Screen-Film Radiography – Chapter 6

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a copy of this lecture may be found at:
http://courses.washington.edu/radxphys/PhysicsCourse.html

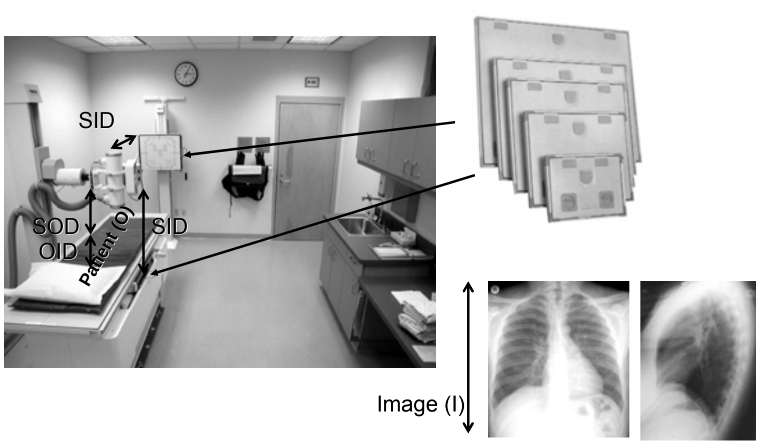
Objectives of Lecture

- Understand the principles of basic geometric principles and apply to projection imaging
- How screen-film detector systems work
- Define the characteristics of screens

One of Roentgen's earliest photographic plate from his experiments was a film of his wife, Bertha's hand with a ring, was produced on Friday, November 8, 1895.

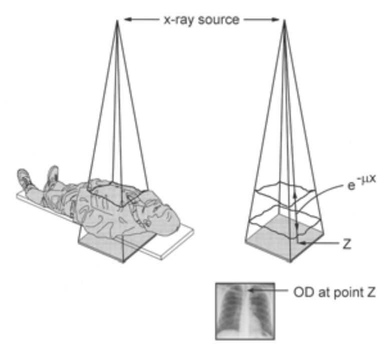
 http://www.resonancepub.com/images/XRAY_of_hand.gif

Projection Imaging



1. Projection Radiography

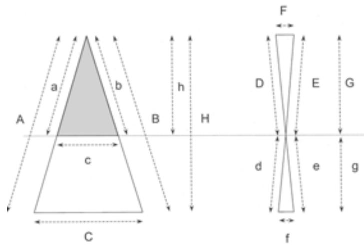
- Projection imaging
  - acquisition of a 2D image of patient's 3D anatomy
  - transmission imaging procedure
  - The optical density (measure of film darkening) at any location on the film corresponds to the attenuation characteristics of the patient at that location



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 146.

2. Basic Geometric Principles

- Similar triangles (geometry)
  - 3 angles of one = 3 angles of the other
  - a/A = b/B = c/C = h/H
  - d/D = e/E = f/F = g/G
- Similar triangles are encountered during image magnification and when evaluating image unsharpness caused by focal spot size and patient motion



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 147.

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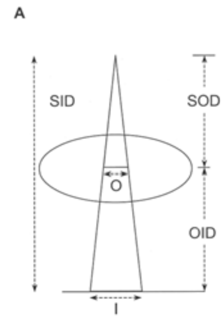
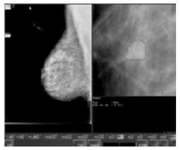
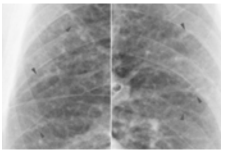
2. Basic Geometric Principles

- Magnification (M)
  - occurs because x-ray beam diverges from focal spot to image plane
  - for a point source,
    - M = I/O = SID/SOD
  - largest when SOD large (patient in front of receptor)



http://www.medgadget.com/archives/img/mammo1_sm.jpg





http://www.mevis.de/~hhj/Lunge/ima/inf_bot_chrbr2.JPG

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 147.

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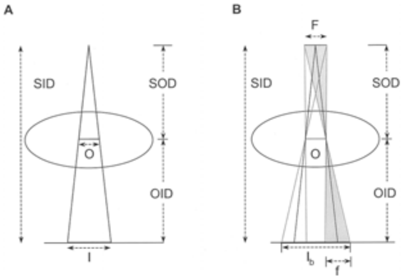
2. Basic Geometric Principles

- For a extended source (focal spot),
- Penumbra or blur (f)
  - edge gradient blurring due to finite size of focal spot (F)
  - f/F = OID/SOD
  - f/F = (SID-SOD)/SOD
  - f/F = (SID/SOD)-1
  - f = F(M-1)
  - f or blur increases with F and M



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 147.

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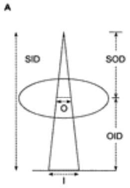
Review Question

- **D12.** L-4 is radiographed at a source-to-image distance (SID) of 100 cm, and an object-to-image distance (OID) of 20 cm. The width of L-4 measured on the radiograph is 35 mm. The true width is:

- A. 25 mm
- B. 28 mm
- C. 30 mm
- D. 35 mm
- E. 44 mm



- The magnification is M = I/O = SID/SOD = SID / (SID - OID), or 100 / (100 - 20) = 1.25. M = I/O so the true size is 35 / 1.25 = 28.

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Review Question

- **D15.** The penumbra associated with the image of the edge of an object placed 50 cm above the film plane, for an SID of 100 cm, and a focal spot size of 1.0 mm is ______ mm.

- A. 0.01
- B. 0.1
- C. 1.0
- D. 10

- f/F = OID/SOD
- f = F (OID/SOD) = 1 (50/50) = 1.0

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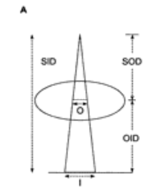
Review Question

- Object on fluoro table is 4 inches and projects as 7 inches on the image receptor which is 12 inches above the fluoro table. What is the distance from the x-ray tube (source) to the table?



- A) 8 in
- B)12 in
- C) 16 in
- D) 20 in

- using similar triangles, (SOD+12)/SOD = I/O, SOD= 16

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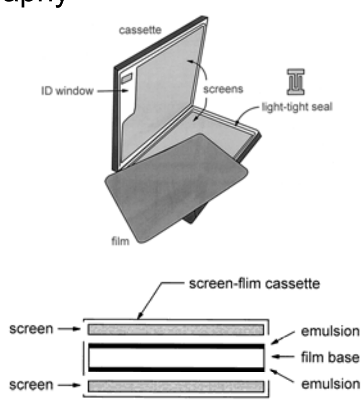
3. The Screen-Film Cassette for General Radiography

- Cassette
  - Light-tight and ensures screen contact with film
  - Front surface - carbon fiber
  - ID flash card area on back

- 1 or 2 Intensifying Screens
  - Convert x-rays to visible light
  - Mounted on layers of compressed foam (produces force)

- Sheet of film
  - Register the x-ray distribution
  - Chemically processed
  - Storage and display



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 148.

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4. Characteristics of Intensifying Screens

- Film relatively insensitive to x-rays, requires a lot of x-ray energy to produced a properly exposed x-ray film
- Patient receives a large dose

- To reduce dose and exposure times, screens are used
- Screens made of scintillating material: phosphor

- When x-rays interact with phosphor, visible or UV light is emitted
  - Light emitted darkens the film
- → Screen-film detectors are considered an *Indirect* detector

- Using film-screen versus film only reduces radiation dose to patient by a factor of 50!

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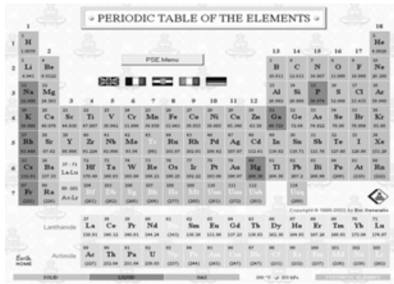
4. Screen Composition and Construction

- Early 20th century: calcium tungstate, $CaWO_4$
- Since early 70's: rare earth phosphor
- Lanthanide series: Z = 57 – 71
- Gd_2O_2S:Tb (gadolinium oxysulfide: terbium) - common
- LaOBr:Tm (lanthanum oxybromide: thulium)
- $YTaO_4$:Nb (yttrium tantalate: niobium)

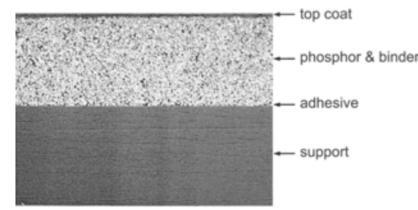


c.f. http://www.ktf-split.hr/periodni/en/

4. Screen Composition and Construction

- Top coat
- Phosphor and binder
- Adhesive
- Support

- General radiography: two screens used
- Mammography: single screen used



Cross-sectional image of an intensifying screen

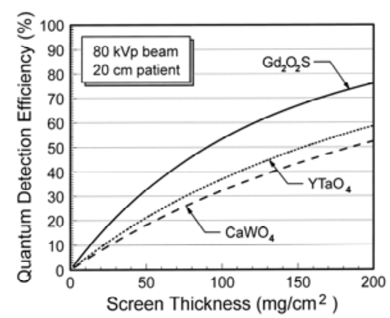
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 150.

4. Intensifying Screen Function and Geometry

- Function: absorb x-rays, convert to visible or UV light which exposes the film emulsion
- Conversion efficiency of a phosphor = fraction of absorbed energy emitted as UV or visible light
- $CaWO_4$ ≈ 5% intrinsic conversion efficiency
- Gd_2O_2S:Tb ≈ 15% intrinsic conversion efficiency
- 200-1000 photons reach film after diffusing through phosphor layer and being reflected at the interface layers

4. Intensifying Screen Function and Geometry

- Quantum Detective Efficiency (QDE) of a screen = fraction of incident x-rays photons that interact with it
- QDE increases with screen thickness

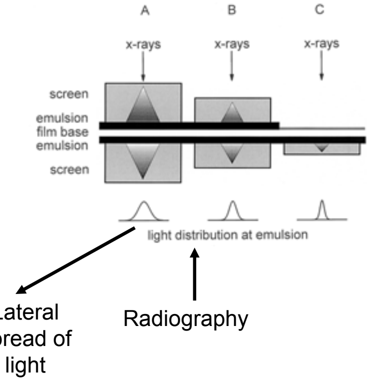


c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 151.

4. Intensifying Screen Function and Geometry

- Thicker screens
  - absorb more x-rays, but
  - have greater lateral spread of light
  - causes blurring and reduces spatial resolution
- A thin screen
  - results in less x-ray absorption but
  - has less lateral spread of light and
  - better spatial resolution

Cross-section of a screen-film cassette



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 152.

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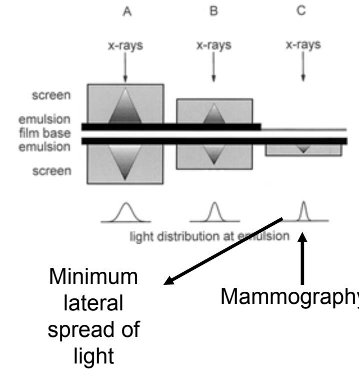
4. Intensifying Screen Function and Geometry

- For maximum resolution,
  - a single-screen cassette is used
  - X-rays first traverse the film and then strike screen
  - Less light spread and maximum spatial resolution
- Screen is a linear device at a given x-ray energy
  - If number of x-ray photons doubles, light intensity produced by screen also doubles

Cross-section of a screen-film cassette



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 152.

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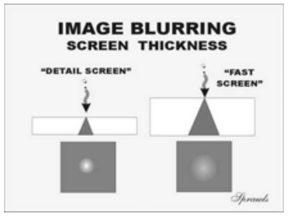
4. Intensifying Screen Function and Geometry

- As screen thickness ↑ QDE ↑ and screen sensitivity ↑, but light-diffusion increases
- Compromise between sensitivity and resolution depending on clinical application



c.f. http://www.sprawls.org/resources/RADDETAIL/classroom.htm

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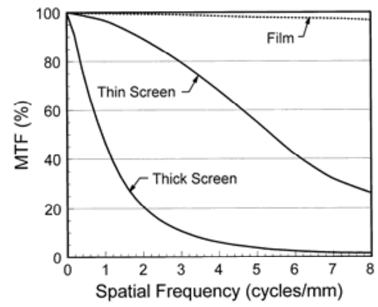
4. Intensifying Screen Function and Geometry

- Modulation Transfer Function (MTF) describes the resolution properties of an imaging system
- The MTF illustrates the fraction (or %) of an object's contrast that is recorded by the imaging system as a function of object size (spatial frequency)
- As screen thickness ↑ MTF ↓



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 152.

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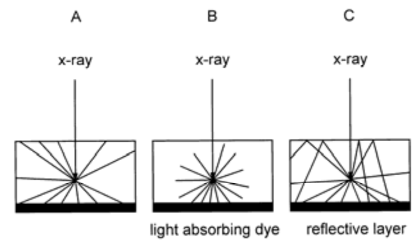
4. Conversion Efficiency (CE)

- Total conversion efficiency (CE) of a screen-film combination refers to the ability of the screen or screens to convert the energy deposited by the *absorbed* x-rays into film darkening or optical density
- CE depends on:
  - Intrinsic conversion efficiency of phosphor
  - Efficiency of light propagation through the screen to film emulsion layer
  - Efficiency of the film emulsion in absorbing the emitted light

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 153.

4. Conversion Efficiency (CE)

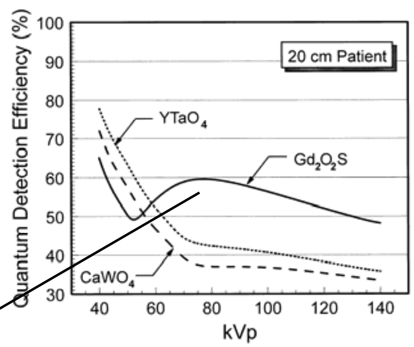


- Light propagation in screen affected by:
  - Distance from absorption to film
  - Light-absorbing dye reduces lateral distance: CE ↓ (slow), Spatial resolution or MTF ↑
  - Reflective layer redirect light photons: CE ↑ (fast), Spatial resolution or MTF ↓

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p 153.

4. Absorption Efficiency (AE)

- Screen-film systems are energy detectors
  - The number of light photons produced in the screen is determined by the total amount of x-ray energy absorbed by the screen, not by the number of x-ray photons

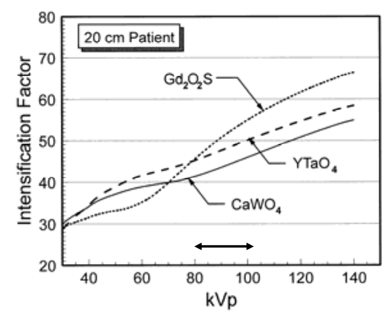


QDE great for rare earth phosphor

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 154-155.

4. Overall Efficiency of a Screen-Film System

- Total efficiency = AE · CE
- A SF system increases x-ray detection efficiency compared to film only (29.5% vs. 0.65% at 80 kVp)
- Using film-screen versus film only reduces radiation dose to patient by a factor of 50!
- Intensification factor (IF) = ratio of exposures, without and with intensifying screens, required to obtain a given film density



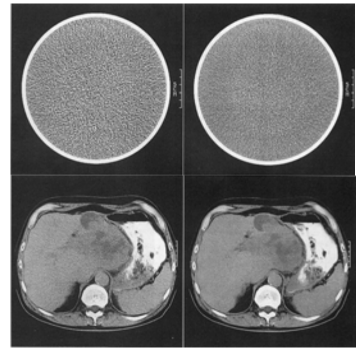
Diagnostic radiographic procedures

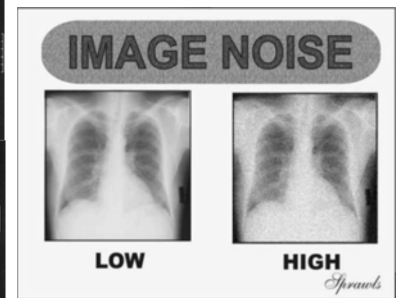
c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 156.

4. Noise Effects of Changing CE vs. AE

- Noise: local variations in film OD, not representing variations of attenuation in patient
- Includes random noise caused by factors such as
  - Statistical fluctuation in x-ray quantity interacting with screens
  - Statistical fluctuation in fraction of light emitted by the screen that is absorbed by the film emulsion
  - Statistical fluctuation in the distribution of silver halide grains in film emulsion
- The noise in the radiographic image is governed principally by the number of x-ray photons that are detected by the screen-film detector system

4. Noise Effects of Changing CE vs. AE





The visual perception of noise is reduced (better image quality) when the number of detected x-ray photons increases (more in Chapter 10)

 c.f. http://www.sprawls.org/resources/IMGCHAR/module/#20

4. Noise Effects of Changing CE vs. AE

- What happens to noise in image when the CE is increased (or fast film screen system) by adding reflective layer? (keep OD on film same before and after)
  - If "speed" of the SF system is increased by increasing the CE (so that each detected x-ray photon becomes more efficient at darkening the film):
  - few x-ray photons are required to achieve same film darkening (as before increasing CE), so noise increases

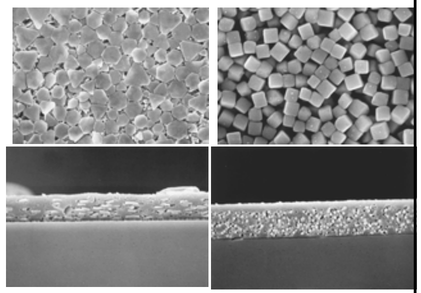
4. Noise Effects of Changing CE vs. AE

- What happens to noise in image when the AE is increased (thicker screen)? (keep OD same before and after)
  - If AE is increased, 10% more x-ray photons detected, then reduction of 10% in incident x-ray beam is required to deliver same amount of film darkening (as before increasing AE)
  - Since the fraction of increase in x-ray photon detection and reduction in incident x-ray intensity is same, the total number of detected x-ray photons is the same.
  - No change in noise
  - However, spatial resolution will get worse with thicker screens

5. Characteristics of Film

- 1 or 2 layers of film emulsion coated onto a flexible Mylar plastic sheet
- Emulsion: silver halide (AgBr and AgI) bound in a gelatin base
- Emulsion of an exposed sheet of film contains the latent image
- Latent image rendered visible through film processing by chemical reduction of silver halide into metallic silver grains

Tubular grains | Cubic grains



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 157.

Optical Density

- Film is negative recorder which means increased x-ray exposure → developed film becomes darker
- Degree of darkness of the film is quantified by the optical density (OD) which is measured with a *densitometer*
- Transmittance (T) is the fraction of incident light passing through the film
- $T = I/I_0$ where I – intensity measured at a particular location on film and I_0 – intensity of light measured with no film in densitometer

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 158.

Optical Density

- $OD = -\log_{10}(T) = \log_{10}(1/T) = \log_{10}(I_0/I)$, inverse relationship is $T = 10^{-OD}$
- As OD increases, transmittance decreases
- The OD of superimposed films is additive

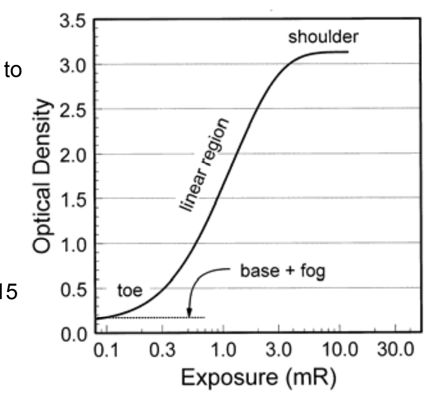
TABLE 6-1. RELATIONSHIP BETWEEN OPTICAL DENSITY (OD) AND TRANSMISSION (T) PERTINENT TO DIAGNOSTIC RADIOLOGY APPLICATIONS

T	T	OD	Comment
1.0000	10^{-0}	0	Perfectly clear film (does not exist)
0.7760	10^{-11}	0.11	Unexposed film (base + fog)
0.1000	$10^{-1.0}$	1	Medium gray
0.0100	$10^{-2.0}$	2	Dark
0.0010	$10^{-3.0}$	3	Very dark; requires hot lamp
0.00025	$10^{-3.6}$	3.6	Maximum OD used in medical radiography

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 158.

The Hurter and Driffield (H&D) Curve

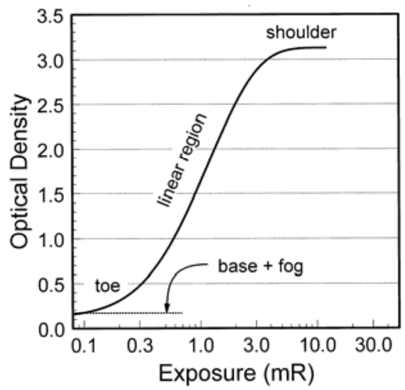
- H&D (characteristic) curve describes how film responds to x-ray exposure
- Non-linear, sigmoidal shape
- $\log_{10}$-$\log_{10}$ plot (OD vs. log relative exposure)
- Film base → OD = 0.11 – 0.15



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 159.

The Hurter and Driffield (H&D) Curve

- Fogging due to long storage, heat and low background exposure
- Base + Fog ≤ 0.20 OD
- Toe
- Linear region
- Shoulder



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 159.

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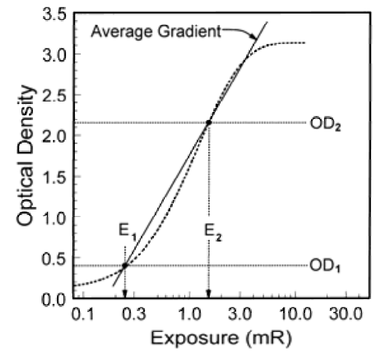
Contrast of Film (Average Gradient)

- Contrast of film is related to the slope of the H&D curve:
  - Higher slope have higher contrast
  - Reduced slope have lower contrast
- Overall contrast given by Average gradient =
- $[OD_2-OD_1]/[\log_{10}(E_2)-\log_{10}(E_1)]$
  - $OD_2 = 2.0 + B + F$
  - $OD_1 = 0.25 + B + F$
- Range from 2.5 – 3.5



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 160.

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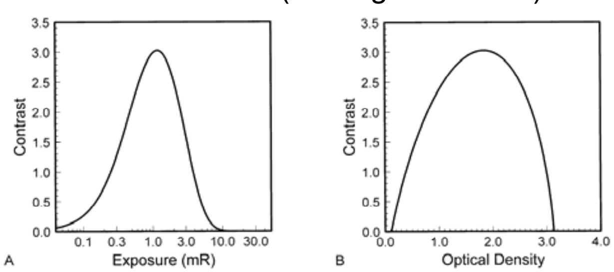
Contrast of Film (Average Gradient)



- Describes the contrast properties of the film-screen system
- Important to obtain well controlled exposure levels to ensure good contrast
- Film manufacturer physically controls contrast on film by varying the size distribution of the sliver grains

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 161.

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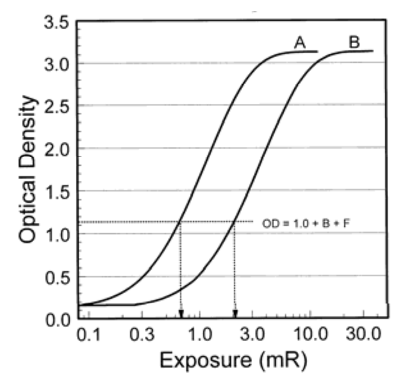
Sensitivity or Speed

- As the speed of SF system increases, the amount of x-ray exposure required to achieve same OD decreases
- Fast films requires less exposure to achieve a given OD; slow films require more exposure
- Faster (higher-speed) SF systems result in lower patient doses but in general exhibit more quantum mottle (noise) than slower systems



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 162.

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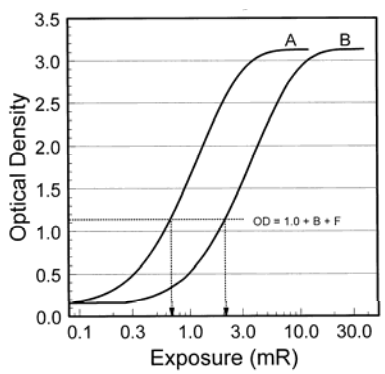
Sensitivity or Speed

- Absolute speed = 1 / Exposure (R) required to achieve OD = 1.0 + B + F
- Relative speed of a SF combination– relative to a common standard (100 speed), commercially used
- Most US institutions that use screen-film use 400 speed for general radiography



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 162.

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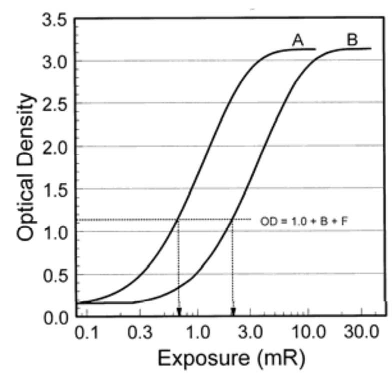
Sensitivity or Speed

- 100-speed – detail work bony radiographs of extremities, (thinner screens, slower, better spatial resolution)
- 600-speed – angiography (thicker screens, decreased spatial resolution)



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 162.

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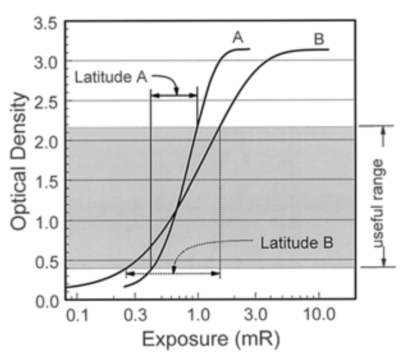
Latitude

- Horizontal shift between 2 H&D curves – systems differ in speed
- Systems with different contrast have H&D curves with different slopes
- Latitude is the range of x-ray exposures that deliver ODs in the usable range
- Latitude is also called dynamic range



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 162.

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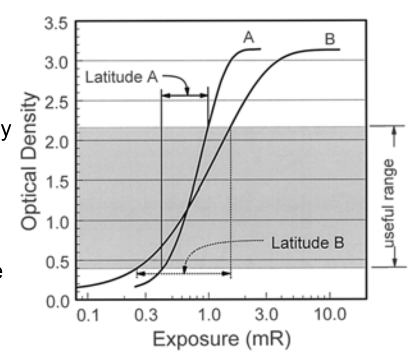
Latitude

- System A has higher contrast but reduced *latitude*
- It is more difficult to consistently achieve proper exposures with low-latitude SF systems.
- Chest radiography needs a high-latitude system to achieve adequate contrast in both the mediastinum and lung fields



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 162.

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6. The Screen-Film System

- Film emulsion should be sensitive to light emitted by screen
- $CaWO_4$ emits blue light to which film is sensitive
- Gd_2O_2S:Tb emits green light
- Wavelength sensitizers added to film
  - green: orthochromatic
  - red: panchromatic
- Screens and films usually purchased in combination since matching of spectral sensitivity very important

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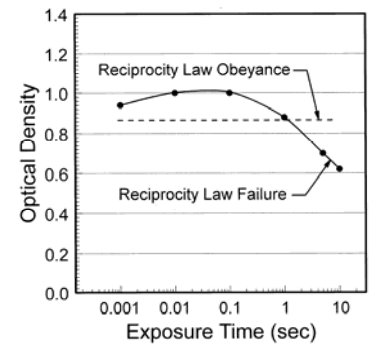
Reciprocity Law of Film

- Reciprocity law of film - the relationship between exposure and OD should remain constant regardless of the exposure rate
- Reciprocity law failure: at long and short exposure times, the film becomes less efficient at using the light incident on it and lower ODs result
- This is a factor in mammography when long exposure times are needed for large and dense breasts



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2st ed., p. 163.

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7. Contrast and Dose in Radiography

- The SF system governs the overall detector contrast
- The contrast of a specific radiographic study depends on the requirements of the study, total exposure time, radiation dose, size of patient and so on…
- The kVp (quality) and mAs (quantity) are adjusted by the technologist to adjust the subject contrast
- Technique still an art, but:
  - Technique chart
  - Phototimer (automatic technique)
  - Different body habitus

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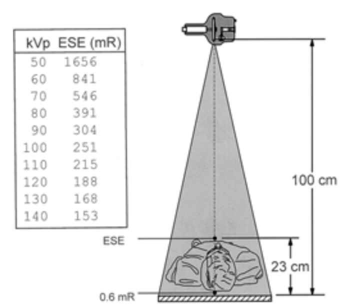
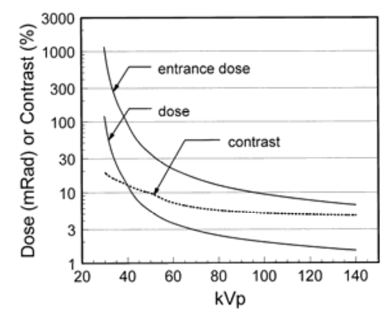
7. Contrast and Dose in Radiography (2)





- kVp ↑ → dose and contrast ↓
- Classic compromise between image contrast and patient dose

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 165-166.

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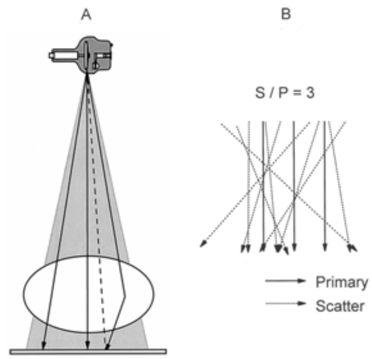
8. Scattered Radiation in Projection Radiography

- Scattered photons → violation of the basic principle of projection imaging: mis-information reducing contrast
- The scattered photon if detected by film causes film darkening but provides no useful information to the image
- Scatter-to-primary (S/P) ratio refers to how many scattered x-ray photons there are for every primary photon



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 167.

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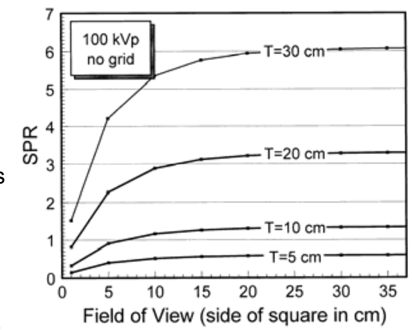
8. Scattered Radiation in Projection Radiography

- Scatter-to-Primary ratio (S/P)
  - Area of collimated x-ray field
  - Object thickness
  - Energy of x-ray beam
  - As FOV is reduced, scatter is reduced
  - Larger patients create more scatter
  - Scatter seen in all modalities (Compton scatter)



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 167.

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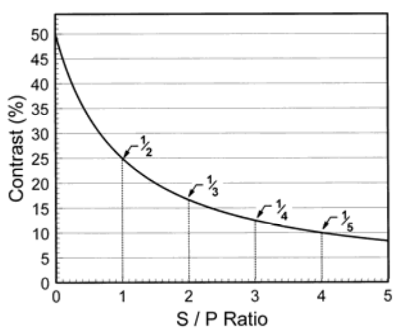
8. Scattered Radiation in Projection Radiography

- Scatter radiation causes loss of contrast
- In the absence of scatter, for two adjacent areas transmitting photon fluences of A and B, the contrast is:
  - $C_0 = [A-B]/A$
- In the presence of scatter:
  - $C = C_0 \times [1 / (1 + S/P)]$
- S/P ↑ → contrast ↓
- 1/(1+S/P): contrast reduction factor



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p. 168.

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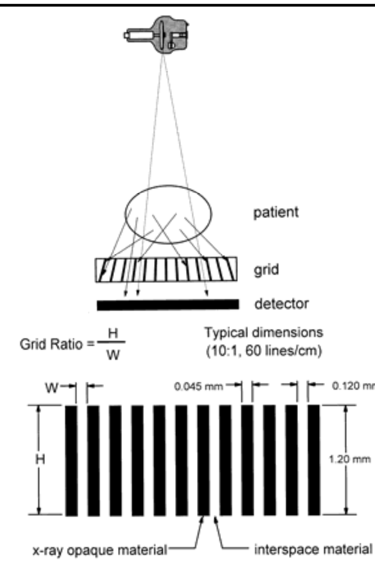
8. The Antiscatter Grid

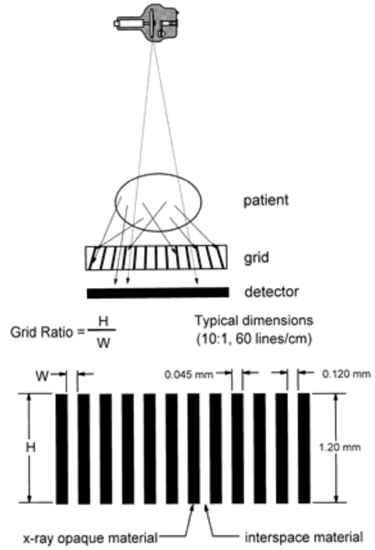
- The antiscatter grid is used to clean up scatter
- Between object and detector
- Uses geometry to ↓ scatter
- Thin lead septa separated by aluminum or carbon fiber, aligned with focal spot



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 168-169. 48

8. The Antiscatter Grid

- Grid ratio (GR) = H/W = septa height/interspace width
- 8:1, 10:1 and 12:1 common, 5:1 for mammography
- ↑ GR → ↓ S/P
- ↑ GR → ↑ dose



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c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 168-169.

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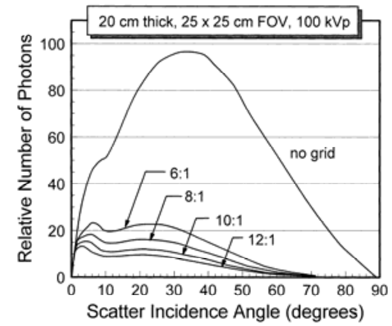
8. The Antiscatter Grid

- ↑ GR → ↑ clean-up of scatter striking the grid at large angles, less effective for smaller angles
- Grid frequency: lines/cm
  - grid freq. doesn't alter S/P
  - 60 lines/cm



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 170.

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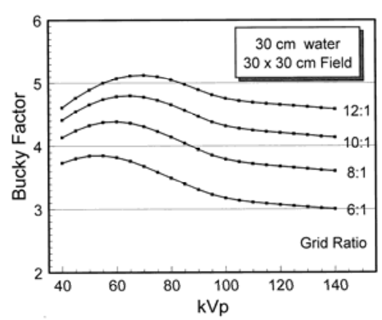
8. The Antiscatter Grid

- Stationary grids: lines appear on image
- Bucky: device that moves grid
- Grid lines could cause aliasing when digitizing film
- Bucky factor =
  - $dose_{w\ grid}/dose_{w/o\ grid}$
  - Range from 3 to 5



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 171.

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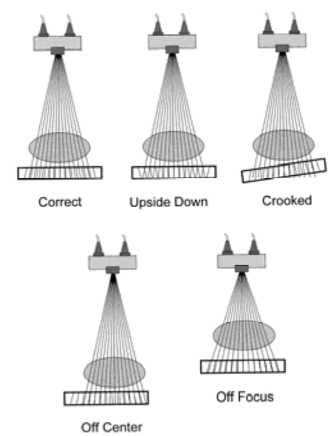
8. Grid Artifacts

- Most grid artifacts due to mispositioning
- Upside down: severe loss of OD at margins
- Crooked & off-center: general decrease of OD across entire image
- Off-focus: loss at lateral edges



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 172.

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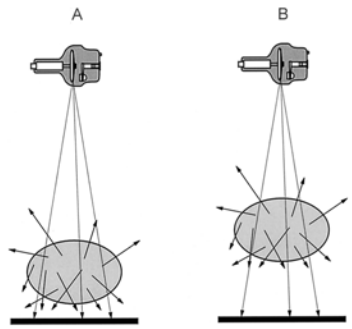
8. Air Gaps

- Air gap: ↓ S/P, but ↑ M, ↓ FOV and ↓ MTF (unless very small focal spot used)
- Not used all that often in radiography except chest radiography, used in mammography



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., pp. 173.

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Review Question

- **D15**. If the absorption efficiency of each intensifying screen in a dual screen system is 30%, what percentage of x-rays is stopped by the screens together?
- A. 9%
- B. 30%
- C. 51%
- D. 60%
- E. 70%

- 30% is absorbed in the first screen, 70% passes through. The second screen absorbs 30% of that 70% (or 21%). Total stopped is 30% + 21%.

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Review Question

- **D14**. Which system has the highest noise and the highest resolution?
-
- A. Thin Gd_2O_2S:Tb screen with slow film.
- B. Thin Gd_2O_2S:Tb screen with fast film.
- C. Medium Gd_2O_2S:Tb screen with medium speed film.
- D. Thick Gd_2O_2S:Tb screen with slow film.
- E. Thick Gd_2O_2S:Tb screen with fast film.

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Review Question

- **D19**. Changing to a higher speed film will:
-
- A. Decrease patient exposure and increase noise.
- B. Decrease patient exposure and decrease noise.
- C. Not change exposure or noise, but decrease contrast.
- D. Increase patient exposure and increase noise.
- E. Increase patient exposure and decrease noise.

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Review Question

- **G70**. A radiograph has little contrast in density from one region to the next. Which of the following would improve contrast in a "retake" film?
  - 1. Change to higher ratio grid.
  - 2. Move the film closer to the patient.
  - 3. Collimate the beam to as small a field as possible.
  - 4. Raise the kVp to lower the exposure time.
- A. 1, 3
- B. 1, 4
- C. 2, 3
- D. 1, 2 and 4
- E. 1, 2, 3, and 4

Review Question

- **G77**. The purpose of a screen is to:
- 1. Convert x-rays to light photons.
- 2. Reduce scatter reaching the film.
- 3. Reduce patient's exposure.
- 4. Increase radiographic resolution.
- A. 1, 2, 3 and 4
- B. 2 only
- C. 2, 4
- D. 1, 3
- E. 4 only

Review Question

- **G72.** Which of the following does *not* reduce patient dose (for the same optical density on the film)?
- A. Use of screens
- B. Using a high kVp
- C. Using a high ratio grid
- D. Collimation

Review Question

- **G72**. A radiograph transmits 10% of the light from a viewbox with an illumination level of 400 lux. The optical density of the radiograph is:
  - A. 10
  - B. 2
  - C. 1
  - D. 0.1
  - E. 11400
  - $OD = -\log_{10}(T) = \log_{10}(1/T) = \log_{10}(1/0.1) = \log_{10}(10) = 1$

Review Question

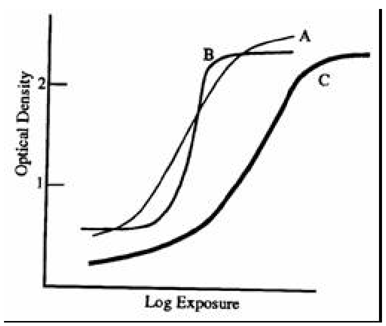
- **G78**. A film of optical density (OD) 0.75 is placed over another identical film. The OD of the pair is:
-
- A. 0.75
- B. 1.0
- C. 1.5
- D. 1.75
- E. 2.25

Review Question

- **D20**. Optical density (OD) regions on film of 1.0, 1.3, and 2.0 will transmit _______________of the light from a viewbox:
- A. 10%, 5%, 1%
- B. 10%, 13%, 20%
- C. 1%, 5%, 10%
- D. 90%, 87%, 20%
- E. 50%, 33%, 25%
- $T = 10^{-OD}$

Review Question

- **D23.** Consider the three characteristic curves in the diagram. Which statement is *false*?
- A. System B has the highest contrast.
- B. System C has the widest latitude.
- C. System A has the highest maximum density.
- D. System B has the highest base-fog density.
- E. System C is the fastest.



Review Question

- **D24.** In some situations, e.g., a chest exam, it is important to see radiographic anatomy in both high- and low-density regions. To aid in this, one could choose a film with a __________.
- A. High gradient
- B. High gamma
- C. Slow speed
- D. Long latitude
- E. Low fog

Review Question

- **D19**. In order to decrease the optical density of an over-exposed radiograph from 2.0 to 1.2, the mAs should be reduced by approximately ______ %. (Assume a slope of the characteristic curve of 3.0):
- A. 5-10
- B. 10-20
- C. 20-40
- D. 40-60
- E. Greater than 95

- $OD_2 - OD_1$ = Average Gradient x $\log_{10} (E_2/E_1)$ where E is exposure, proportional to mAs.
- $-0.8 = 3.0 \log_{10} (E_2/E_1)$
- $E_2/E_1 = 0.54$ or 46% reduction.

Review Question

- What advantage does a high kVp on an upright chest film provide over low kVp?

- A) decrease quantum mottle
- B) decrease scatter radiation
- C) decrease the amount of scatter radiation that penetrates the grid
- D) improve contrast

