X-ray Emission

(Chapter-5)

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X-ray Emission

X-rays emitted through a window in the glass or metal enclosure of the x-ray tube in the form of a spectrum of energies. The x-ray beam is characterized by quantity (the number of x-rays in the beam) and quality (the penetrability of the beam). This chapter discusses the numerous factors that affect x-ray beam quantity and quality

X-RAY QUANTITY

X-ray Intensity: The intensity of the x-ray beam of an x-ray imaging system is measured in milligray in air (mGya) [formerly milliroentgen (mR)] and is called the x-ray quantity. Another term, radiation exposure, is often used instead of x-ray intensity or x-ray quantity. All have the same meaning, and all are measured in mGya (mR).

X-ray quantity is the number of x-rays in the useful beam.

Table-1

Factors That Affect X-ray Quantity and Image Receptor Exposure

The Effect of Increasing	X-ray Quantity Is	Image Receptor Exposure Is
mAs	Increased proportionately	Increased
kVp	Increased by $\left(\frac{kVp_2}{kVp_1}\right)^2$	Increased by $\left(\frac{kVp_2}{kVp_1}\right)^5$
Distance	Reduced by $\left(\frac{d_1}{d_2}\right)^2$	Reduced by $\left(\frac{d_1}{d_2}\right)^2$
Filtration	Reduced	Reduced

kVp, kilovolt peak; mAs, milliampere seconds.

the number of electrons striking the tube target is doubled, and therefore the number of x-rays emitted is doubled.

X-Ray Quantity and mAs:

$$\frac{I_1}{I_2} = \frac{mAs_1}{mAs_2}$$

X-ray quantity is proportional to mAs.

where I_1 and I_2 are the x-ray intensities at mAs_1 and mAs_2, respectively.

Q1. A lateral chest technique calls for 110 kVp, 10 mAs, which results in an x-ray intensity of 320 µGya (32 mR) at the position of the patient. If the mAs is increased to 20 mAs, what will the x-ray intensity be?

Answer:

$$\frac{x}{320\ \mu Gy_a} = \frac{20\ mAs}{10\ mAs}$$

$$x = \frac{(320\ \mu Gy_a)(20\ mR)}{10\ mAs} = 640\ \mu Gy_a$$

Note:

Remember that mAs is just a measure of the total number of electrons that travel from cathode to anode to produce x-rays.

$$
\begin{aligned}
mAs &= mA \times s \\
&= mC/s \times s \\
&= mC
\end{aligned}
$$

where C (coulomb) is a measure of electrostatic charges and

1 C = 6.25×10^{18} electrons.

Kilovolt Peak (kVp)

X-ray quantity varies rapidly with changes in kVp. The change in x-ray quantity is proportional to the square of the ratio of the kVp; in other words, if kVp were doubled, the x-ray intensity would increase by a factor of 4. Mathematically, this is expressed as follows:

$$\frac{I_1}{I_2} = \left(\frac{kVp_1}{kVp_2}\right)^2$$

where I_1 and I_2 are the x-ray intensities at kVp_1 and kVp_2, respectively.

In practice, a slightly different situation prevails. Radiographic technique factors must be selected from a relatively narrow range of values, from approximately 40 to 150 kVp. Theoretically, doubling the x-ray intensity by kVp manipulation alone requires an increase of 40% in kVp. This relationship is not adopted clinically because as kVp is increased, the penetrability of the x-ray beam is increased, and relatively fewer x-rays are absorbed in the patient. More x-rays go through the patient and interact with the image receptor. Consequently, to maintain a constant exposure of the image receptor, an increase of 15% in kVp should be accompanied by a reduction of one half in mAs.

Q2. A radiographic technique calls for 80 kVp/30 mAs and results in 1.4 mGya. What is the expected **ESE (Entrance Skin Exposure)** if the kVp is increased to 92 kVp (+15%) and the mAs reduced by one half to 15 mAs? H.W

Note that by increasing **kVp** and reducing **mAs** so that image receptor exposure remains constant, the patient dose is reduced significantly. The disadvantage of such a technique adjustment is reduced image contrast when screen film is the image receptor. There is no change in contrast when using digital image receptors.

Distance: X-ray intensity varies inversely with the square of the distance from the x-ray tube target. This relationship is known as the inverse square

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2$$

where I_1 and I_2 are the x-ray intensities at distances d_1 and d_2, respectively.

Q3. Mobile radiography is conducted at 100 cm SID **(Source to Image-Receptor Distance)** and results in an exposure of 0.13 mGya (13 mR) at the image receptor. If 91 cm is the maximum SID that can be obtained for a particular examination, what will be the image receptor exposure?

Solution:

$$\frac{0.13\ \text{mGy}_a}{I_2} = \left(\frac{91\ \text{cm}}{100\ \text{cm}}\right)^2$$

$$I_2 = (0.13\ \text{mGy}_a)\left(\frac{100\ \text{cm}}{91\ \text{cm}}\right)^2$$

$$= (0.13\ \text{mGy}_a)(1.1)^2$$

$$= (0.13\ \text{mGy}_a)(1.1) = 0.14\ \text{mGy}_a$$

Note: When SID is increased, mAs must be increased by SID_2 to maintain constant exposure to the image receptor

Compensating for a change in SID by changing mAs by the factor SID_2 is known as the square law, a corollary to the inverse square law.

The Square Law

$$\frac{mAs_1}{mAs_2} = \frac{SID_1^2}{SID_2^2}$$

where mAs_1 is the technique at SID_1, and mAs_2 is the technique at SID_2.

In practical terms, this can be rewritten as follows:

$$\frac{\text{Old mAs}}{\text{New mAs}} = \frac{\text{Old distance squared}}{\text{New distance squared}}$$

Filtration.

X-ray imaging systems have metal filters, usually 1 to 5 mm of aluminum (Al), positioned in the useful beam. The purpose of these filters is to reduce the number of low-energy x-rays. Low-energy x-rays contribute nothing useful to the image. They only increase the patient dose unnecessarily because they are absorbed in superficial tissues and do not penetrate to reach the image receptor

When filtration is added to the x-ray beam, patient dose is reduced because fewer low-energy x-rays are found in the useful beam. Calculation of the reduction in exposure requires knowledge of half-value layer (**HVL**).

X-RAY QUALITY

Penetrability: As the energy of an x-ray beam is increased, the penetrability is also increased. Penetrability refers to the ability of x-rays to penetrate deeper in tissue. High-energy x-rays are able to penetrate tissue more deeply than low-energy x-rays. The penetrability of an x-ray beam is called the x-ray quality. X-rays with high penetrability are termed high-quality x-rays. Those with low penetrability are low-quality x-rays.

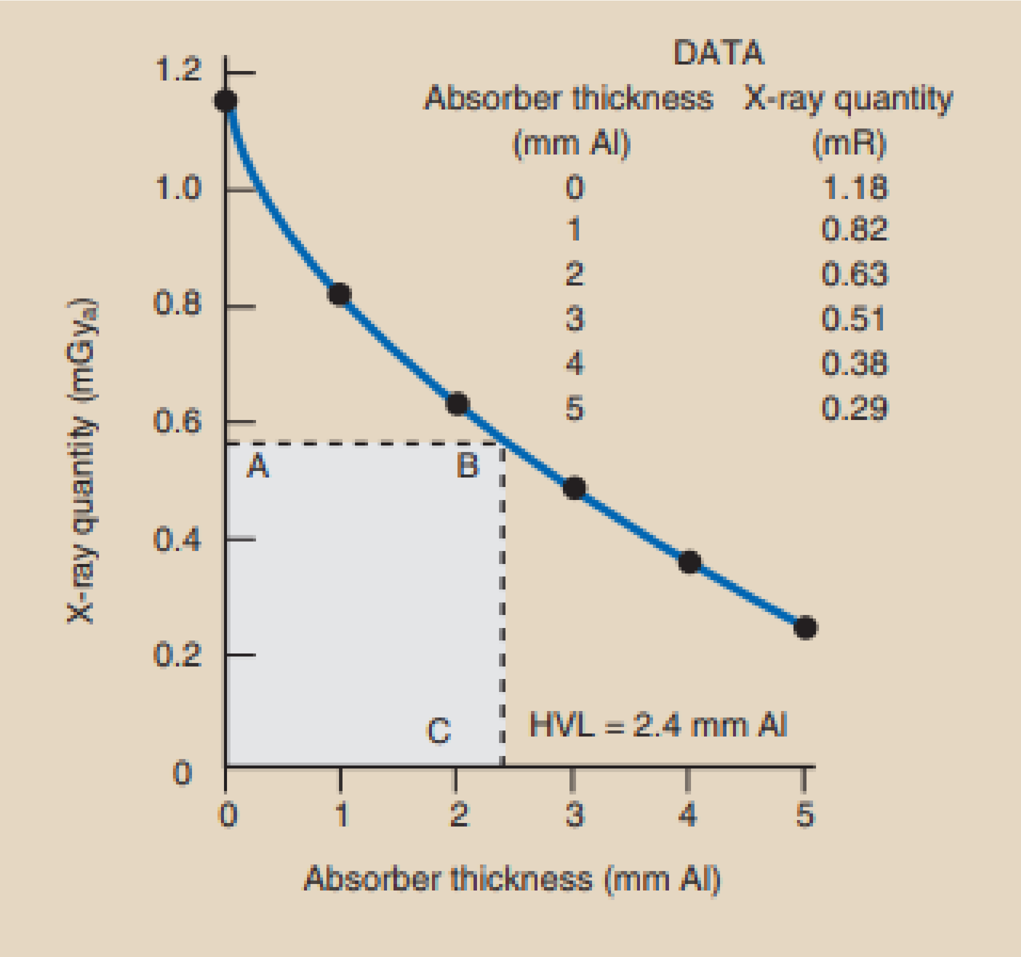
Factors that affect x-ray beam quality also influence radiographic contrast when screen film is the image receptor. Distance and mAs do not affect radiation quality; they do affect radiation quantity.

Half-Value Layer:

Although x-rays are attenuated exponentially, high energy x-rays are more penetrating than low-energy x-rays. Whereas 100-keV x-rays are attenuated at the rate of approximately 3%/cm of soft tissue, 10-keV x-rays are attenuated at approximately 15%/cm of soft tissue. X-rays of any given energy are more penetrating in material of low atomic number than in material of high atomic number.

Attenuation is the reduction in x-ray intensity that results from absorption and scattering.

The HVL of an x-ray beam is the thickness of absorbing material necessary to reduce the x-ray intensity to half of its original value.



Factors That Affect X-ray Quality

Some of the factors that affect x-ray quantity have no effect on x-ray quality. Other factors affect both x-ray quantity and quality. These relationships are summarized in Table 2. Kilovolt Peak (kVp). As the kVp is increased, so is x-ray beam quality and therefore the HVL. An increase in kVp results in a shift of the x-ray emission spectrum toward the high-energy side, indicating an increase in the effective energy of the beam. The result is a more penetrating x-ray beam.

Table.2

Factors That Affect X-ray Quality and Quantity

	EFFECT ON	
An Increase in	**X-ray Quality**	**X-ray Quantity**
mAs	None	Increased
kVp	Increased	Increased
Distance	None	Reduced
Filtration	Increased	Reduced

Filtration. The primary purpose of adding filtration to an x-ray beam is to remove selectively low-energy x-rays that have little chance of getting to the image receptor.

Types of Filtration:

Filtration of diagnostic x-ray beams has two components: inherent filtration and added filtration. Inherent Filtration. The glass or metal enclosure of an x-ray tube filters the emitted x-ray beam. This type of filtration is called inherent filtration. Inspection of an x-ray tube reveals that the part of the glass or metal enclosure through which x-rays are emitted—the window—is very thin. This provides for low inherent filtration.

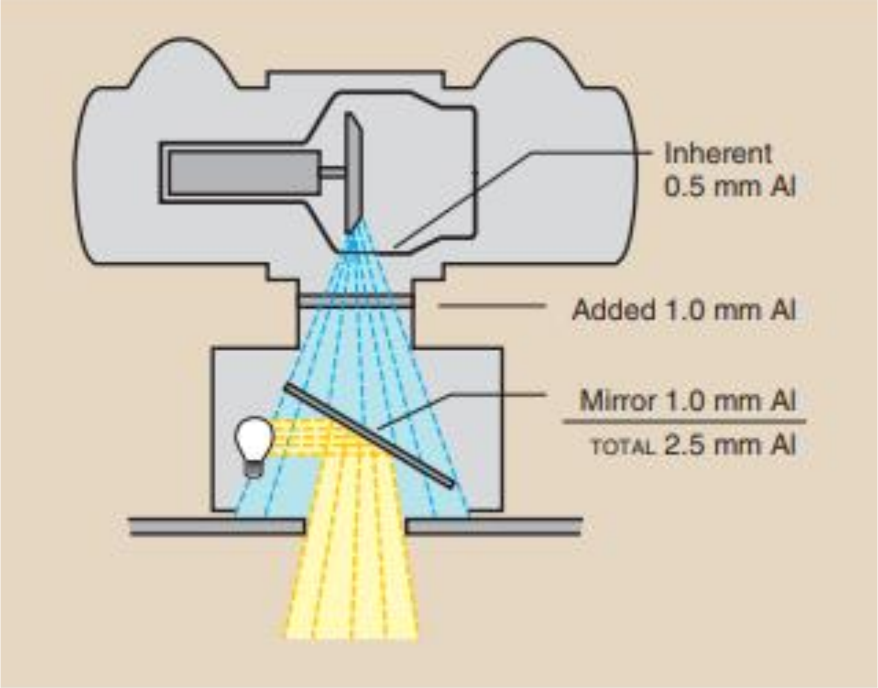
The inherent filtration

Of a general purpose x-ray tube is approximately 0.5 mm Al equivalent. With age, **inherent filtration** tends to increase because some of the tungsten metal of both the target and filament is vaporized and is deposited on the inside of the window. Special-purpose tubes, such as those used in mammography, have very thin x-ray tube windows. They are sometimes made of beryllium (Z = 4) rather than glass and have an inherent filtration of approximately 0.1 mm Al. **Added Filtration**. A thin sheet of Al positioned between the protective x-ray tube housing and the x-ray beam collimator is the usual form of added filtration.

Add Filtration

The addition of a filter to an x-ray beam attenuates x-rays of all energies emitted, but it attenuates a greater number of low-energy x-rays than high-energy x-rays. This shifts the x-ray emission spectrum to the high energy side, resulting in an x-ray beam with higher energy, greater penetrability, and better quality. The HVL increases, but the extent of increase in the HVL cannot be predicted even when the thickness of added filtration is known. Because added filtration attenuates the x-ray beam, it affects x-ray quantity. This value can be predicted if the HVL of the beam is known. The addition of filtration equal to the beam HVL reduces the beam quantity to half its prefiltered value and results in a higher x-ray beam quality.

Added filtration usually has two sources. First, 1-mm or more sheets of Al are permanently installed in the port of the x-ray tube housing between the housing and the collimator. With a conventional light-localizing variable-aperture collimator, the collimator contributes an additional 1 mm Al equivalent added filtration. This filtration results from the silver surface of the mirror in the collimator shown in Figure below.



Compensating Filters

One of the most difficult tasks facing radiographers is producing an image with a uniform intensity when a body part is examined that varies greatly in thickness or tissue composition. When a filter is used in this fashion, it is called a compensating filter because it compensates for differences in subject radiopacity

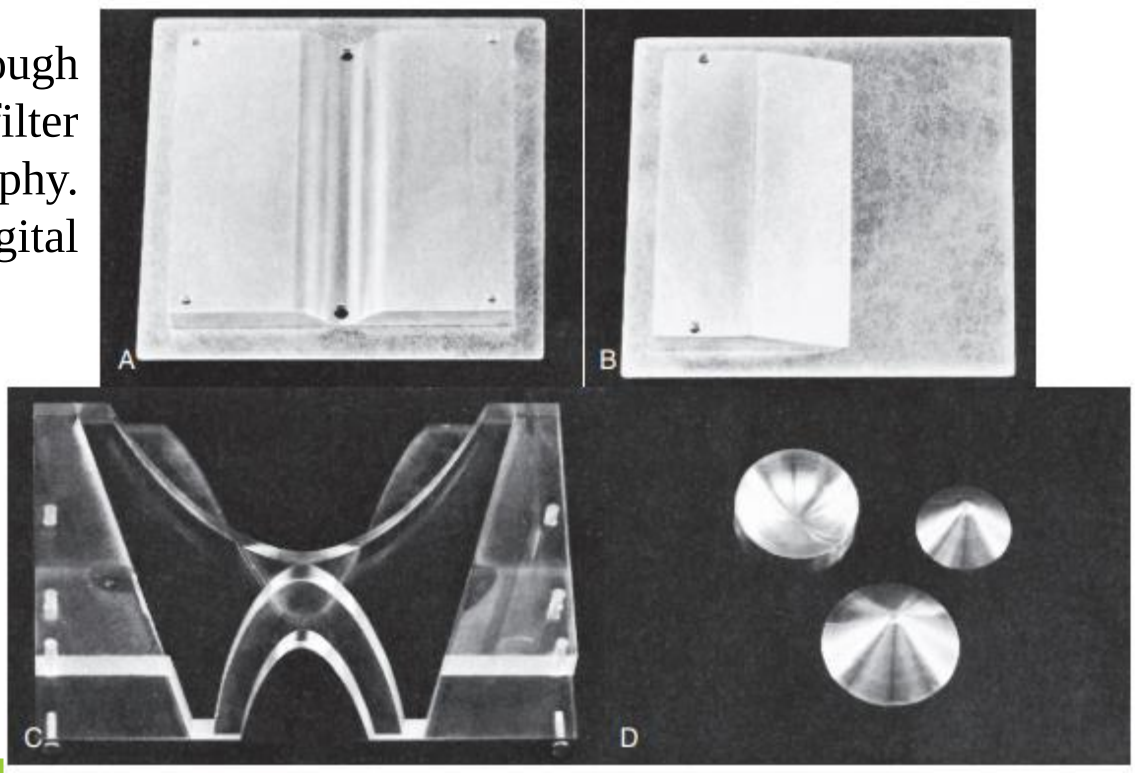


Fig.1. Compensating filters. A, Trough filter. B, Wedge filter. C, “Bow-tie” filter for use in computed tomography. D, Conic filters for use in digital fluoroscopy

SUMMARY

Radiation quantity is the number of x-rays in the useful beam. Factors that affect radiation quantity include the following:

- mAs: X-ray quantity is directly proportional to mAs.
- kVp: X-ray quantity is proportional to the square of the kVp.
- Distance: X-ray quantity varies inversely with distance from the source.
- Filtration: X-ray quantity is reduced by filtration, which absorbs low-energy x-rays in the beam. Radiation quality is the penetrating power of the x-ray beam. The penetrability is represented by the HVL, which is the thickness of additional filtration that reduces x-ray intensity to half its original value.

Factors that affect x-ray beam penetrability or radiation quality include the following:

- kVp: X-ray penetrability is increased as kVp is increased.
- Filtration: X-ray penetrability is increased when filtration is added to the beam. **Following are the three types of filtration:**

(1) inherent filtration of the glass or metal enclosure.

(2) added filtration in the form of Al sheets; and

(3) compensating filters, which provide variation in intensity across the x-ray beam.