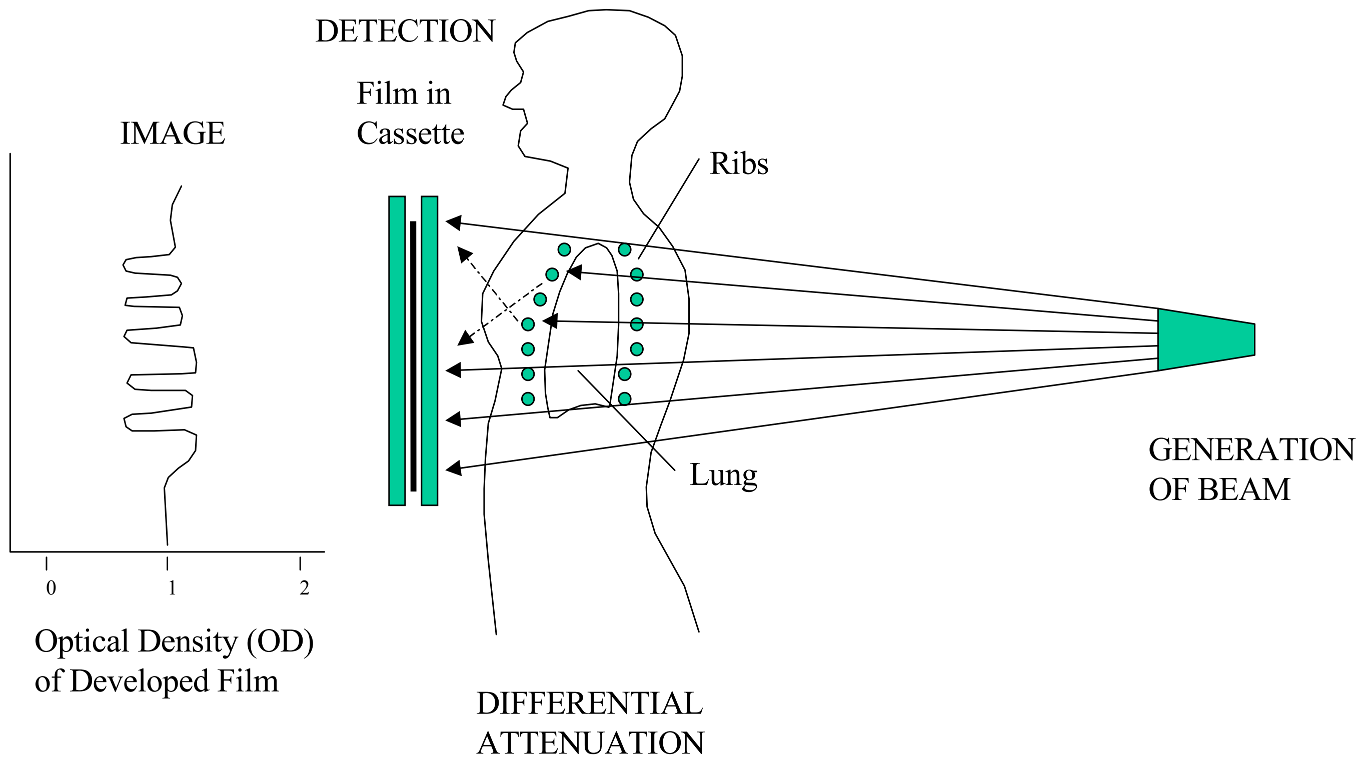
Handout #3
Projection Radiography

3.1 Screen-film System

❖ Schematic of projection radiography



❖ In this system, film is used to record images.

The x-ray film has several major functions:

(a) Detector
(b) Display device
(c) Archival medium

More exposure, the darker the film

The film itself is very **inefficient** under direct x-ray exposure, only about 5% of x-ray photons can be absorbed by the film and react with the emulsion. Therefore, **scintillating screens** (phosphor) are used.

❖ **Screen-film combination**

- Scintillating screen: convert high energy x-ray photons to a large number of light photons
- Film: record an image

The fraction of X-rays absorbed by a calcium tungstate screen is about 20-40% depending on the speed (determined mainly by screen thickness), while rare earth screens absorb about 60%.

❖ The x-ray quantum efficiency (absorption efficiency) of the scintillating screen is much higher than the film.

Example 1:

Assume: a 50KeV x-ray photon is absorbed in a calcium tungstate screen that emits most of its light at a wavelength of 430 nm. The energy of the light photon is:

$$\lambda \text{ (nm)} = 1.24 / E \text{ (KeV)}$$

$$E \text{ (KeV)} = 1.24 / 430 = 0.00288 \text{ KeV} = 3 \text{ eV}$$

The energy of the light photon at a wavelength of 430 nm is about 3 eV.

Therefore the number of light photons produced is:

$$(50{,}000 \text{ eV} / 3 \text{ eV}) \times 0.05 = 17{,}000 \times 0.05 = 850$$

The 5% efficiency in the above calculation is termed the **Intrinsic conversion efficiency** of the phosphor, (the ratio of the light energy liberated by the crystal to the x-ray energy absorbed).

The Intrinsic conversion efficiency of rare earth screens is about 12-18%

Among all of these 850 photons, about half of them (?), say 425, will reach the film.

Example 2:

Assume 1000 x-ray photons irradiate both screen-film and film alone:

	Screen-film	**Film alone**
X-ray photons absorbed by	400	50
Light photons produced	$400 \times 850 = 340{,}000$	
Light photons reaching film	170,000	
Latent image centers formed	1700	50

The intensification factor = 1700 / 50 = 34

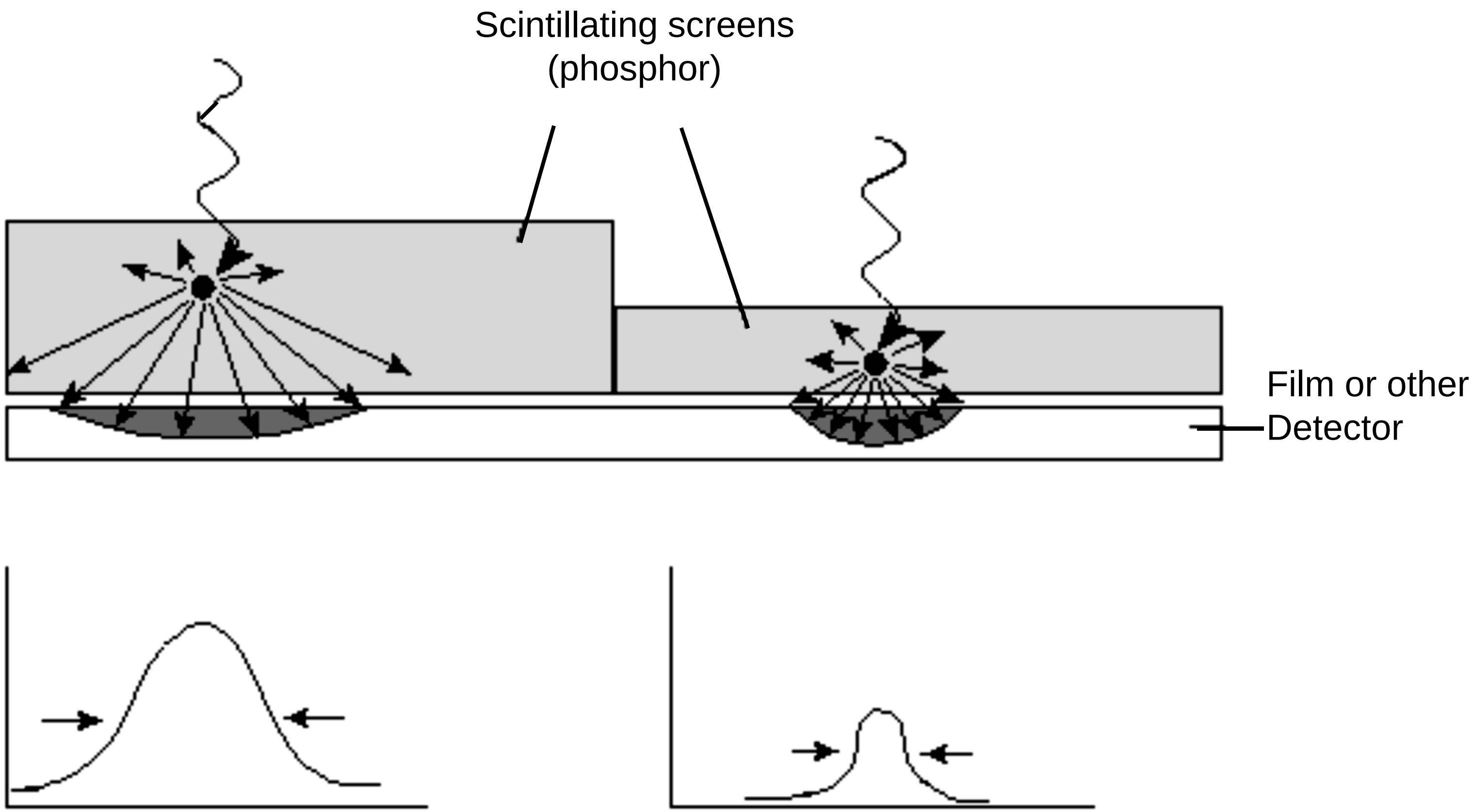
The intensification factor = (X-ray exposure required without screen) / (x-ray exposure required with screen)

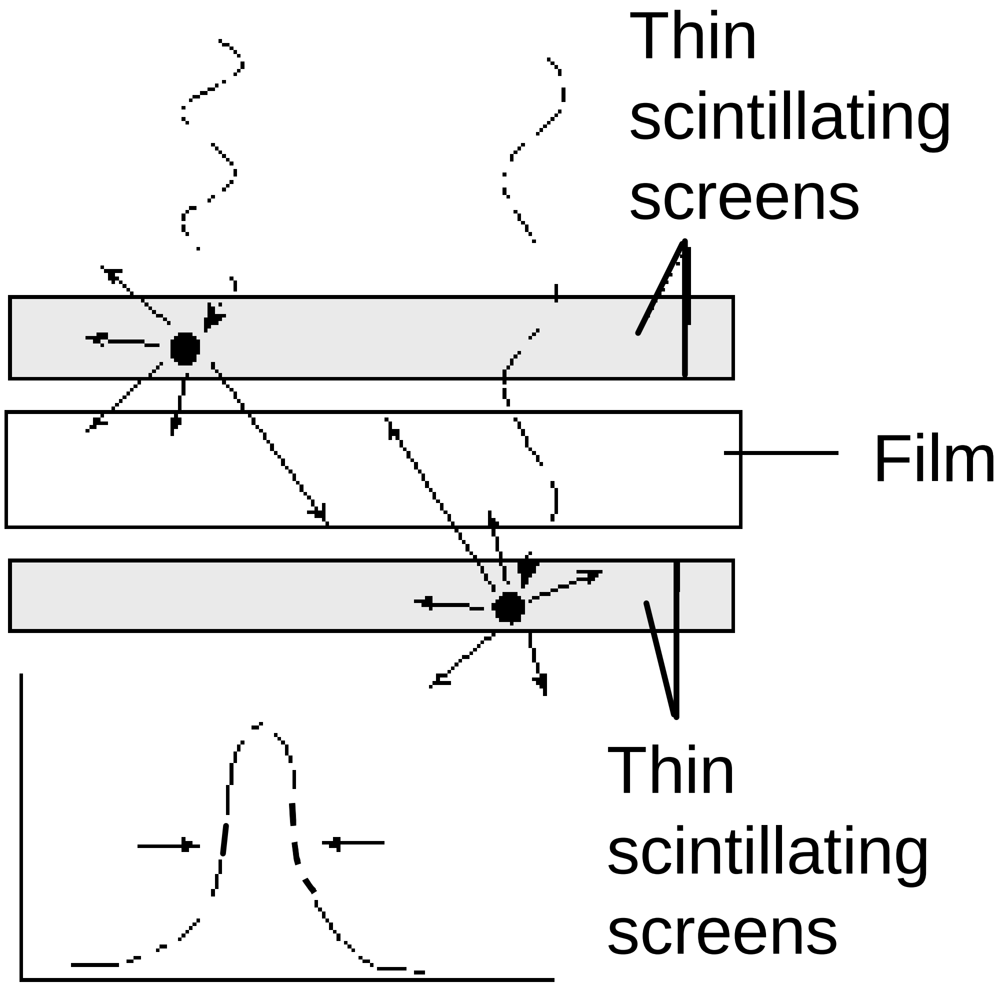
Note: At this point, let us simply define the latent image center as the end product of the photographic effect of light or x-rays on the film emulsion.

❖ The screen amplifies the photographic effect of x-rays

❖ **Screen thickness considerations**:

In order to absorb more x-ray photons: Thicker screen
In order to have higher resolving power: Thinner screen

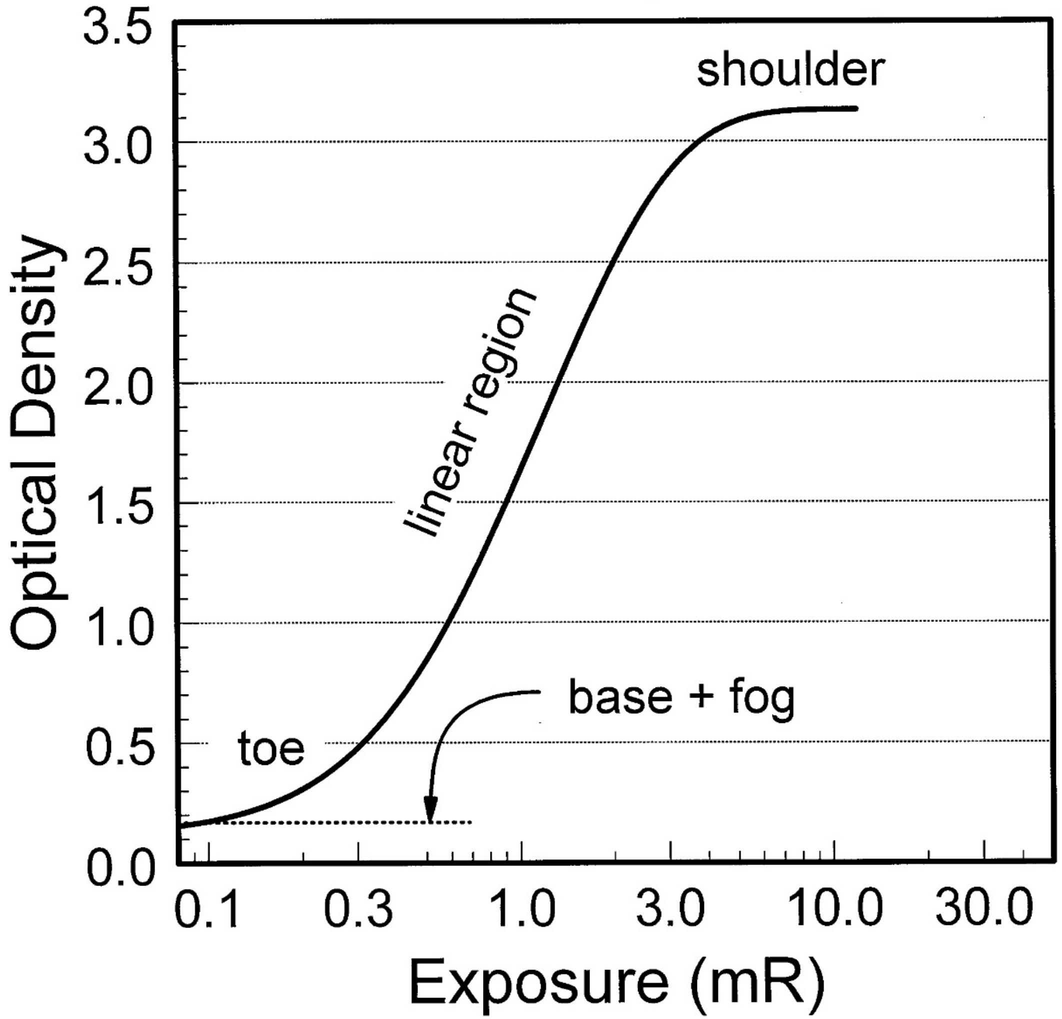




Thin
scintillating
screens
Film
Thin
scintillating
screens

❖ **The characteristics curve of the film** [Hurter and Driffield (H & D) curve]

The film has a non-linear response to exposure

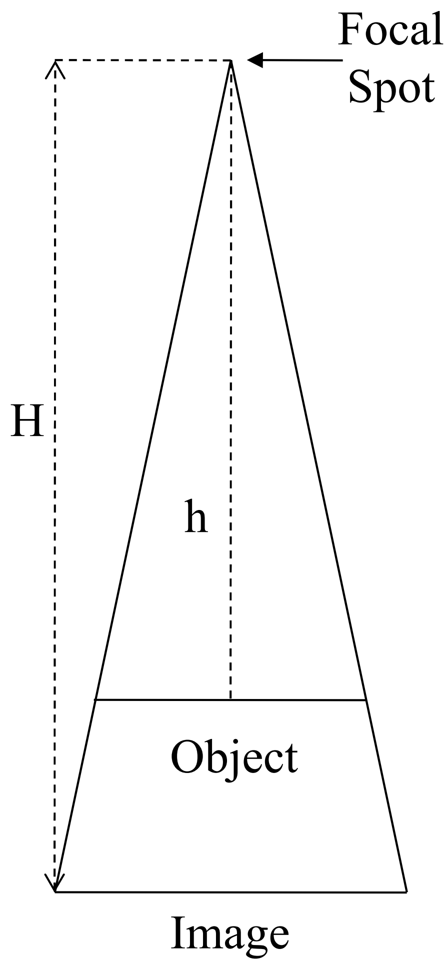


3.2 Geometry of Projection Radiography

- ❖ We must briefly consider some geometric factors that influence the quality of the x-ray image

(1) Magnification

M = (size of the image) / (size of the object)
= (source-to-image detector distance) /(source-to-object distance)
= H / h



Under usual radiographic situations, magnification should be kept to a minimum.

Two rules apply:

(a) Keep the object as close to the film as possible,

(b) Keep the source-to-image detector distance as large as possible.

Example:

A patient is placed so that a vertebral body and the sternum are 5cm and 25 cm from the cassette, respectively. The cassette is 100cm from the focal spot of the X-ray tube. By how much are the images of the vertebral body and the sternum magnified?

Solution:

For vertebral body: $H = 100\text{cm}$, $h = 100 - 5 = 95$ cm

$$M = 100 / 95 = 1.05$$

For sternum: $H = 100\text{cm}$, $h = 10 - 25 = 75$ cm

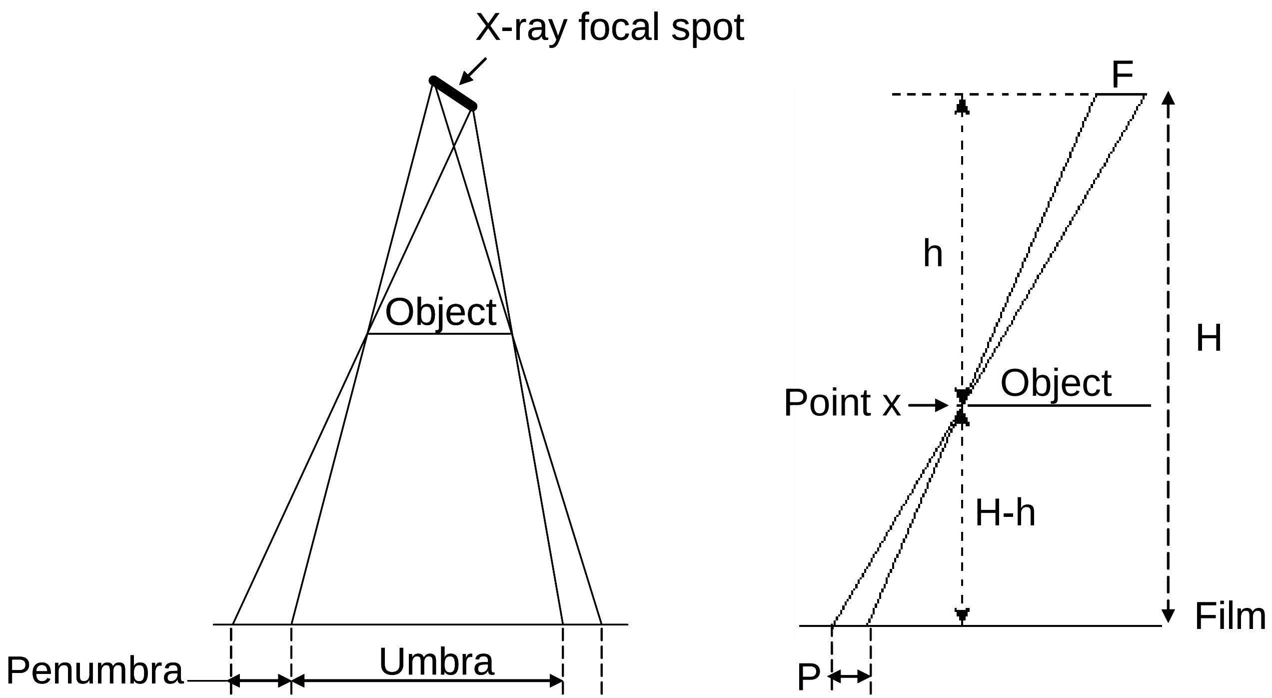
$$M = 100 / 75 = 1.33$$

Note: In clinical projection radiography, M is always larger than 1.

(2) Penumbra (from the latin *pene*, meaning almost and umbra, meaning shadow), also called geometric unsharpness, penumbra, or edge gradient, which is due to the fact that the x-ray source is not a perfect point source.

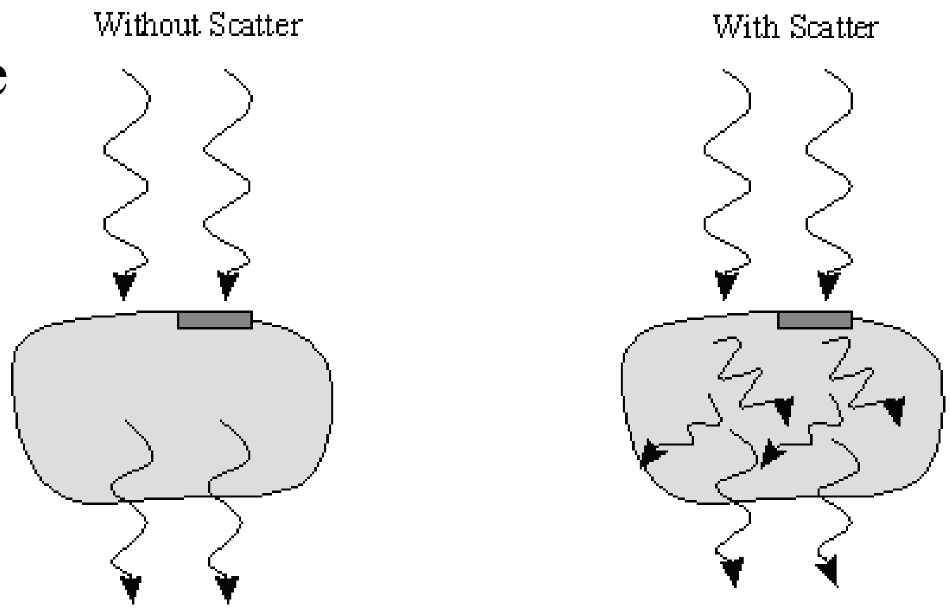
The width of penumbra $$P = F\,\frac{H-h}{h}$$

(a) Keep the object as close to the film as possible,
(b) keep the source-to-image detector distance as large as possible.
(c) Use as small as a focal spot as possible



3.3 Scatter Control

- X-ray scatter decrease the contrast
- X-ray scatter increase the noise



$$C = \frac{N_b - N_l}{N_b}$$

$$C' = \frac{N_b - N_l}{N_b + S}$$

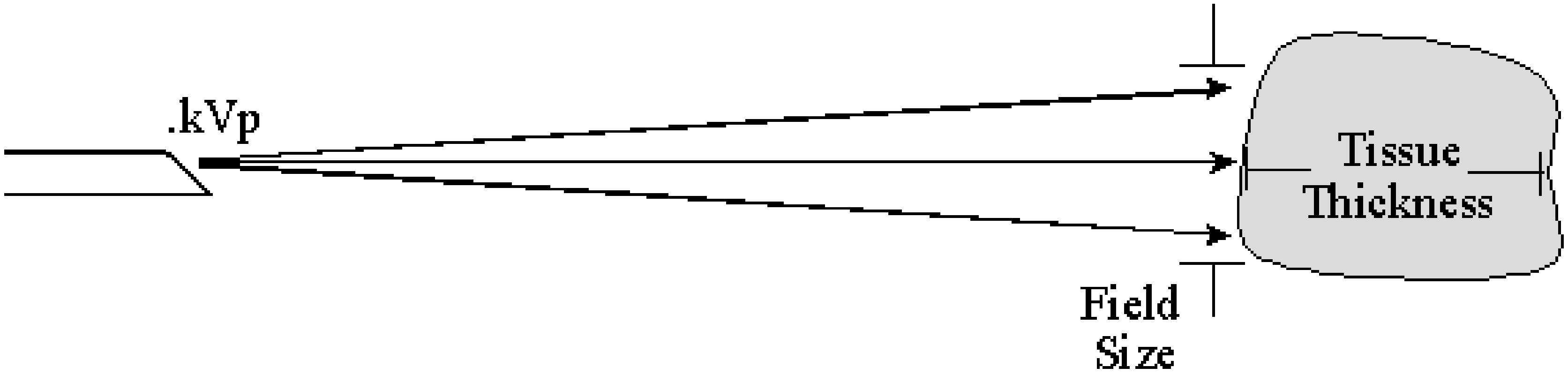
$$= \frac{\frac{N_b - N_l}{N_b}}{1 + \frac{S}{N_b}} = \frac{1}{1 + \frac{S}{N_b}} C$$

$$= \frac{1}{1 + \frac{S}{P}} C$$

In the above equation, S/P is called **Scatter to Primary Ratio**

❖ The following factors may affect the amount of scatter:

- Radiation field size (smaller field size, less scatter);
- Patient thickness (less thickness, less scatter);



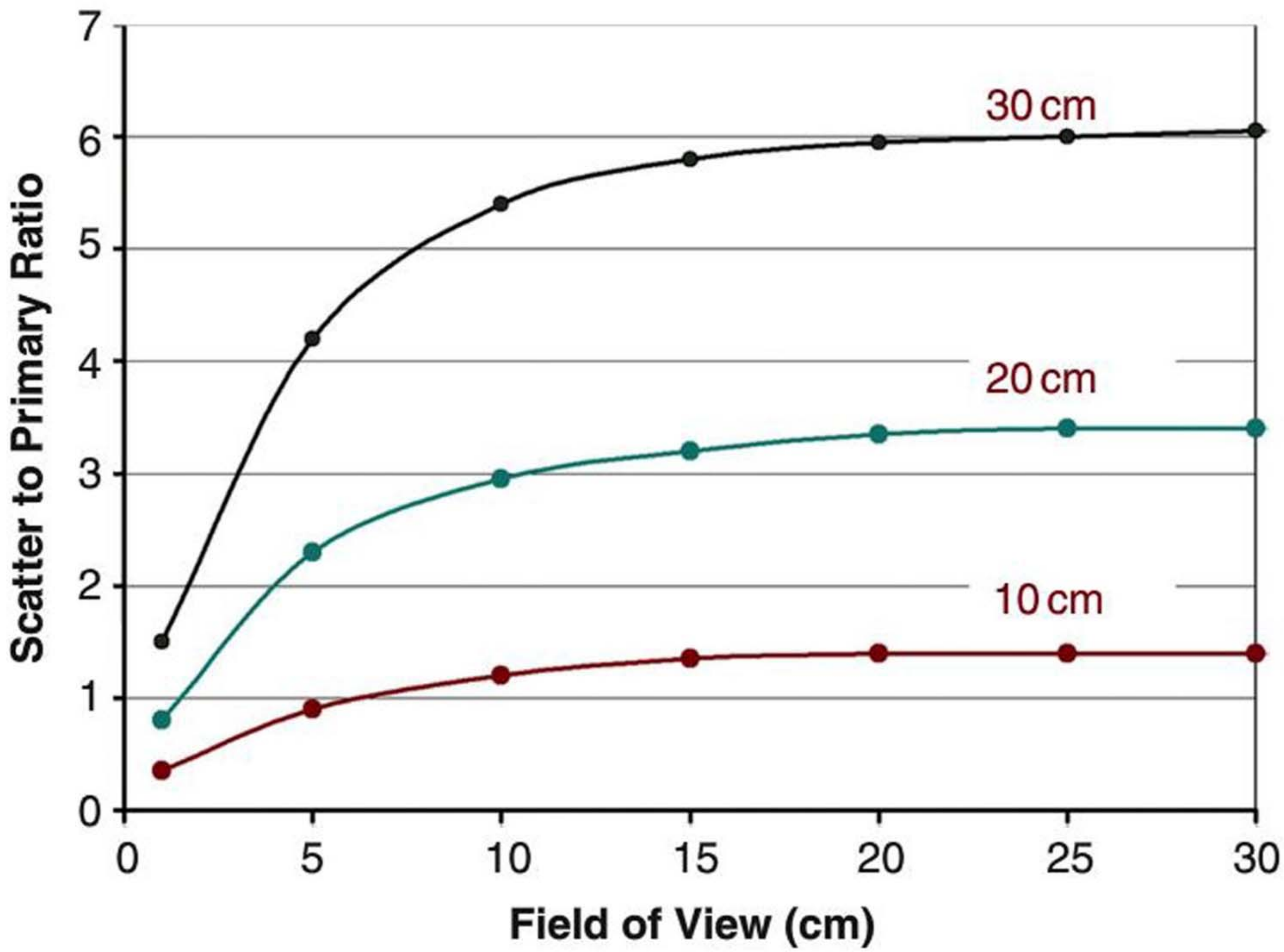
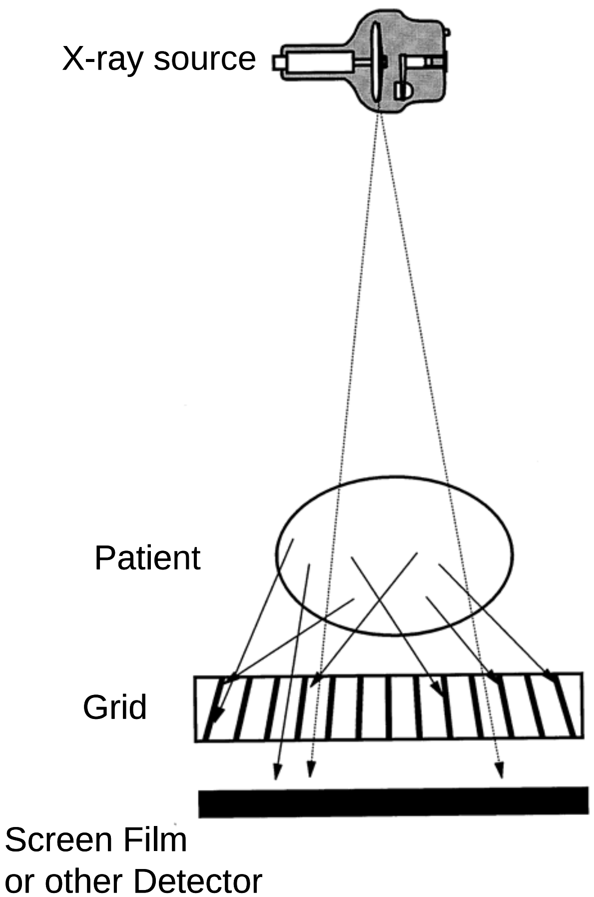
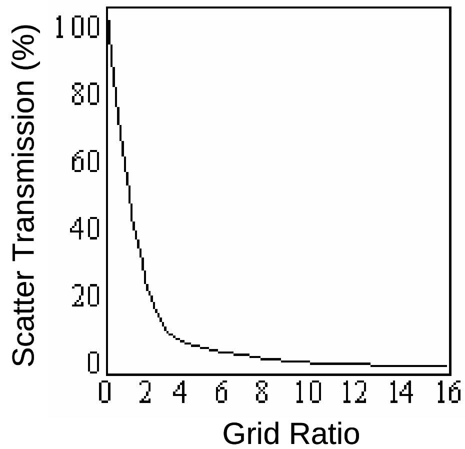


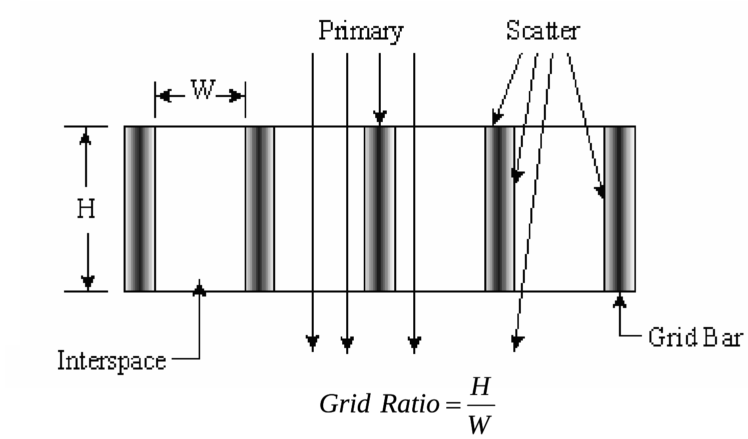
Figure The S/P is shown as a function of the side dimension of a square field of view, for three different patient thicknesses. The S/P increases with increasing field size and with increasing patient thickness. Thus, scatter is much more of a problem in the abdomen as compared to extremity radiography. Scatter can be reduced by aggressive use of collimation, which reduces the field of view of the x-ray beam. (Page231, The Essential Physics of Medical Imaging, Third Edition)

Methods to reduce scattered radiation

(a) Grid







Grid Ratio: The **Grid Ratio** is determined by the **height** of the grid bars divided by the **width** of the **interspace** material

$$Grid\ Ratio = \frac{H}{W}$$

❖ When Grid is used, the contrast is improved, the following table is an example*

Grid Ratio	No Grid	2:1	4:1	8:1	12:1	16:1
Relative Contrast* (70KVp)	1	2	3	4.8	5.3	5.8
Relative Contrast* (95KVp)	1	1.5	2.0	3.3	3.8	4.0
Relative Contrast* (120KVp)	1	1.3	1.5	2.5	3.0	3.3

*Contrast relative to that with no Grid, using a 20cm thick water phantom and a test pattern.

- National Council on Radiation Protection and Measurements (NCRP): Medical X-ray, Electron Beam and Gamma-Ray Protection for energies up to 50MeV (equipment Design), Performance, and Use (Report No 102). Bethesda, MD NCRP, 1989 (Table B.4)

- When a grid is used, the x-ray exposure to the patient has to be increased (so the exposure to the detector remains the same with and without grid).
- The **Bucky factor** is a measure of the ratio in incident exposure to the patient, with and without the grid.

Another way to describe the Bucky factor:

Bucky factor = (the total exposure incident to the grid) / (the total exposure transmitted through the grid)

The following table is an example of **Bucky** factors under certain conditions

Grid Ratio	No Grid	2:1	4:1	8:1	12:1	16:1
Bucky factor (70KVp)	1	1.1	2.7	3.5	4.0	4.5
Bucky factor (95KVp)	1	1.1	2.7	3.8	4.3	5.0
Bucky factor (120KVp)	1	1.1	2.7	4.0	5.0	6.0

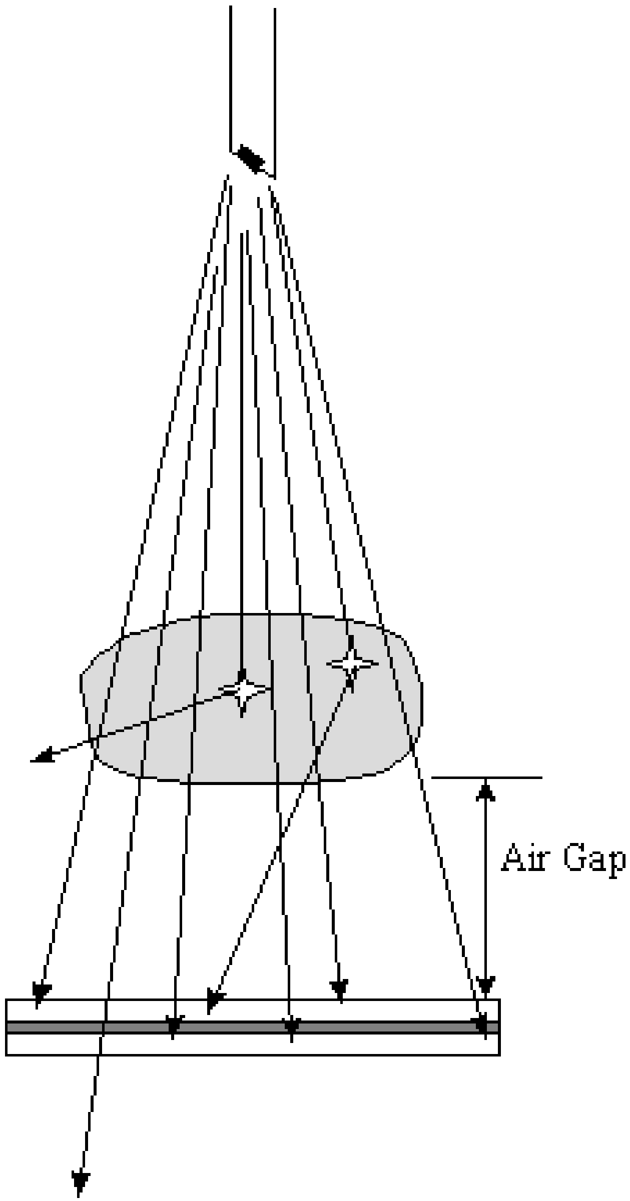
- National Council on Radiation Protection and Measurements (NCRP): Medical X-ray, Electron Beam and Gamma-Ray Protection for energies up to 50MeV (equipment Design), Performance, and Use (Report No 102). Bethesda, MD NCRP, 1989 (Table B.4)

Discussions:

- ❖ Why one has to increase the x-ray exposure to the patient when a grid is used ?

- ❖ The grid has to be moved back and forth during the x-ray exposure, why?

(b) Air gap



SUMMARY

- The **intensification factor** = (X-ray exposure required without screen) / (x-ray exposure required with screen)
- The film has a **nonlinear** response to exposure
- **Penumbra:**
  (i) Keep the object as close to the film as possible,
  (ii) keep the source-to-image detector distance as large as possible.
  (iii) Use as small as a focal spot as possible
- **Scatter to primary ratio : (S/P)**

  (i) Radiation field size (smaller field size, less scatter);

  (ii) Patient thickness (less thickness, less scatter);
- **Grid**

  Grid ratio: the **height** of the grid bars divided by the width of the **interspace** material
- **Bucky factor**: a measure of the ratio in incident exposure to the patient, **with** and **without** the grid.
- **Air gap**: larger the air gap, less the scatter

Homework # 3

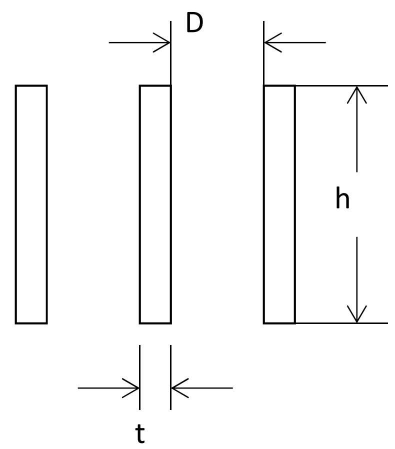
1. What is a radiographic penumbra? (Draw a simple picture to illustrate), and what causes it ?

2. What is the "intensification factor" of a screen?

3. Assume that 1000 x-ray photons, each with an energy of 100 keV, are incident on a intensifying screen with an absorption efficiency (quantum efficiency) of 50% and an intrinsic efficiency of 20%.
   (a) How many x-rays photons will contribute to the image?
   (b) Assuming the average energy of a blue light photon is 3eV, how many blue light photons will be produced for each x-ray photon absorbed?

4. If a screen is made thicker, what happens to the spatial resolution?

5. A linear scatter grid has dimensions shown here, where D is 0.1mm and h is 0.2mm. What is the grid ratio?



6. If the grid ratio is doubled, does the number of scattered x-rays contributing to the image increase or decrease?___________.