distinguish fact from artifact. In some cases, the patient needs to be rescanned. An example of a motion artifact is shown in Fig. 13-40B.

Partial Volume Averaging

The CT number in each pixel is proportional to the average μ in the corresponding voxel. For voxels containing all one tissue type (e.g., all bone, all liver), μ is representative of that tissue. Some voxels in the image, however, contain a mixture of different tissue types. When this occurs, for example with bone and soft tissue, the μ is not representative of either tissue but instead is a weighted average of the two different μ values. Partial volume averaging is most pronounced for softly rounded structures that are almost parallel to the CT slice. The most evident example is near the top of the head, where the cranium shares a substantial number of voxels with brain tissue, causing details of the brain parenchyma to be lost because the large μ of bone dominates. This situation is easily recognizable and therefore seldom leads to misdiagnosis. Partial volume artifacts can lead to misdiagnosis when the presence

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FIGURE 13-40. A: A beam-hardening artifact caused by four calcium-filled cylinders is illustrated. **B** Artifacts due to motion are shown.

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FIGURE 13-41. A partial volume artifact occurs when the computed tomographic slice interrogates a slab of tissue containing two or more different tissue types. Many partial volume artifacts are obvious (e.g., with bone), but occasionally a partial volume artifact can mimic pathologic conditions.

- Shown a CT with 6 images. 3 were of an area higher up in the chest (axial, sag, coronal), and 3 were of the same patient but down in the pelvis. The axial pelvis image had streak artifacts. Asked to discuss what caused the artifacts and how you would get rid of them of the physician wanted a new scan. I didn't see any hip implants, so that wasn't it. There was an area of high contrast anterior to the pelvic bones, but I don't know what it was. I said maybe it was the bladder with contrast in it. He asked if CT contrast would cause streaking

In this case, the streak is due to the high density material because of the beam hardening effect. The way to avoid can be 1. Increase energy, 2. Put extra bowie tie filter to increase beam hardening (DABR p425)3. Reduce the contrast concentration.

Another reason to cause the streak artifacts is the

Different streak artifacts may be caused by: high density objects; motion; large patients – beam hardening; photon starvation.

- Showing two sets of CT images, one of a small patient, one of a large patient. Discuss the CT artifacts, causes of artifacts. (2008) Shown a group of CT axial, sagittal and coronal views. This patient has a normal upper body and big around stomach. Explain the contrast to noise ratio difference between the two areas on axial planes.

Bigger patient has poor signal to noise ratio because of **stronger attenuation so less photon** reaching the detector compared to a thin patient, thus the SNR is worse (Bushberg p369).

(Fluoroscopy)

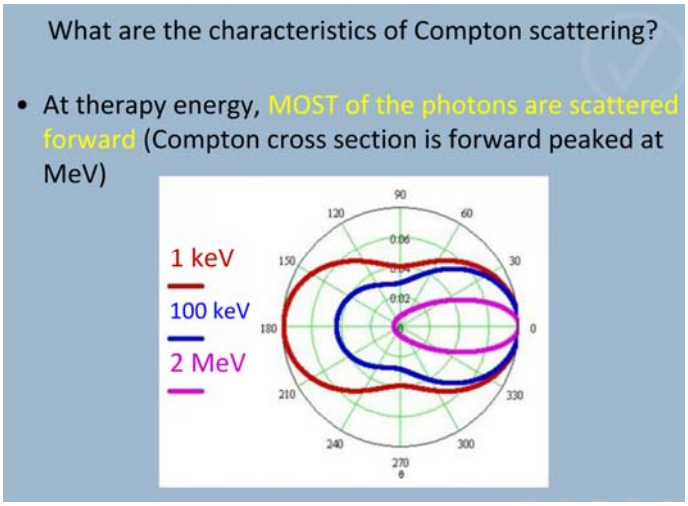
- Shown diagram of flouro beam incident on patient (fluoroscopy energy is about 80 kVp with 2 mA)
  - In which directions is scatter greatest, smallest?

For the fluoroscopy, the scatter is more forward and backward and less at the side compared to the MV.

  - How is this situation different interactions-wise from therapy beam scatter?

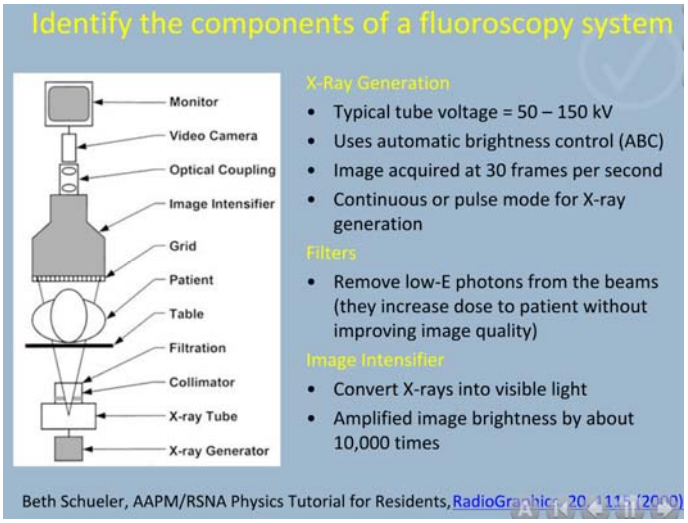
Both are Compton scattering, but scattered photon is most forward peaked for MV

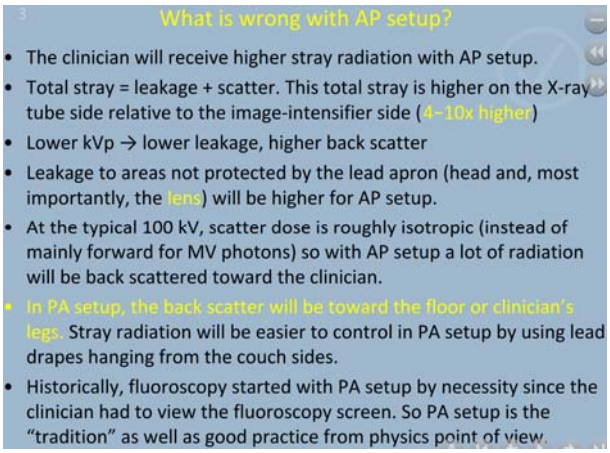
  - What are maximal side scatter and backscatter energies? 511keV, 255keV

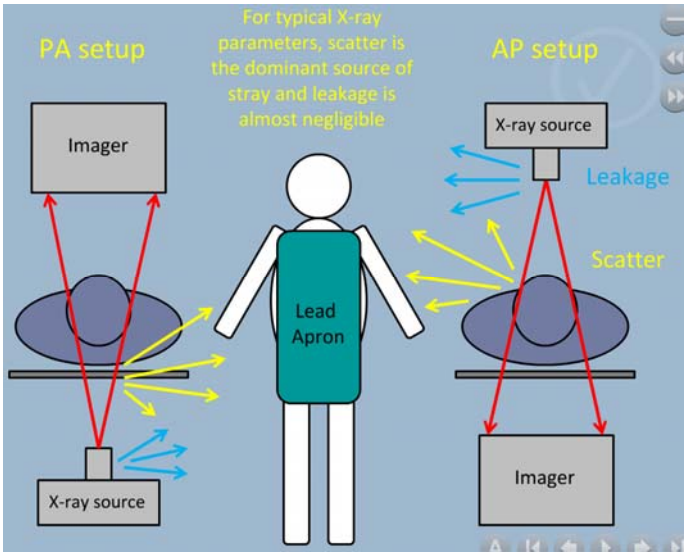


- Picture of fluoro-explain all components
- Explain how a fluoroscopy works

Fluoroscopy is the one kind of x-ray imaging which continuously shows x-ray image in the real-time manner.







Back scatter; dose to operator; image intensifier; MTF

- What is virtual fluoroscopy?

FluoroNav (Virtual fluoroscopy) works with pre-acquired fluoroscopic views. In other words, the surgeon takes pictures of the spine with the fluoroscope while the patient is in the operating room, but prior to navigating in the spine. These pictures are stored in the surgical computer. The computer then tracks a surgical instrument in the operating room using a special camera that can "see" the precise position of the instrument using harmless infrared light. The computer plots the location of the instrument on the spine pictures that it has "remembered." As the position of the instrument changes (when the surgeon inserts it into the spine, for example), the computer display shows this new position. All of this is done without any additional x-rays!

Q: if u have a c arm fluoroscopy, how will you arrange the c-arm so it can reduce dose to the staff (it's already in PA)?
A: put x-ray source close to the pt so it will need less field size and not much scatter coming out. (put lead shield on the bed side, wear lead apron are other way to protect staff)