Chapter 5

X-Ray Production

Learning Objectives

At the conclusion of this chapter, you will be able to:

- Draw a simple x-ray tube and label its parts
- Describe both the composition and the function of the basic parts of the x-ray tube
- Associate the terms *anode* and *cathode* with the appropriate parts of the x-ray tube
- Describe the production of both bremsstrahlung and characteristic radiation
- Explain what is meant by a dual-focus tube and describe its advantages
- Explain the significance of the target angle with respect to the line focus principle and the maximum field size
- Define "effective focal spot" and state its significance with respect to the radiographic image
- Explain the function of a rotating anode and state its purpose
- State the effect of changes in milliampere (mA) and kilovolt (kVp) levels on the resulting x-ray beam
- Describe the concept of x-ray beam filtration

Key Terms

actual focal spot
added filtration
anode heel effect
bremsstrahlung radiation
characteristic radiation
dual-focus
effective focal spot
electron stream
exposure time
filament
filtration
focal spot
focal track
focusing cup
heterogeneous
inherent filtration
kilovolts peak (kVp)
line focus principle
milliampere-second (mAs)
millisecond (ms)
photon
rotating anode
space charge
spatial resolution
target
target angle
thermionic emission
total filtration
tungsten

This chapter is about x-ray tube structure and function and how these factors affect the primary x-ray beam. The electric factors that control x-ray production are introduced in this chapter. Chapters 4 and 5 contain a tremendous amount of detail, and most of it is probably unfamiliar to you. Although it is all interrelated and is presented in a logical order, you may feel a bit overwhelmed if you try to comprehend it too quickly. Do not attempt to assimilate it all at once. When this material is taken in small bites and reviewed as needed, the entire process of creating and controlling x-rays will gradually come into focus.

Roentgen discovered x-rays while working with a Crookes tube (Fig. 5.1), a cathode ray tube that was the forerunner of the fluorescent tube and the neon light. These tubes were used in physics laboratories in the late 19th century for the investigation of electricity. In 1913, the General Electric Company introduced the Coolidge tube (Fig. 5.2), a "hot cathode" tube that was the prototype for modern x-ray tubes.

X-RAY TUBE

Fig. 5.3 illustrates a simple x-ray tube with its principal parts labeled. There are four essential requirements for the production of x-rays: (1) a vacuum, (2) a source of electrons, (3) a **target**, and (4) a high potential difference (voltage) between the electron source and the target.

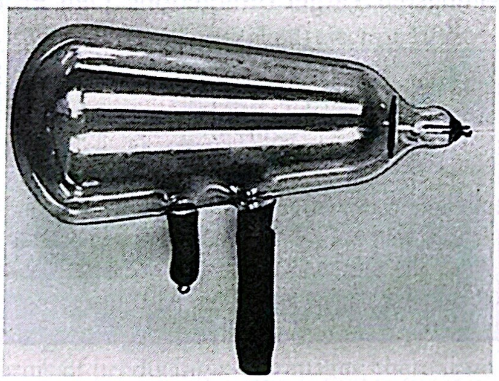


Fig. 5.1 Crookes tube used by Roentgen, 1895.

A Pyrex glass envelope forms the basic structure of the x-ray tube. It is made of strong, heat-resistant glass and contains both the source of electrons and the target. The air is removed from the glass envelope to form a near-perfect vacuum so that gas molecules will not interfere with the process of x-ray production. The tube is fitted on both ends with connections for the electric supply.

The source of electrons is a **filament** at one end of the tube. The filament consists of a small coil of **tungsten** wire. Tungsten (chemical symbol W) is a metal element; it is a large atom with 74 electrons in orbit around its nucleus. An electric current flows through the filament to heat it. An advantage of using tungsten is that it has a high melting point, which enables it to last through thousands of exposures. As explained in Chapter 4, heat speeds up the movement of the electrons in their orbits and increases their distance from the nucleus. Electrons in the outermost orbital shells move so far from the nucleus that they are no longer held in orbit but are flung out of the atom, forming an "electron cloud" around the filament (Fig. 5.4). This process is called **thermionic emission.** The electron cloud is called a **space charge** and is the source of free (in air) electrons for x-ray production.

At the opposite end of the tube is the anode (also referred to as the target), a hard, smooth, slanted metal surface that is also made of tungsten. The electrons are directed toward the target, which is the place where x-rays are generated.

A high-voltage electric source provides acceleration of the electrons. A large step-up transformer supplies the voltage (40 to 125 kVp) required for x-ray production. The two ends of the x-ray tube are connected in the transformer circuit so that the filament end is negative and the target end is positive during an exposure. The positive, target end of the tube is called the *anode*; the negative, filament end is called the *cathode*.

The high positive electric potential at the target attracts the negatively charged electrons of the space charge,

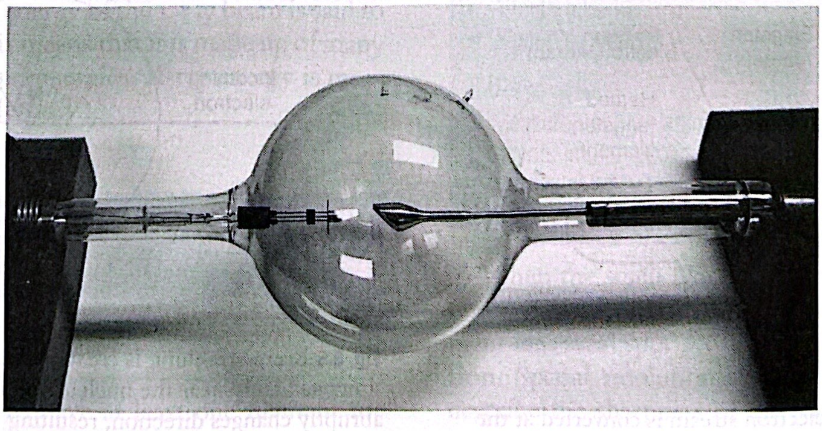


Fig. 5.2 Coolidge "hot cathode" tube, 1913.

which move rapidly across the tube, forming an **electron stream.** When these fast-moving electrons collide with the target, the kinetic energy of their motion is converted into a different form of energy. The great majority of this kinetic energy (>99%) is converted into heat, and only a small amount is converted into the energy form that we know as x-rays (Fig. 5.5).

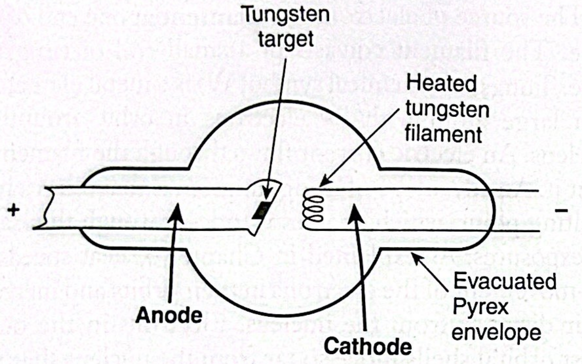


Fig. 5.3 Simple x-ray tube. The anode is the positive end of the tube; the target is part of the anode. The cathode is the negative end of the tube; the filament is part of the cathode.

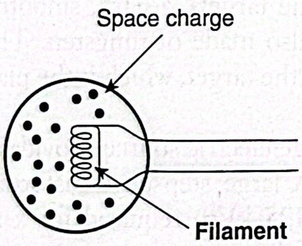


Fig. 5.4 Thermionic emission. As tungsten is heated, electrons in the tungsten atom's orbits spin faster, moving farther from the nucleus. Electrons in outer orbits are flung out of the atom, forming an "electron cloud," or space charge. The space charge provides the electron source for x-ray production.

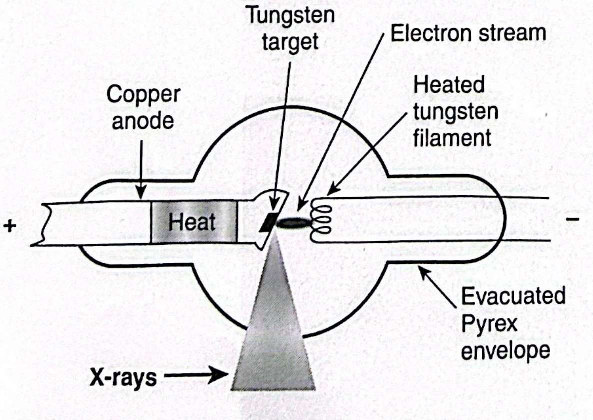


Fig. 5.5 The energy of the electron stream is converted at the anode into heat (>99%) and x-rays (<1%).

BREMSSTRAHLUNG AND CHARACTERISTIC RADIATION

X-rays are produced at the target as a result of either a sudden deceleration or an absorption of the electron stream. These interactions of electrons with tungsten atoms may occur in one of two ways (Box 5.1).

Bremsstrahlung Radiation

X-rays are produced when an incoming electron misses all the electrons in the tungsten atom, gets very close to the nucleus, and then suddenly slows down and abruptly changes direction. As a result, the electron loses energy. This sudden energy change is converted into an **x-ray photon** (Fig. 5.6). The photon produced is a small "bundle" of electromagnetic energy. X-rays created by this interaction are called **bremsstrahlung radiation.** *Bremsstrahlung* is a German word that means braking or slowing. The short term "brems" is often used instead of the long word. Every x-ray exposure will contain photons produced from bremsstrahlung interactions in the anode.

Box 5.1

Tungsten Target Interactions That Produce X-Rays

Bremsstrahlung radiation: Created when an incoming electron is suddenly slowed down, changes direction, and leaves the tungsten atom. The kinetic energy of the electron is converted into an x-ray photon.

Characteristic radiation: Created when an incoming electron interacts with the K-shell electron and knocks it out of orbit. When the electron void is filled with an outer shell electron, an x-ray photon is created.

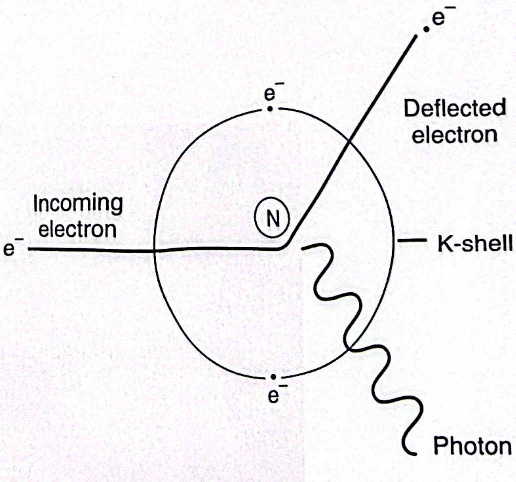


Fig. 5.6 Bremsstrahlung is created when an incoming electron slows suddenly near the nucleus (*N*) of the tungsten atom and abruptly changes direction, resulting in the creation of an x-ray photon.

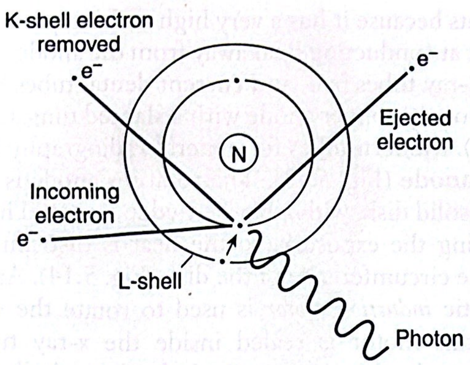


Fig. 5.7 Formation of characteristic radiation. An incoming electron removes an inner orbital electron from the tungsten atom, creating a "hole" in the K-shell. When an outer-shell electron drops to fill the hole, a characteristic photon is emitted. *N*, Nucleus.

Below 70 kVp, 100% of the photons in the x-ray beam are from bremsstrahlung interactions. Above 70 kVp, about 85% of the beam is bremsstrahlung. Therefore it is evident that the majority of all x-ray photons produced are from the bremsstrahlung interactions.

Characteristic Radiation

X-rays are also produced when an incoming electron collides with the K-shell (inner shell) electron of the tungsten atom and ejects it out of orbit. Both the incoming electron and the K-shell electron are removed. The void in the K-shell is filled with an electron from any of the other orbits. X-rays created by this interaction are called **characteristic radiation** (Fig. 5.7). Below 70 kVp, there are no characteristic photons produced. Above 70 kVp, about 15% of the beam is characteristic. This is because the binding energy of a K-shell is 69.5 and it takes at least a 70-kVp exposure to eject this electron.

In terms of producing x-ray images, there is no difference between a bremsstrahlung and characteristic photon. They are simply produced by different interactions of the incoming electrons in the anode. Technically, this cannot be controlled. The primary x-ray beam is made up of both bremsstrahlung and characteristic radiation.

The wavelength and energy of the x-ray beam is said to be **heterogeneous.** This means that it is made up of many different wavelengths and energies. X-ray energy is measured in kiloelectron volts (keV).

CHARACTERISTICS OF THE CATHODE AND THE ANODE

Cathode

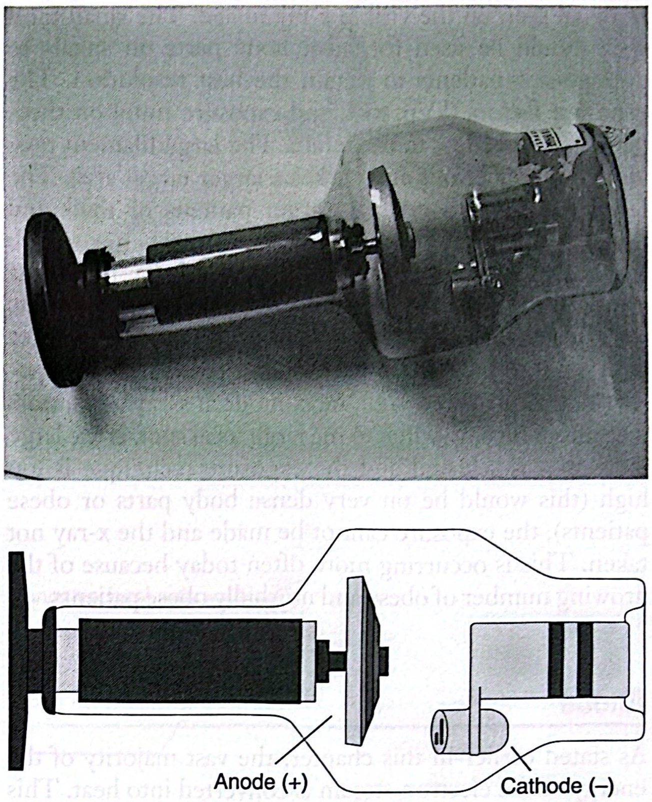


Fig. 5.8 Modern, dual-focus x-ray tube.

Although it is essential to have at least one filament for x-ray production, modern multipurpose x-ray tubes are **dual-focus** tubes (Fig. 5.8). They contain two filaments, one large and one small. Only one filament is used at a time.

Each filament is situated in a hollow area in the cathode called a **focusing cup** (Fig. 5.9). The focusing cup has a slight negative charge. The shape of the focusing cup and its negative electric charge cause the electrons to be repelled in the direction of a very precise area on the target called the **focal spot** (Fig. 5.10).

Focal Spot Size

Actual

- Measurement of focal spot on target surface
- Affects tube heat capacity
- *Bigger* is better!

Effective

- Measurement of vertical projection of actual focal spot
- Affects image resolution
- *Smaller* is better!

When the small filament is activated, its electrons are directed to a small focal spot on the target. The small filament and focal spot provide much better **spatial resolution.** Spatial resolution is the new digital term used to describe the sharpness of the structures recorded in the image. Generally speaking, it simply refers to the amount of detail seen on the visible x-ray image. The small focal spot should be used for most body parts on small- to average-size patients to obtain the best resolution. The exposure factors (kVp, mA, and exposure time) on these patients will be low to moderate. The large filament provides more electrons and strikes a larger target area. The large focal spot is used on larger patients or thick and dense body parts. The large focal spot can better absorb the heat generated by the increased exposure technique required for these patients. The two focal spots have the same center on the target and strike the same area (Fig. 5.11). If the small focal spot is selected and the exposure technique is too high, most modern x-ray generators will automatically switch to the large focal spot. If the large focal spot is selected and the exposure technique is too high (this would be on very dense body parts or obese patients), the exposure cannot be made and the x-ray not taken. This is occurring more often today because of the growing number of obese and morbidly obese patients.

Anode

As stated earlier in this chapter, the vast majority of the energy of the electron stream is converted into heat. This energy conversion takes place at the target, *so the anode tends to get very hot*. Anodes are therefore constructed to dissipate heat. Tungsten is an excellent material for x-ray tube targets because it has a very high melting point and it is efficient at conducting heat away from the anode.

Early x-ray tubes had, and current dental tubes have, a solid, stationary copper anode with a slanted tungsten face (Fig. 5.12). Modern tubes for general radiography have a **rotating anode** (Fig. 5.13). The rotating anode is in the form of a solid disk, with a beveled-edge target. This disk spins during the exposure, so the heat is distributed all around the circumference of the disk (Fig. 5.14). An electromagnetic *induction motor* is used to rotate the anode. Because this motor is sealed inside the x-ray tube, it works through electromagnetic induction, similar to a transformer.

The tungsten focal area all around the beveled edge of the rotating anode is called a **focal track.** The focal spot remains in the same location in space, but the target metal

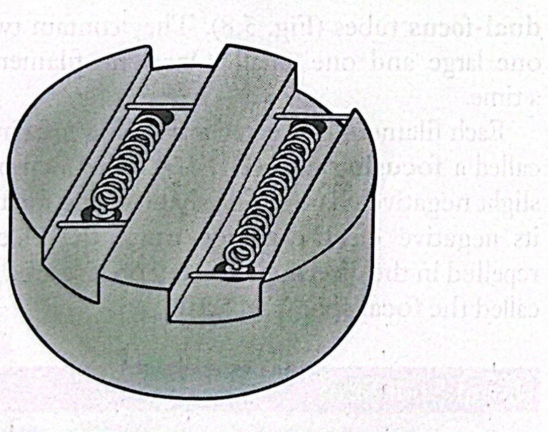


Fig. 5.9 Dual filaments in their focusing cups.

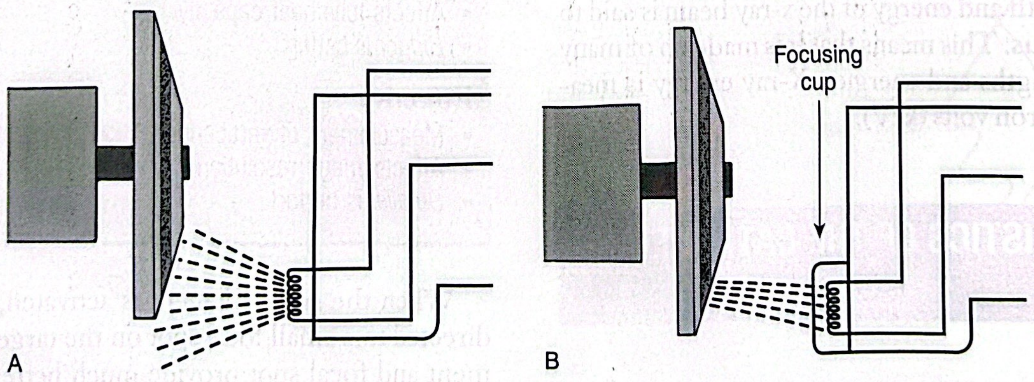


Fig. 5.10 (A) Without a focusing cup, the electron stream spreads beyond the target area. (B) Negatively charged focusing cup repels electrons, focusing them on a small target area, the focal spot.

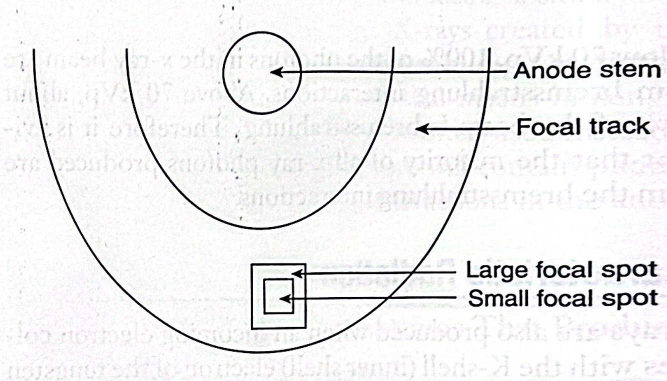


Fig. 5.11 Actual focal spot on lower part of anode. This is the area on the target where the electron stream is focused. Dual-focus tubes have two focal spots: one large and one small.

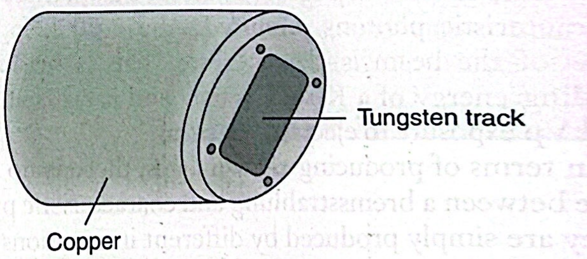


Fig. 5.12 Stationary anode.

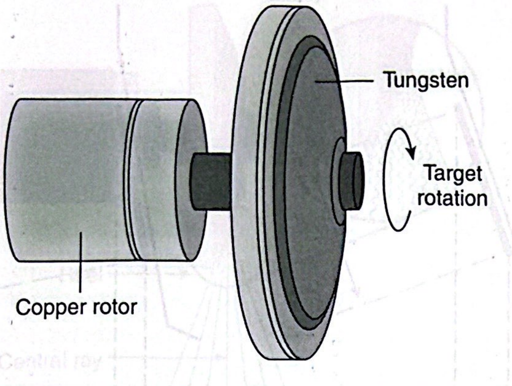


Fig. 5.13 Rotating anode. The copper rotor stem is part of the induction motor used to turn the anode disk.

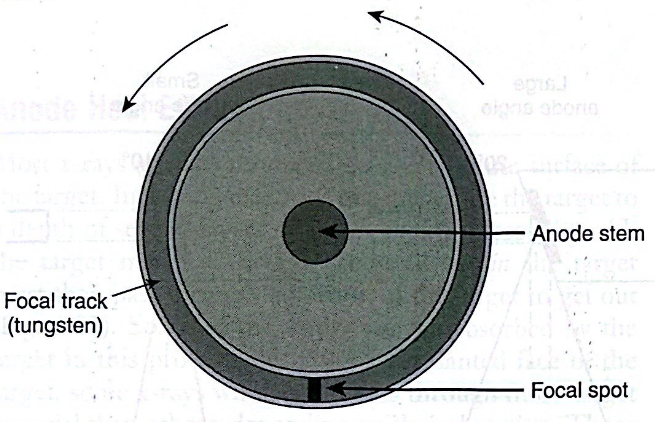


Fig. 5.14 Rotating anode face. The electrons strike the anode in the tiny focal spot area, but the heat is spread around the entire focal track of the spinning anode face.

is spinning. The tungsten struck by the electron stream is constantly rotating during the exposure, distributing the anode heat over a larger area and increasing the heat capacity of the tube. X-ray tubes rotate at a standard speed of about 3600 revolutions per minute (rpm) during the exposure. Most x-ray tubes in use today also have a high-speed rotation at 10,000 rpm. The high-speed rotation automatically engages when high exposure factors (kVp, mA, and exposure time) are reached. The high-speed rotation enables the anode to dissipate the heat generated by the high technical factors more efficiently. When the operator pushes the exposure button on the generator, there is a short delay before the exposure is made. This delay allows the rotor to accelerate to its designated rpm while, at the same time, the filament is heated. Only then is the kVp applied to the x-ray tube. An audible sound is made during the exposure. When the sound ends, the exposure ends and the operator releases the button or switch. When the exposure is completed, the rotor slows down quickly.

Both the slanted face of the stationary anode and the beveled edge of the rotating anode present an angled surface to the oncoming electron stream. The slant of the anode surface is called the **target angle** (Fig. 5.15). X-ray tube target angles are between 7 and 17 degrees, with 12 degrees being most common. The target angle is built into the x-ray tube and cannot be changed. The target angle affects the tube's heat capacity, the sharpness of the radiographic image, and the maximum size of the x-ray beam. These effects of the target angle are discussed in the following section.

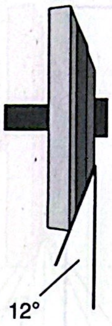


Fig. 5.15 Target angle.

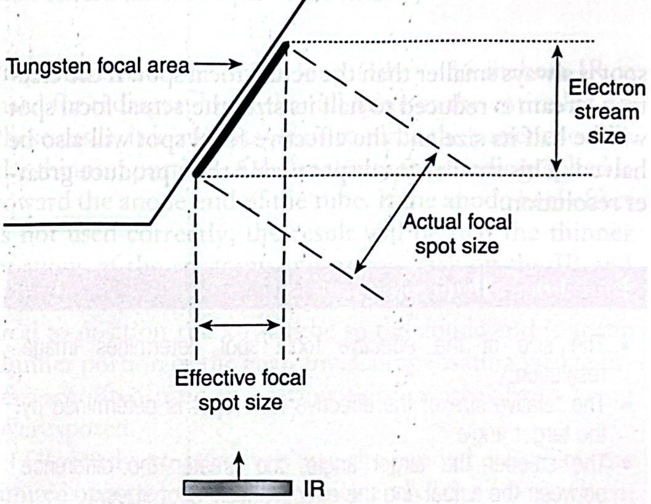


Fig. 5.16 The effective focal spot is the vertical projection of the actual or "true" focal spot. *IR*, Image receptor.

Line Focus Principle

The term **actual focal spot** refers to the area on the target surface that is struck by the electron stream. The **effective focal spot** refers to the *vertical projection* of the actual focal spot onto the patient and image receptor (IR) (Fig. 5.16). The size of the *effective* focal spot influences resolution in the image. This fact is called the **line focus principle.** When vertical lines are drawn from each corner of the slanted actual focal spot, these lines define an "image" of the focal spot as viewed from the IR. The effective focal

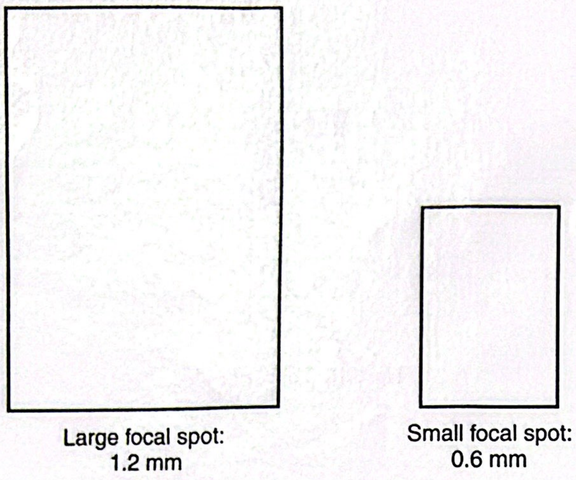


Fig. 5.17 Effective focal spot sizes.

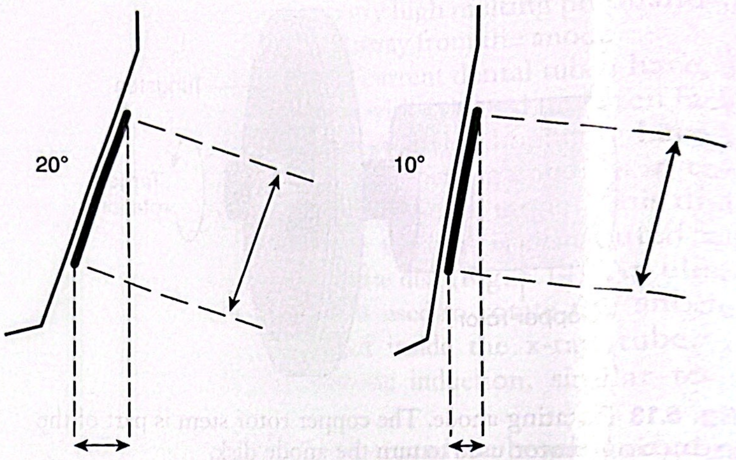


Fig. 5.18 A smaller target angle results in a smaller effective focal spot with a given actual focal spot size.

spot is always smaller than the actual focal spot. If the electron stream is reduced to half its size, the actual focal spot will be half its size and the effective focal spot will also be halved. This smaller focal spot would then produce greater resolution.

Line Focus Principle

- The size of the *effective* focal spot determines image resolution.
- The relative size of the effective focal spot is determined by the target angle.
- The steeper the target angle, the greater the difference between the actual and the effective focal spot sizes.

Focal spots are rectangular as seen on the face of the target. Most x-ray tubes used today contain a 0.6-mm small focal spot and a 1.2-mm large focal spot. The small focus is half the size of the large but will provide double the resolution (Fig. 5.17). Some x-ray tubes may be purchased with larger focal spots of 1.0 mm for the small and 2.0 mm for the large.

Just how the effective focal spot influences resolution is explained in Chapter 7. At this point, simply note the fact that a smaller effective focal spot size will result in greater resolution in the image and that a larger effective focal spot will have the opposite effect.

The angle of the target face determines the size difference between the actual focal spot and the effective focal spot. Fig. 5.18 shows two targets with the same-size actual focal spot but different target angles. It demonstrates that the "steeper" (more vertical) target has a smaller effective focal spot. *The smaller the target angle, the greater the size difference between the actual and effective focal spots.*

Although a *small effective* focal spot is desirable for greater resolution, a large actual focal spot is desirable to dissipate the heat of large exposures. The best solution would seem to be to use the smallest possible target angle. There is a practical limit, however, on how steep the target angle can be. As you can see in Fig. 5.19, a straight line extended from the target face defines the margin of the x-ray beam on the anode side and, by default, the opposite margin of the beam. Thus the target angle determines the maximum possible size of the x-ray beam and the radiation field. A target angle of at least 12 degrees is needed to produce a radiation field that will cover a 14- × 17-inch IR at a distance of 40 inches, the largest IR in general use and a common, convenient working distance. Understand that once a given x-ray tube is purchased, the two focal spot sizes and the angle of the anode cannot be changed. Therefore the amount of resolution needed for the x-ray projections that are done in the room has to be determined in advance.

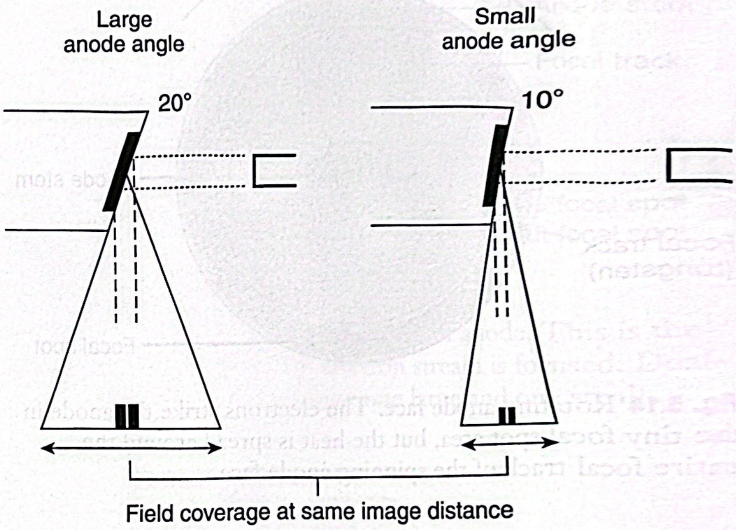


Fig. 5.19 The anode angle controls the maximum field size. The anode margin of the field extends from the anode face at the same angle. The cathode side is the mirror image of the anode side. A 12-degree target angle is needed to cover a 14- × 17-inch image receptor at a 40-inch distance from the source.

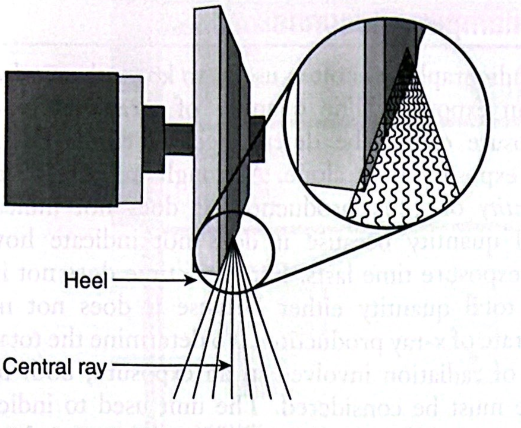


Fig. 5.20 Anode heel. X-rays are formed within the target material and are absorbed by the target as they exit. The sloping target face causes uneven absorption of the primary beam.

Anode Heel Effect

Most x-rays are not produced on the absolute surface of the target. Incoming electrons may penetrate the target to a depth of several layers of atoms before interacting with the target material. X-rays produced *within* the target must then pass through a portion of the target to get out (Fig. 5.20). Some of the x-rays will be absorbed by the target in this process. Because of the slanted face of the target, some x-rays will have to pass through more target material than others, depending on their direction. Those x-rays that are directed away from the cathode are more likely to be absorbed than those that are directed toward it. This results in uneven distribution of radiation intensity in the x-ray beam and is called the **anode heel effect.**

Anode Heel Effect

- Variation in radiation intensity across the length of the radiation field
- Greater radiation intensity toward the cathode end of the field
- Only significant when using the whole beam (14- × 17-inch IR at 40 inches or full spine at 72 inches)
- Place thinner portion of body part toward anode end of tube

Fig. 5.21 illustrates the relative intensity of the x-ray beam from one end to the other. If the intensity of the beam is measured at the central ray and that intensity is designated as 100%, the intensity at the cathode end can be as high as 120%. At the anode end, it can be as low as 75%—a 45% difference.

The anode heel effect is only significant in radiography when the entire beam is in use. This is the case when a large IR (14 × 17 inches) is used at a distance of 40 inches. Examples include examinations of the femur (thigh bone), the thoracic spine and chest, and the lumbar spine and abdomen. The anode heel effect is also important when an extra-long (14 × 36 inches) IR is used for radiography of the full spine or the entire leg. In these cases, it is advantageous to place the patient so that the thinnest portion of the anatomy to be radiographed is toward the anode end of the tube. If the anode heel effect is not used correctly, the result will be that the thinner portions of the anatomy appear too dark on the IR and the thicker portions will be too light. It is not always practical to position the x-ray tube so the anode end is at the thinner portion of the anatomy. Compensating wedge filters are often used to prevent thinner areas from being overexposed.

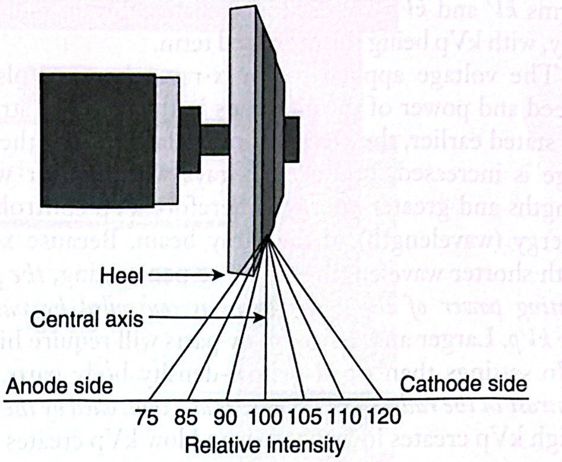


Fig. 5.21 Anode heel effect. The intensity of the x-ray beam is least toward the anode end of the field.

Obviously, to effectively use the anode heel effect, the limited operator must know which end of the tube is which. Sometimes this is easily determined by examining the tube housing. The cable connections to the housing are often labeled. If no labels are apparent on or near the tube housing, try following the cables to their connections at the other end, the transformer cabinet, and check for labels there. A definitive determination can be made by taking a radiograph. Expose a 14- × 17-inch IR at a 40-inch distance using approximately 1 mAs and about 40 to 44 kVp. Open the collimator so that the radiation field covers the IR. Place a lead marker at one end so that you will be able to tell from the finished radiograph how it was placed during the exposure. The radiograph will demonstrate the anode heel effect because one end will be lighter than the other. The light end will signify the anode end of the tube.

ELECTRIC CONTROL OF X-RAY PRODUCTION

Kilovoltage

Voltage is measured at the *peak* of the electric cycle. When the voltage across the x-ray tube is measured, the units are often stated as **kilovolts peak**, abbreviated **kVp**. The terms *kV* and *kVp* are used interchangeably in radiography, with kVp being the preferred term.

The voltage applied to the x-ray tube controls the speed and power of the electrons in the electron stream. As stated earlier, the electrons move faster when the voltage is increased, producing x-rays with shorter wavelengths and greater energy. Therefore kVp controls the energy (wavelength) of the x-ray beam. Because x-rays with shorter wavelengths are more penetrating, *the penetrating power of the x-ray beam is controlled by varying the kVp.* Larger and denser body parts will require higher kVp settings than small or low-density body parts. *The contrast in the radiographic image is also controlled by the kVp.* High kVp creates low contrast, and low kVp creates high contrast.

Milliamperage

Milliamperage (mA) is a measure of the *rate of current flow* across the x-ray tube, that is, the number of electrons flowing from filament to target *each second.* The number of available electrons is determined by the filament heat. When filament heat is increased, more electrons are available each second to cross the tube. Thus, increasing the mA increases the filament heat and decreasing the mA decreases the filament heat. When more electrons strike the target, more x-rays are produced, so *mA controls the volume, or quantity, of x-ray production* and thus also the *rate of exposure.* High mA settings produce more x-rays, and low mA settings produce fewer x-rays. Stated differently, mA controls the intensity of the x-ray beam, determining the number of photons that will strike the patient and IR. *The density in the radiographic image is controlled by the mA, exposure time, or the mAs.* In radiology the mA is directly proportional. If the mA is doubled, the x-rays are doubled, and if the mA is halved, the x-rays are reduced by 50%. In later chapters you will learn that mA, because it controls the volume of x-rays in the beam, affects the density of the x-ray image.

Exposure Time

Exposure time refers to the length of time that the x-rays are turned on. It is the duration of the x-ray exposure. Exposure time is measured in units of seconds (s). Most x-ray exposure times are less than 1 second, and therefore **milliseconds (ms)** are used: 1 ms equals 0.001 second. A timer in the x-ray circuit terminates the exposure after a preset length of time. Like the mA, the quantity of x-rays produced is directly proportional to the exposure time. If the exposure time is doubled, the x-rays are doubled, and if the time is halved, the x-rays are reduced by 50%. One can see that a change in mA or exposure time will produce the same effect on the image. In later chapters there will be a discussion of when to choose mA and when to choose exposure time to change the quantity of x-rays (or density on the IR).

Milliampere-Seconds

In radiography it is often useful to know the *total quantity* of an exposure. The quantity of x-ray photons in an exposure cannot be determined by either the mA or the exposure time alone. Although mA determines the *quantity* of x-ray production, it does not indicate the total quantity because it does not indicate how long the exposure time lasts. Exposure time does not indicate the total quantity either because it does not measure the rate of x-ray production. To determine the total quantity of radiation involved in an exposure, both mA and time must be considered. The unit used to indicate the quantity of exposure is **milliampere-seconds (mAs)**. This unit is the product of mA and exposure time:

$$\text{mA} \times \text{Time (seconds)} = \text{mAs}$$

Milliampere-Seconds (mAs)

Measure of total quantity of electrons involved in exposure

$$\text{mA} \times \text{Time (seconds)} = \text{mAs}$$

Indicative of total quantity of photons produced by an exposure

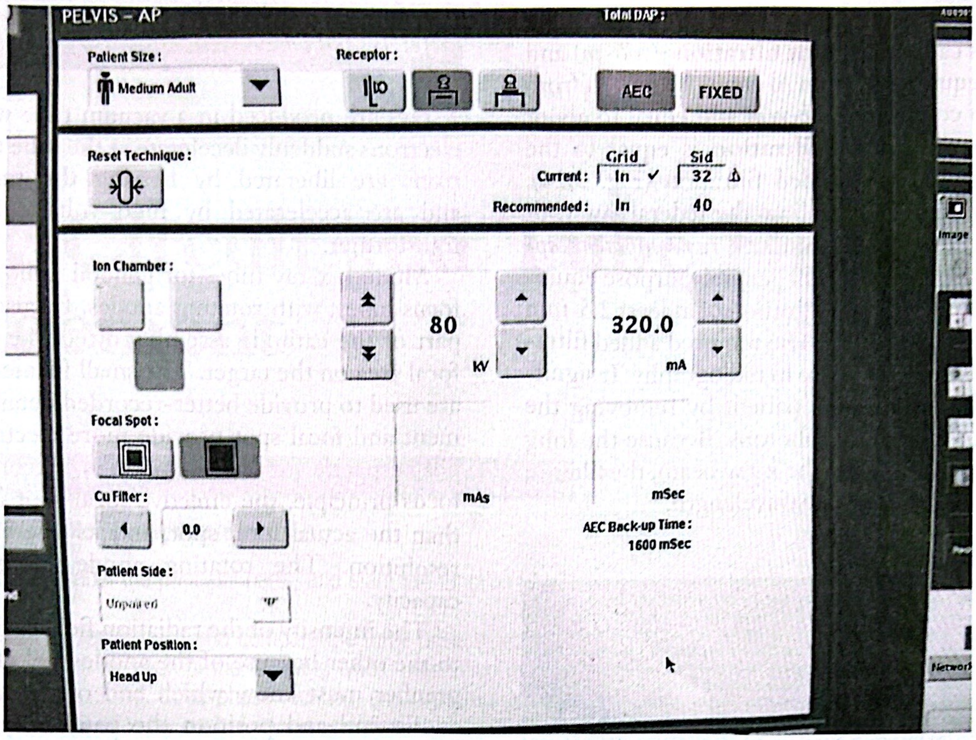
To better understand the concept of mAs, imagine for a moment that the x-ray beam consists of only a few hundred photons and that each mA of current produces only one x-ray photon per second. If this were true, an exposure rate of 100 mA would produce 100 photons per second. If the exposure time were 2 seconds, the mAs would equal 200 and the total number of photons in the exposure would be 200.

A desired quantity of exposure may be obtained by any combination of mA and time that multiplied together equals the desired mAs. In the previous example, for instance, 200 photons could also be obtained using 200 mA and an exposure time of 1 second.

Each of the following mA and time combinations will produce the same number of x-rays and an identical image density because the mAs is the same:

100 mA, 0.40 second = 40 mAs
200 mA, 0.20 second = 40 mAs
400 mA, 0.10 second = 40 mAs
800 mA, 0.05 second = 40 mAs

In the radiology department today, most generators are designed so that the operator sets the kVp and the mAs (Fig. 5.22). The operator always has the advantage of adjusting either the mA or the exposure time separately if needed. For example, if a crying baby's chest x-ray required 40 mAs from the four example techniques above, one would choose the last technique, 800 mA and 0.05 second, because it has the shortest exposure time. A short exposure time would enable considerably less motion in the x-ray image.


PELVIS – AP

Total DAP:

Patient Size: Medium Adult

Reset Technique:

Grid Current: In ✓

Grid Recommended: In

Sid Current: 32

Sid Recommended: 40

80 kV

320.0 mA

Cu Filter: 0.0

AEC Back-up Time: 1600 mSec

Patient Side: Unpaired

Patient Position: Head Up

Fig. 5.22 Computer monitor on the x-ray generator. Note near the center of the monitor that the exposure technique is set for 80 kVp and 320 mAs.

X-RAY BEAM FILTRATION

As explained earlier in this chapter, the x-ray beam is heterogeneous, consisting of photons with many different energy wavelengths. Those photons with long wavelengths are easily absorbed by the body and are unlikely to penetrate the subject and expose the IR. They do not contribute to the x-ray image. If these photons are not eliminated from the x-ray beam, they will be absorbed by the patient. To prevent this unnecessary radiation dose to the patient, the primary x-ray beam is filtered. **Filtration** is the process of removing the long-wavelength photons from the x-ray beam. Filtration material placed between the x-ray tube and the patient absorbs these long-wavelength photons (Fig. 5.23). *The primary purpose of filtration is to reduce patient dose.*

X-Ray Beam Filtration

- Filter material placed between the tube housing port and the patient removes the long-wavelength radiation from the primary beam.
- Because this radiation does not have sufficient energy to penetrate the patient, the cassette, and the table, it does not contribute to the image.
- Filtration lowers patient dose significantly.
- Filtration decreases the average wavelength of the x-ray beam.

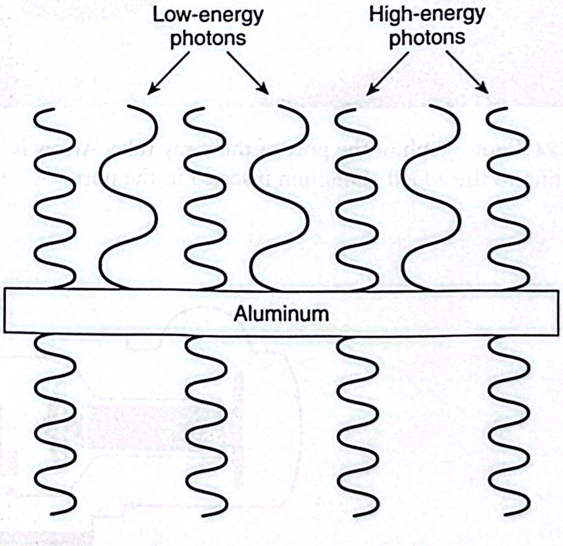


Fig. 5.23 Filtration absorbs long-wavelength photons and reduces dose to the patient.

The material commonly used to filter the x-ray beam is aluminum. This is considered **added filtration**. One or more aluminum plates installed between the tube port and the collimator serve this purpose (Fig. 5.24). Because aluminum is the primary filtration material, all filtration is measured in units of millimeters of aluminum equivalents (mm Al equiv), the amount of filtration provided by a millimeter of aluminum.

The filtration provided by the glass of the tube and the surrounding oil is called **inherent filtration** *(built-in)* and is approximately equal to 0.5 mm Al equiv. Filtration from the mirror is also considered *inherent* and equal to about 1.0 mm Al equiv. The **total filtration** is equal to the inherent filtration plus the added filtration (Fig. 5.25). Radiology departments must follow the federal law with regard to filtration of x-ray machines. *X-ray equipment capable of producing 70 kVp or more* (all general-purpose equipment) is required to have total filtration of at least 2.5 mm Al equiv permanently installed. The required added filtration is an important safety feature in radiography. It significantly reduces the dose to the patient by removing the low-energy (long-wavelength) photons. Because the long wavelengths are removed from the x-ray beam, the filtered beam has a much shorter average wavelength.

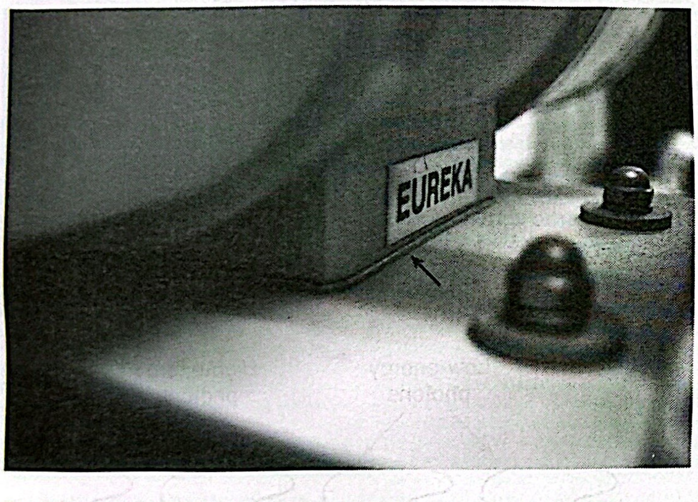


Fig. 5.24 Photograph of the port of the x-ray tube. Arrow is pointing to the added aluminum inserted in the port.

SUMMARY

X-rays are produced in a vacuum tube when high-speed electrons suddenly decelerate at the tube target. The electrons are liberated by heating the tungsten filament and are accelerated by high voltage from a step-up transformer.

Modern x-ray tubes for general radiography are dual-focus tubes, with rotating anodes. Focusing cups that are part of the cathode assembly direct the electrons to the focal area on the target. The small filament and focal spot are used to provide better-recorded detail. The large filament and focal spot provide more electrons and greater heat capacity for large exposures. According to the line focus principle, the effective focal spot is always smaller than the actual focal spot, and its size affects the spatial resolution. The rotating anode increases tube heat capacity.

The intensity of the radiation field varies from one end to the other because of the anode heel effect. The radiographer must know which end of the x-ray tube is the anode end and position the patient so that the anode heel effect is applied correctly when using large IRs at a 40-inch distance.

The penetrating power of the x-ray beam is controlled by the kVp. The *quantity* of the exposure is indicated by the mAs, the product of the mA and exposure time.

Filtration of the x-ray beam significantly reduces the patient's dose, decreases the average wavelength, and increases the average energy of the x-ray beam. A total of 2.5 mm Al equiv filtration is required to be permanently installed on all equipment capable of operating above 70 kVp.

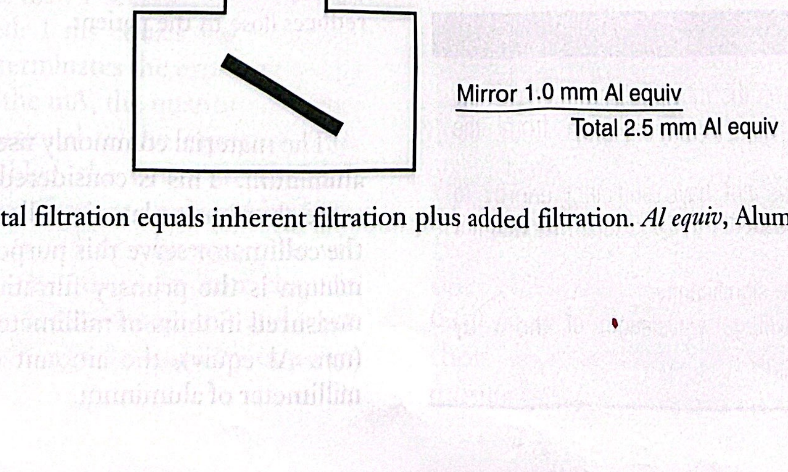


Fig. 5.25 Total filtration equals inherent filtration plus added filtration. *Al equiv*, Aluminum equivalent.