X-RAY IMAGING

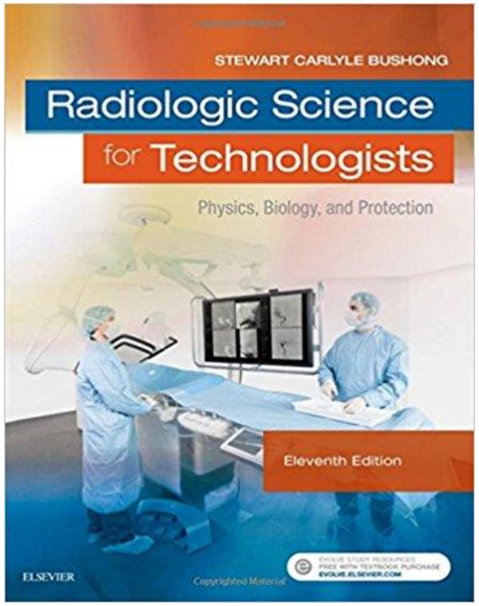
EE 472 – F2017

Prof. Yasser Mostafa Kadah – www.k-space.org

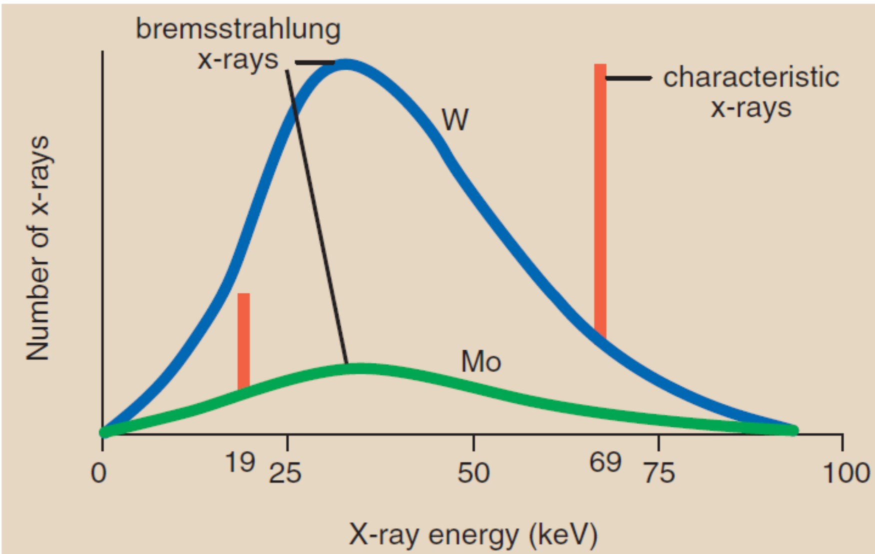
Recommended Textbook

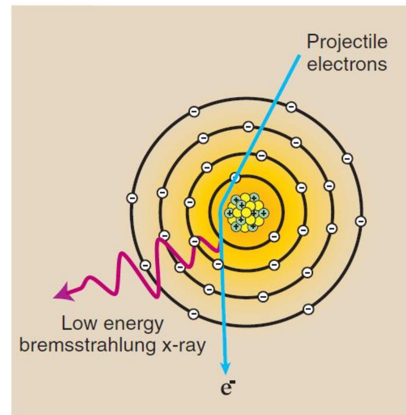
- Stewart C. Bushong, *Radiologic Science for Technologists: Physics, Biology, and Protection*, 10th ed., Mosby, 2012.

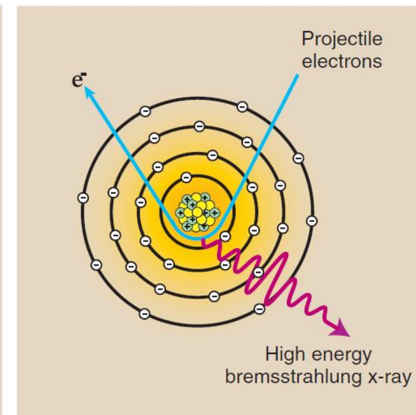
  (ISBN 978-0323081351)

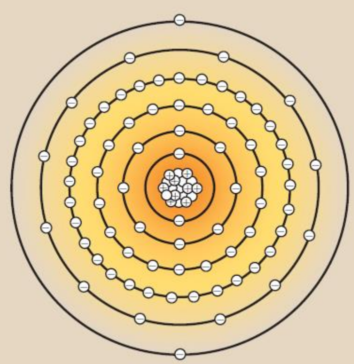


X-Ray Production



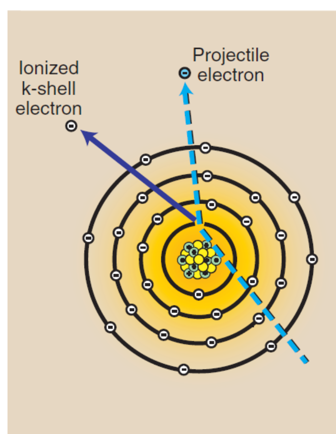


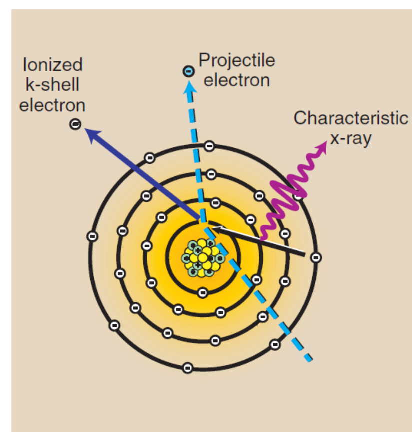


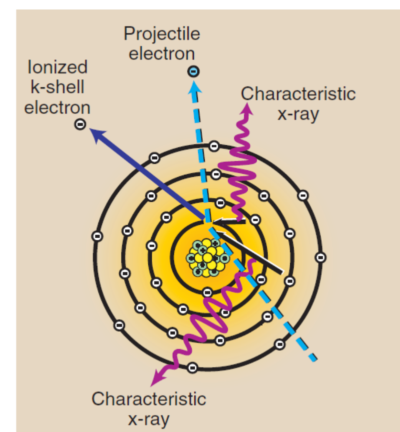


Shell	Number of electrons	Approx. binding energy (keV)
K	2	69
L	8	12
M	18	3
N	32	1
O	12	0.1
P	2	

Tungsten: $^{184}_{74}$W







X-Ray Production

- Bremsstrahlung x-rays are produced when a projectile electron is slowed by the nuclear field of a target atom nucleus
  - In the diagnostic range, most x-rays are bremsstrahlung x-rays
- Characteristic x-rays are emitted when an outer-shell electron fills an inner-shell void
  - This type of x-radiation is called characteristic because it is characteristic of the target element
  - Only the K-characteristic x-rays of tungsten are useful for imaging
- Approximately 99% of the kinetic energy of projectile electrons is converted to heat (Anode heat)

Quantity and Quality of X-ray Beam

- General shape of an emission spectrum is always the same, but its relative position along the energy axis can change
  - The farther to the right a spectrum is, the higher the effective energy or quality of the x-ray beam
  - The larger the area under the curve, the higher is the x-ray intensity or quantity

TABLE 7-2 Factors That Affect the Size and Relative Position of X-ray Emission Spectra

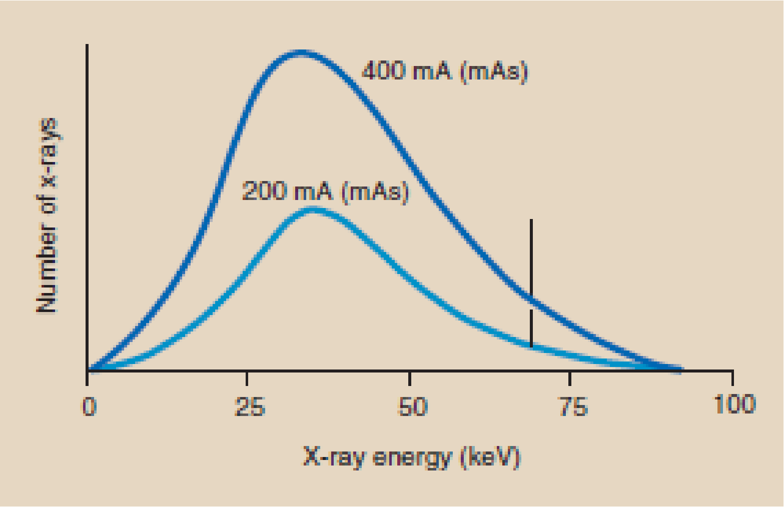
Factor	Effect
Tube current	Amplitude of spectrum
Tube voltage	Amplitude and position
Added filtration	Amplitude; most effective at low energy
Target material	Amplitude of spectrum and position of line spectrum
Voltage waveform	Amplitude; most effective at high energy

TABLE 7-3 Changes in X-ray Beam Quality and Quantity Produced by Factors That Influence the Emission Spectrum

An Increase in	Results in
Current (mAs)	An increase in quantity; no change in quality
Voltage (kVp)	An increase in quantity and quality
Added filtration	A decrease in quantity and an increase in quality
Target atomic number (Z)	An increase in quantity and quality
Voltage ripple	A decrease in quantity and quality

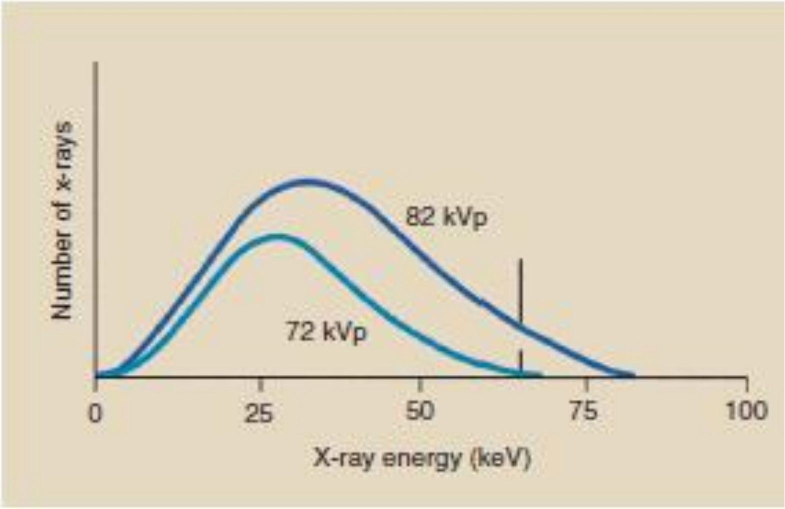
Effect of mA and mAs

- A change in mA or mAs results in a proportional change in the amplitude of the x-ray emission spectrum at all energies.



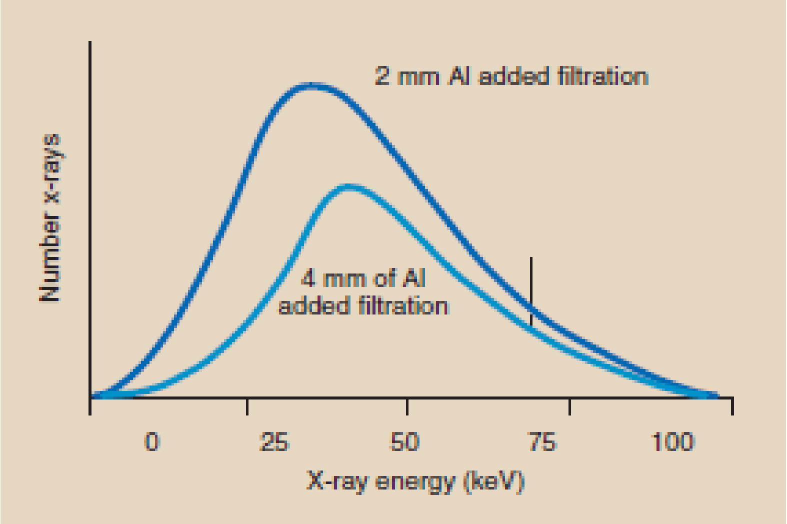
Effect of kVp

- As kVp is raised, area under curve increases by approximating the square of the factor by which kVp was increased
  - Accordingly, x-ray quantity increases with the square of this factor
- Change in kVp affects both amplitude and position of x-ray emission spectrum
  - In diagnostic range, 15% increase in kVp is equivalent to doubling mAs



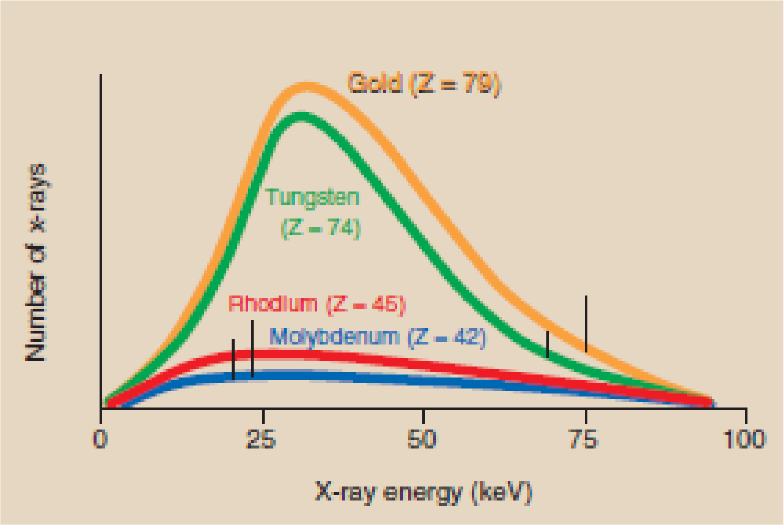
Effect of Added Filtration

- Adding filtration to the useful x-ray beam reduces x-ray beam intensity while increasing the average energy
  - The result of added filtration is an increase in the average energy of the x-ray beam with an accompanying reduction in x-ray quantity



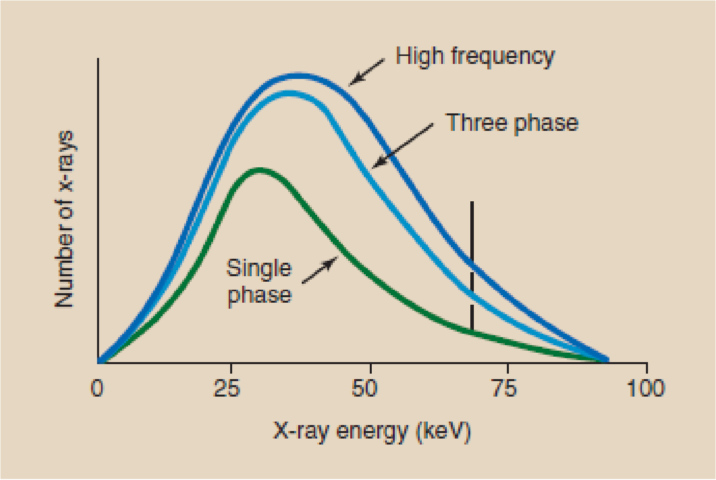
Effect of Target Material

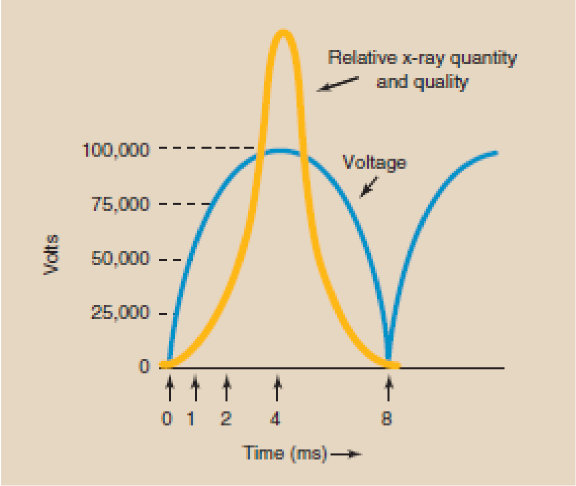
- The atomic number of the target affects both the number (quantity) and the effective energy (quality) of x-rays
  - As the atomic number of the target material increases, the efficiency of the production of bremsstrahlung radiation increases, and high-energy x-rays increase in number to a greater extent than low-energy x-rays.



Effect of Voltage Waveform

- There are five voltage waveforms: half-wave–rectified, full-wave–rectified, three-phase/six-pulse, three-phase/12-pulse, and high-frequency waveforms
- Both quantity and quality decrease by ripple
  - Because of reduced ripple, operation with three-phase power or high frequency is equivalent to an approximate 12% Increase in kVp, or almost a doubling of mAs over single phase power.





Factors Affecting X-Ray Quantity

TABLE 8-1 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

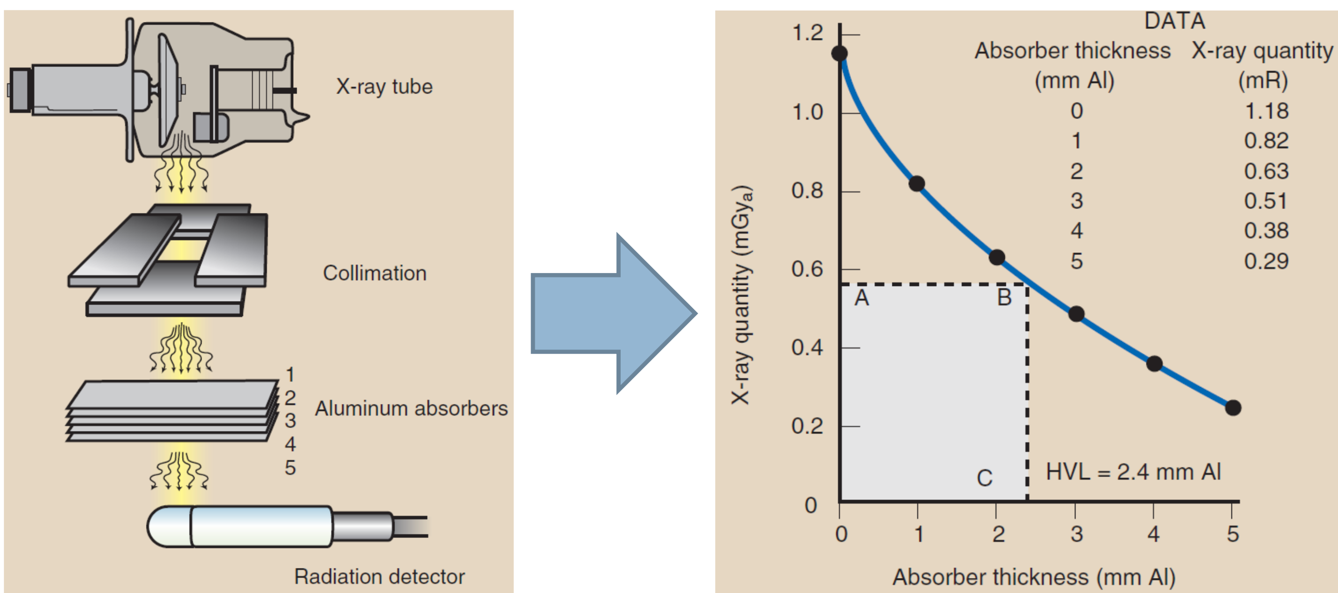
Factors Affecting X-Ray Quality

TABLE 8-2 Factors That Affect X-ray Quality and Quantity

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

Half-Value Layer (HVL)

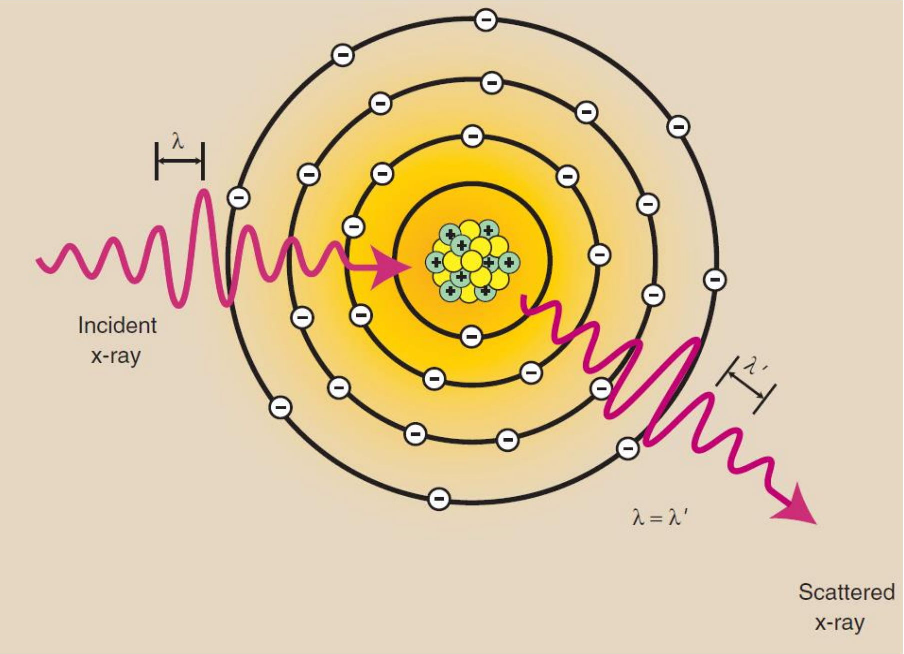
- In radiography, quality of x-rays is measured by the HVL
  - Diagnostic x-ray usually has HVL 3 to 5 mm Al or 3 to 6 cm of soft tissue
- Although x-rays are attenuated exponentially, high-energy x-rays are more penetrating than low-energy x-rays
  - 100-keV x-rays are attenuated at rate of 3%/cm of soft tissue
  - 10-keV x-rays are attenuated at 15%/cm of soft tissue

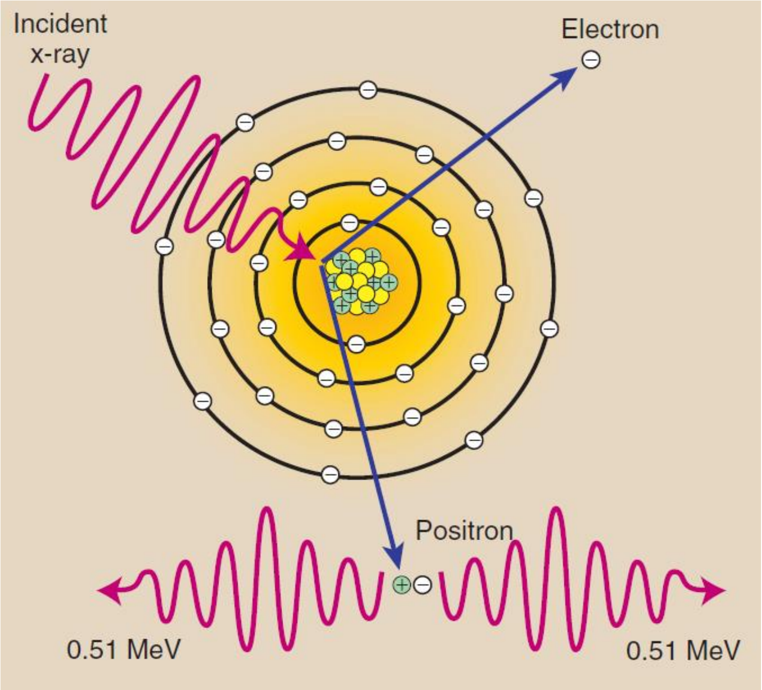


X-Ray Interaction with Matter

- Coherent scattering (energy < 10 keV)
- Compton scattering
- Photoelectric effect
- Pair production (energy > 1.02 MeV)

Important in making an x-ray image (Compton scattering, Photoelectric effect)





Compton (Incoherent) Scattering

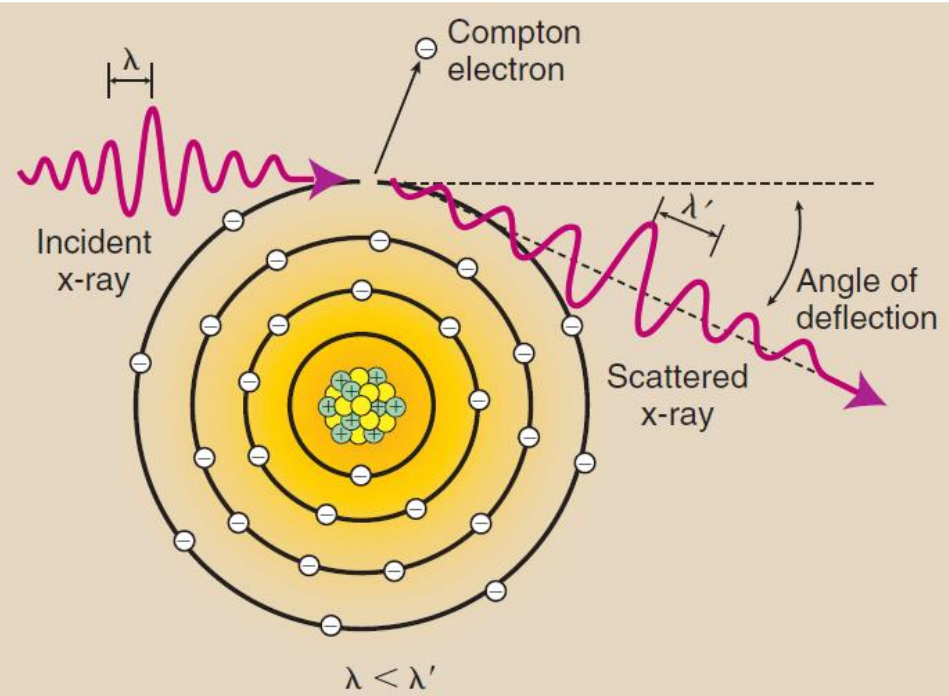
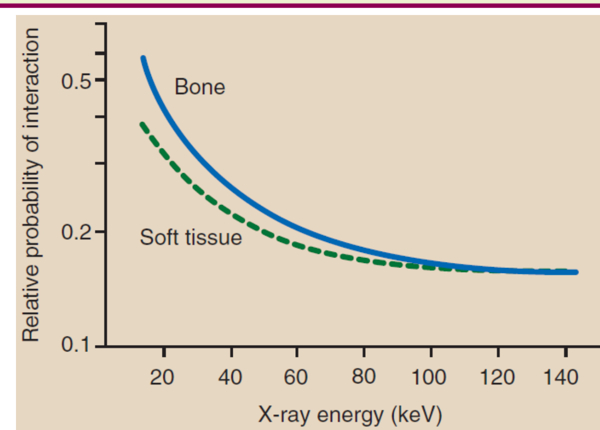


TABLE 9-1	Features of Compton Scattering
Most Likely to Occur	**With Outer-Shell Electrons**
	With loosely bound electrons
As x-ray energy increases	Increased penetration through tissue without interaction
	Increased Compton scattering relative to photoelectric effect
	Reduced Compton scattering (≈1/E)
As atomic number of absorber increases	No effect on Compton scattering
As mass density of absorber increases	Proportional increase in Compton scattering

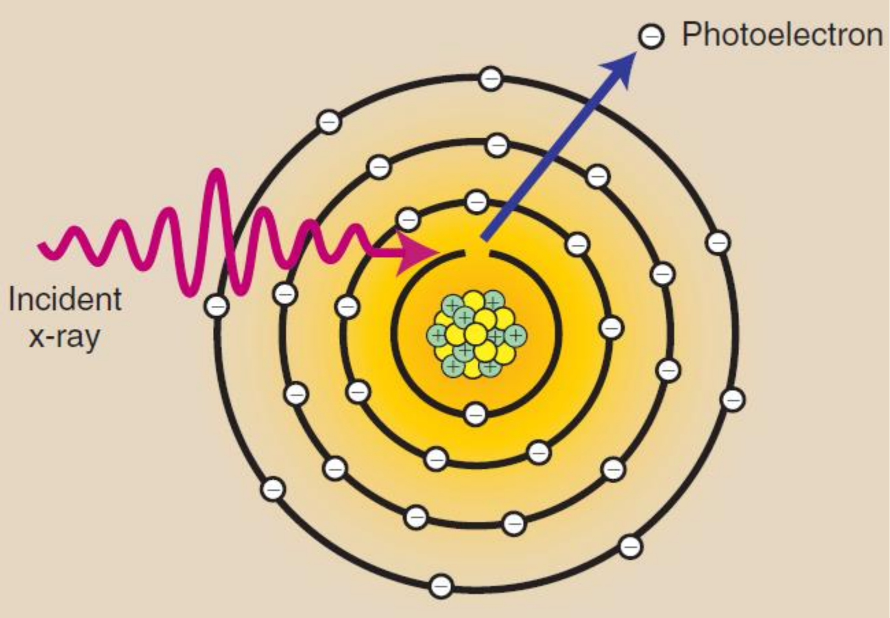
Compton Effect

$E_i = E_s\ (E_b + E_{KE})$

where E_i is energy of the incident x-ray, E_s is energy of the scattered x-ray, E_b is electron binding energy, and E_{KE} is kinetic energy of the electron.



Photoelectric Effect



The photoelectric effect is total x-ray absorption.

Photoelectric Effect

$E_i = E_b + E_{KE}$

where E_i is the energy of the incident x-ray, E_b is the electron-binding energy, and E_{KE} is the kinetic energy of the electron.

TABLE 9-4 Features of Photoelectric Effect

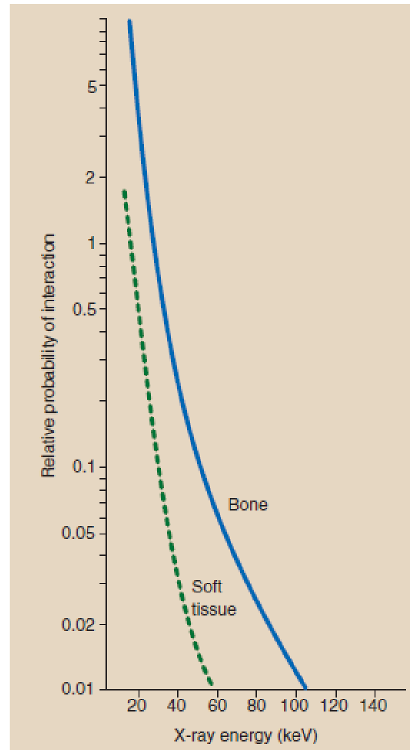
Most likely to occur	With inner-shell electrons
	With tightly bound electrons
	When x-ray energy is just higher than electron binding energy
As x-ray energy increases	Increased penetration through tissue without interaction
	Less photoelectric effect relative to Compton scattering
	Reduced absolute photoelectric effect $(\approx 1/E)^3$
As atomic number of absorber increases	Increases proportionately with the cube of the atomic number (Z^3)
As mass density of absorber increases	Proportional increase in photoelectric absorption

Photoelectric Effect

TABLE 9-3 Effective Atomic Number of Materials Important to Radiologic Science

Type of Substance	Effective Atomic Number
HUMAN TISSUE	
Fat	6.3
Soft tissue	7.4
Lung	7.4
Bone	13.8
CONTRAST MATERIAL	
Air	7.6
Iodine	53
Barium	56
OTHER	
Concrete	17
Molybdenum	42
Tungsten	74
Lead	82

$$Z^3$$



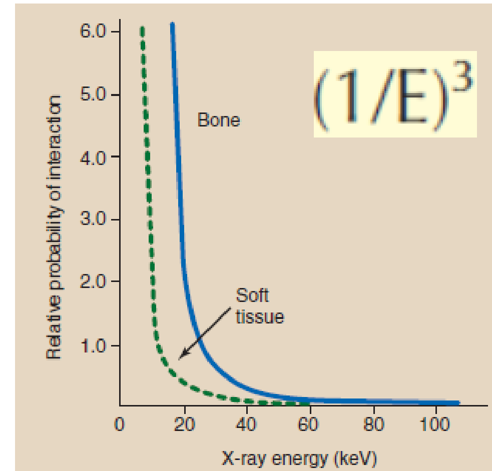


TABLE 9-2 Atomic Number and K-Shell Electron Binding Energy of Radiologically Important Elements

Element	Atomic Number	K-Shell Electron Binding Energy (keV)
Hydrogen	1	0.02
Carbon	6	0.3
Nitrogen	7	0.4
Oxygen	8	0.5
Aluminum	13	1.6
Calcium	20	4.1
Molybdenum	42	19
Rhodium	45	23
Iodine	53	33
Barium	56	37
Tungsten	74	69
Rhenium	75	72
Lead	82	88

Differential Absorption

TABLE 9-6 Characteristics of Differential Absorption

As X-ray Energy Increases	Fewer Compton Interactions
	Many fewer photoelectric interactions
	More transmission through tissue
As tissue atomic number increases	No change in Compton interactions
	Many more photoelectric interactions
	Less x-ray transmission
As tissue mass density increases	Proportional increase in Compton interactions
	Proportional increase in photoelectric interactions
	Proportional reduction in x-ray transmission

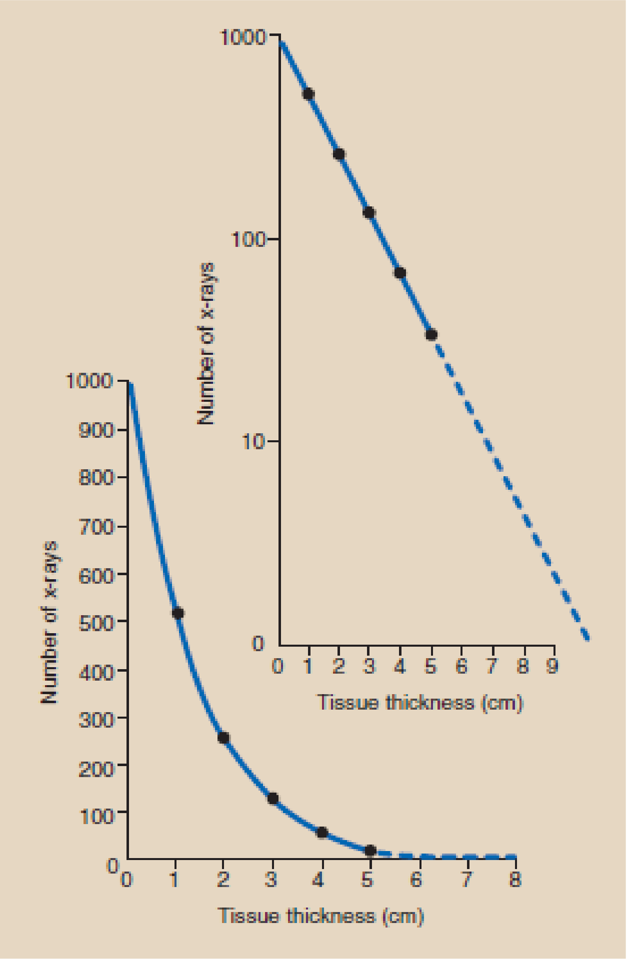
TABLE 9-5 Mass Density of Materials Important to Radiologic Science

Substance	Mass Density (kg/m^3)
HUMAN TISSUE	
Lung	320
Fat	910
Soft tissue, muscle	1000
Bone	1850
CONTRAST MATERIAL	
Air	1.3
Barium	3500
Iodine	4930
OTHER	
Calcium	1550
Concrete	2350
Molybdenum	10,200
Lead	11,350
Rhenium	12,500
Tungstate	19,300

X-Ray Exponential Attenuation

- The total reduction in the number of x-rays remaining in an x-ray beam after penetration through a given thickness of tissue is called *attenuation*
  - When broad beam of x-rays is incident on any tissue, some x-rays are absorbed, and some are scattered
  - The result is a reduced number of x-rays, a condition referred to as x-ray attenuation

Attenuation is the product of absorption and scattering.



Radiologic Units

- Air Kerma (Kinetic Energy Released in Matter) (Gy_a)
  - Kinetic energy transferred from photons to electrons during ionization and excitation measured in J/kg where 1 J/kg = 1 gray (Gy_a)
- Absorbed Dose (Gy_t)
  - Radiation energy absorbed in tissue per unit mass with units of J/kg or Gy_t (gray) which depends on tissue type
- Sievert (Sv): quantity of radiation received by radiation workers and populations
- *Becquerel (Bq):* quantity of radioactive material, not the radiation emitted by that material
  - Radioactivity and the becquerel have nothing to do with x-rays

Radiologic Units

TABLE 1-5 Special Quantities of Radiologic Science and Their Associated Special Units

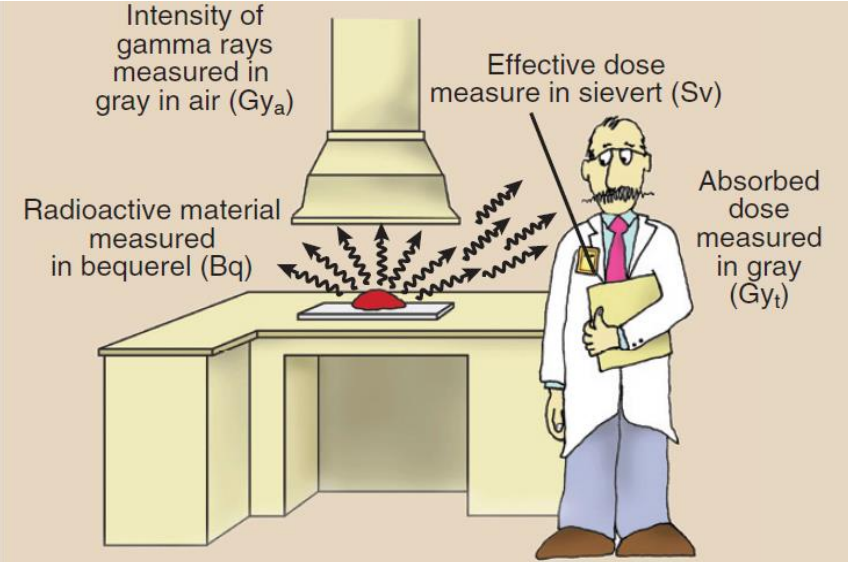
	CUSTOMARY UNIT			INTERNATIONAL SYSTEM OF UNITS (SI)	
Quantity	**Name**		**Symbol**	**Name**	**Symbol**
Exposure	roentgen		R	air kerma	Gy_a
Absorbed dose	rad		rad	gray	Gy_t
Effective dose	rem		rem	sievert	Sv
Radioactivity	curie		Ci	becquerel	Bq
Multiply	R	by	0.01	to obtain	Gy_a
Multiply	rad	by	0.01	to obtain	Gy_t
Multiply	rem	by	0.01	to obtain	Sv
Multiply	Ci	by	3.7×10^{10}	to obtain	Bq

Air kerma (Gy_a) is the unit of radiation exposure or intensity.

The gray (Gy_t) is the unit of **r**adiation **a**bsorbed **d**ose.

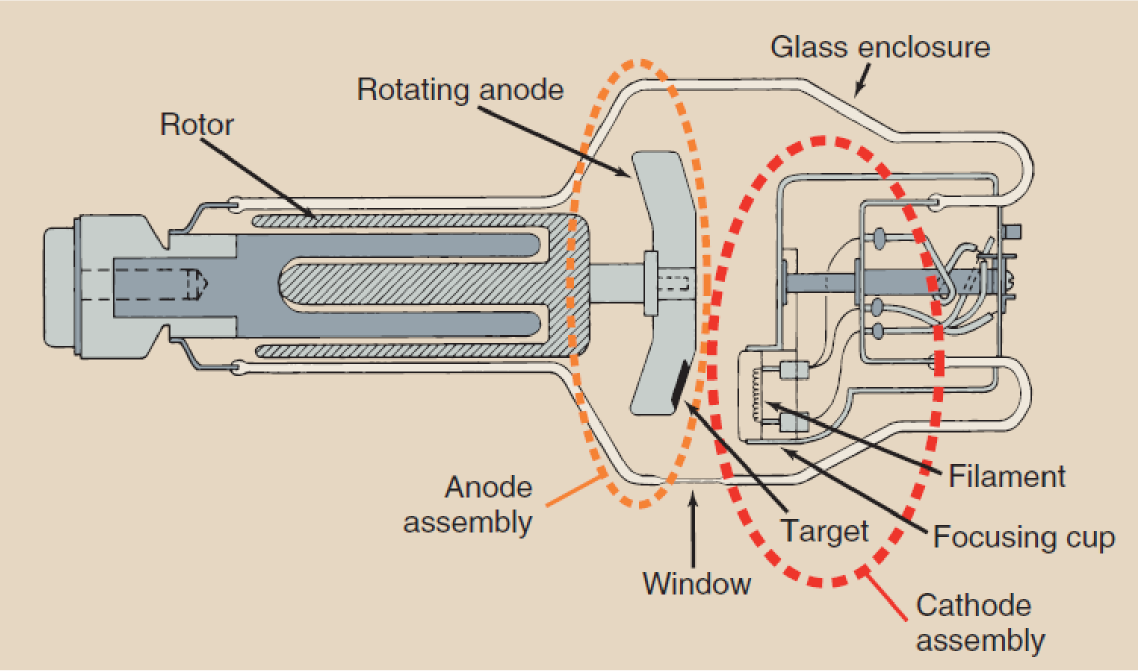
The sievert (Sv) is the unit of occupational radiation exposure and effective dose.

The becquerel (Bq) is the unit of radioactivity.



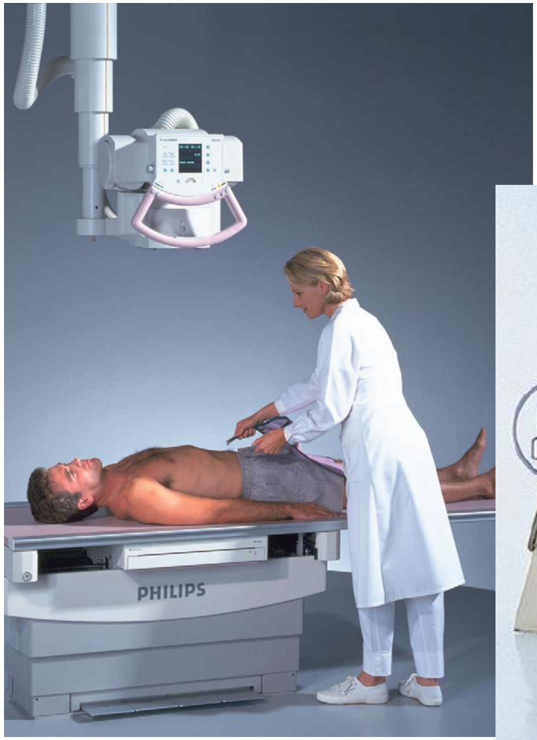
X-Ray Tube

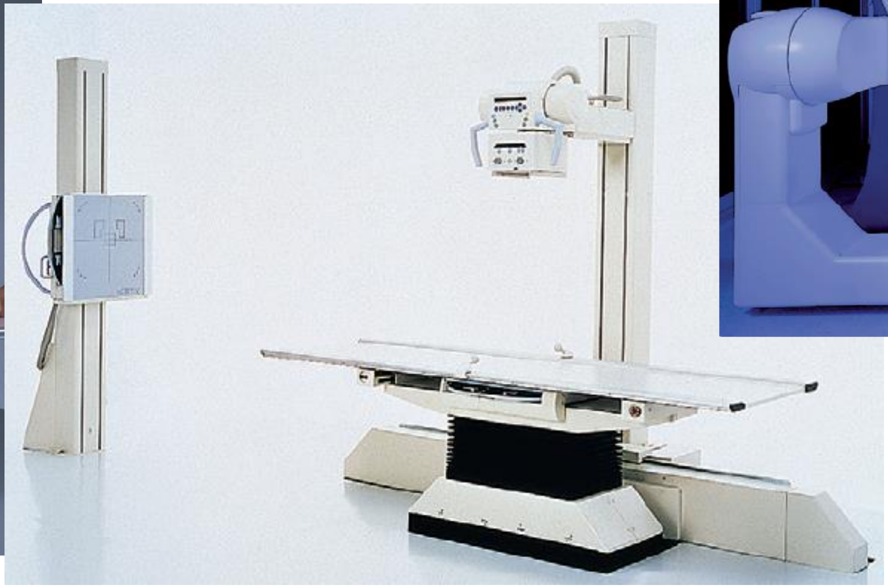
- External structures
  - Support structure
  - Protective housing
  - Glass or metal enclosure. The internal
- Internal structures
  - Anode and cathode

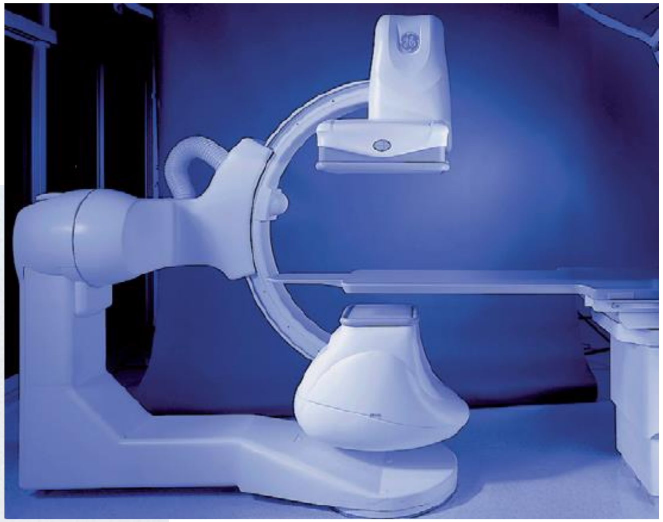


X-Ray Tube Support Structure

- X-ray tube and housing assembly are quite heavy
  - Require support mechanism so radiologic technologist can position them
  - Mainly ceiling, floor or C-arm support systems

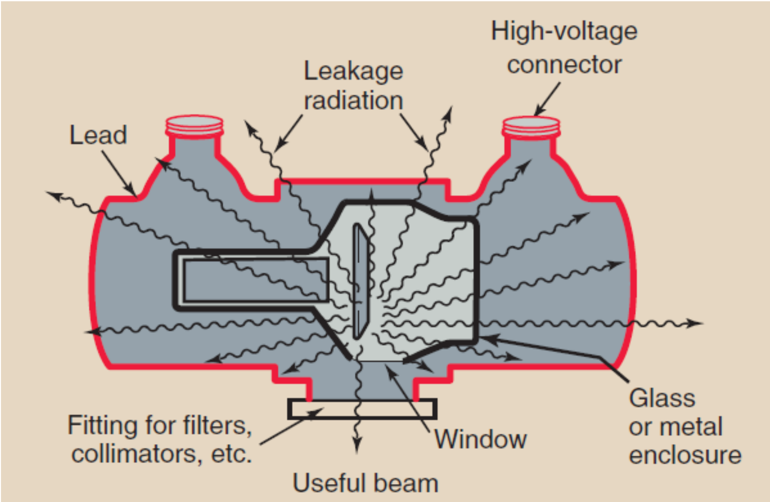






Protective Housing

- When x-rays are produced, they are emitted isotropically
  - That is, with equal intensity in all directions
- Only x-rays emitted through window are called useful beam
  - X-rays that escape through protective housing: *leakage radiation*
  - Leakage radiation contributes nothing to diagnostic information and result in unnecessary exposure of patient and radiologic technologist
- Protective housing guards against excessive radiation exposure and electric shock
  - Also mechanically protects x-ray tube

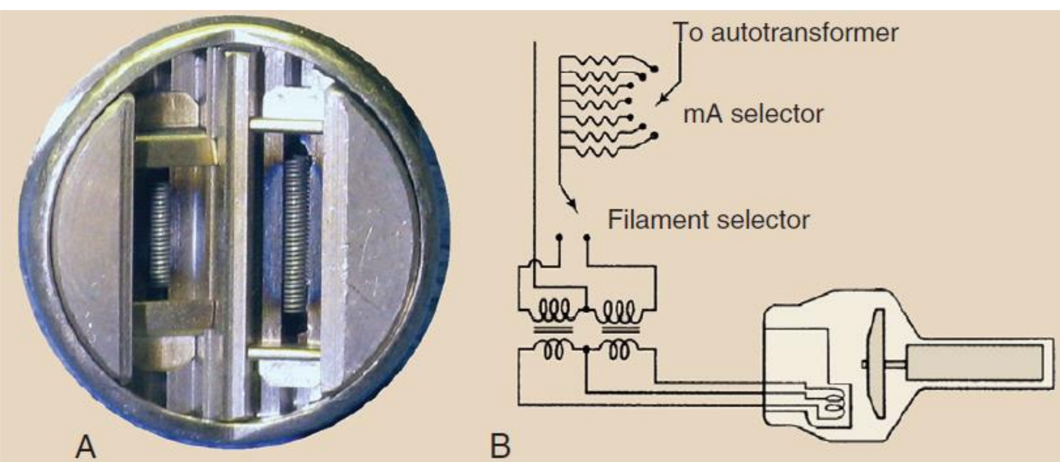


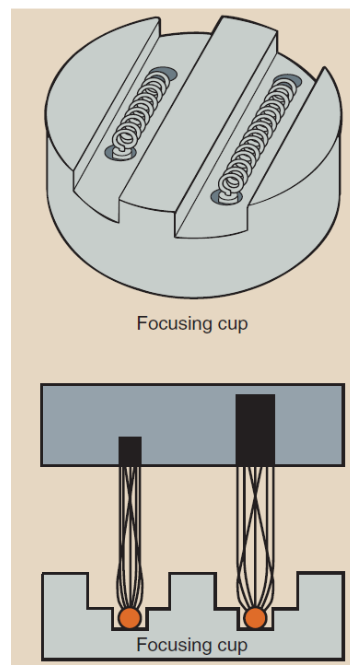
Metal or Glass Enclosure

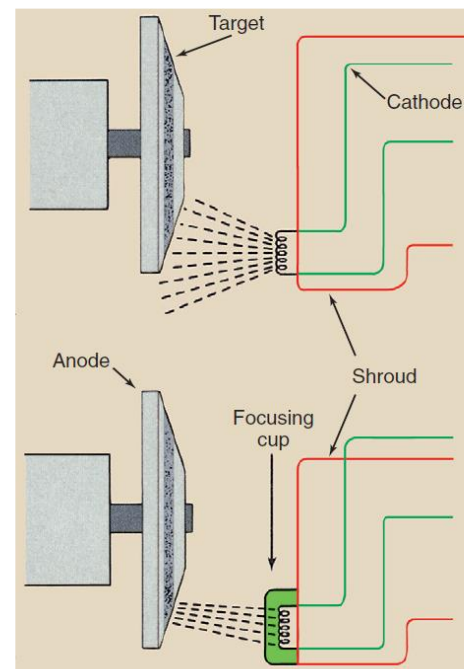
- X-ray tube is an electronic vacuum tube with components contained within a glass or metal enclosure
  - vacuum allows for more efficient x-ray production and longer tube life
- As glass enclosure tube ages, some tungsten vaporizes and coats the inside of glass enclosure
  - Alter electrical properties of the tube, allowing tube current to stray and interact with the glass enclosure resulting in arcing and tube failure
  - Most common cause of tube failure
- Metal enclosures maintain constant electric potential between electrons of tube current and enclosure
  - Longer life and less likely to fail
  - Virtually all high-capacity x-ray tubes now use metal enclosures

Cathode

- Cathode is the negative side of the x-ray tube
- It has two primary parts, a filament and a focusing cup
  - Dual-filament cathode allows two focal spots (e.g., 0.5 and 1.5 mm)
  - Focusing cup is a metal shroud that surrounds filament
  - Tube current is adjusted by controlling filament current





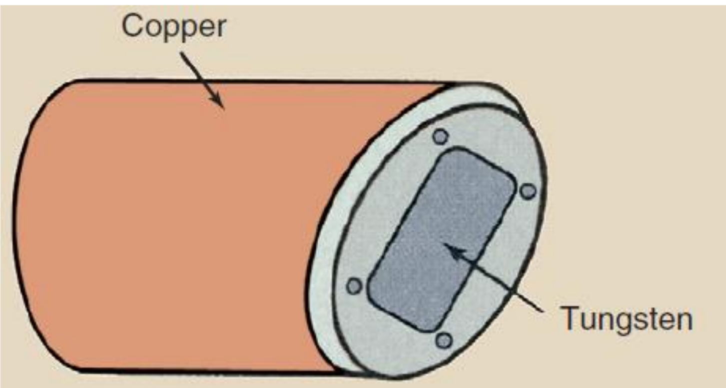


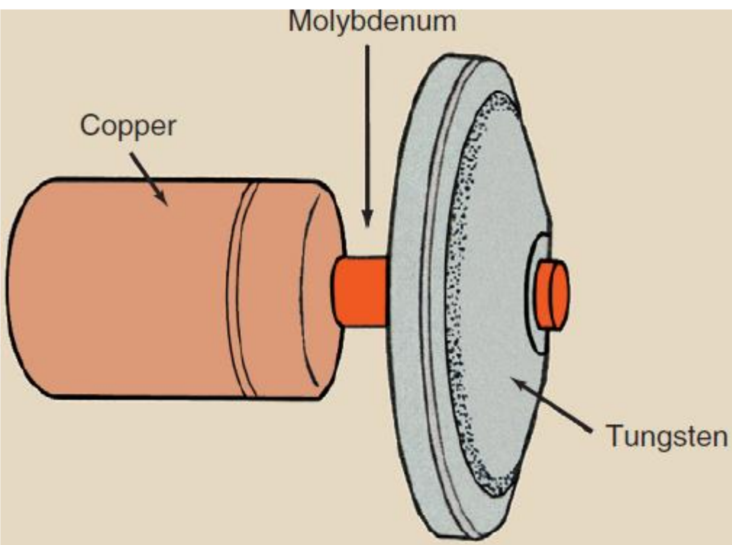
Anode

- Anode is the positive side of the x-ray tube
- Two types: stationary (dental) and rotating (general purpose)
  - Higher tube currents and shorter exposure times are possible with rotating anode because of their better heat dissipation
- Three functions in an x-ray tube:
  - Electrical conductor that receives electrons emitted by cathode and conducts them through the tube to the connecting cables and back to the high-voltage generator
  - Mechanical support for the target
  - Thermal dissipation

Target

- The target is area of anode struck by electrons from cathode



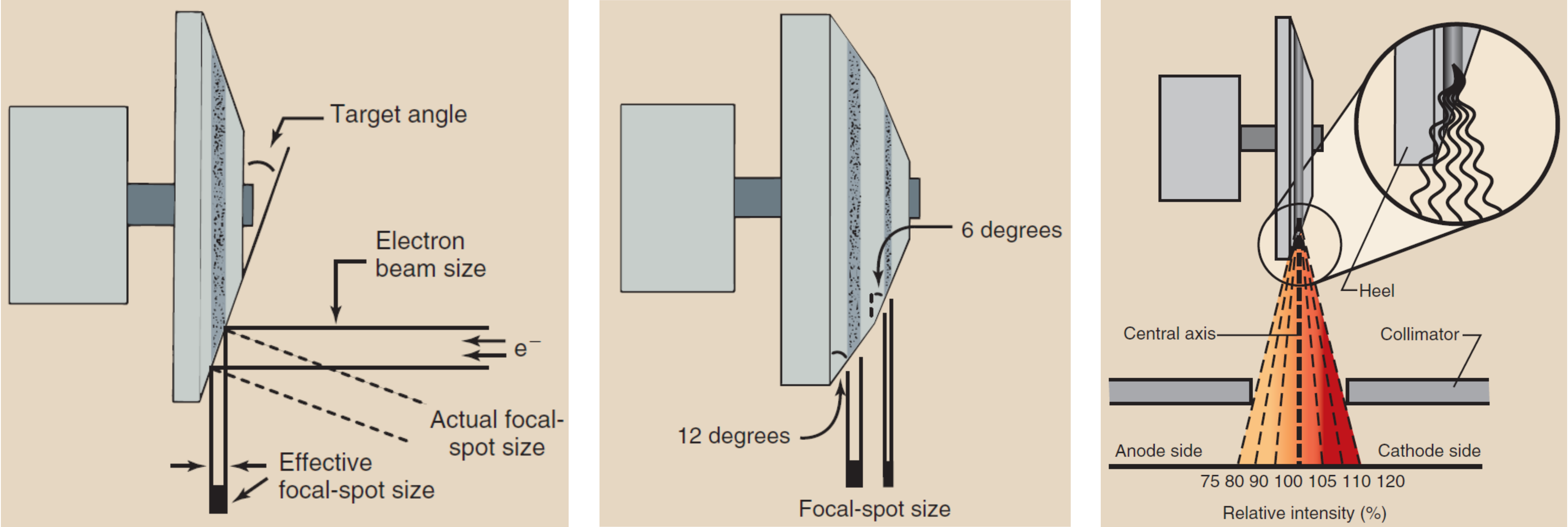


Tungsten is the material of choice for the target for general radiography for three main reasons:

1. **Atomic number**—Tungsten's high atomic number, 74, results in high-efficiency x-ray production and in high-energy x-rays. The reason for this is discussed more fully in Chapter 9.
2. **Thermal conductivity**—Tungsten has a thermal conductivity nearly equal to that of copper. It is therefore an efficient metal for dissipating the heat produced.
3. **High melting point**—Any material, if heated sufficiently, will melt and become liquid. Tungsten has a high melting point (3400°C compared with 1100°C for copper) and therefore can stand up under high tube current without pitting or bubbling.

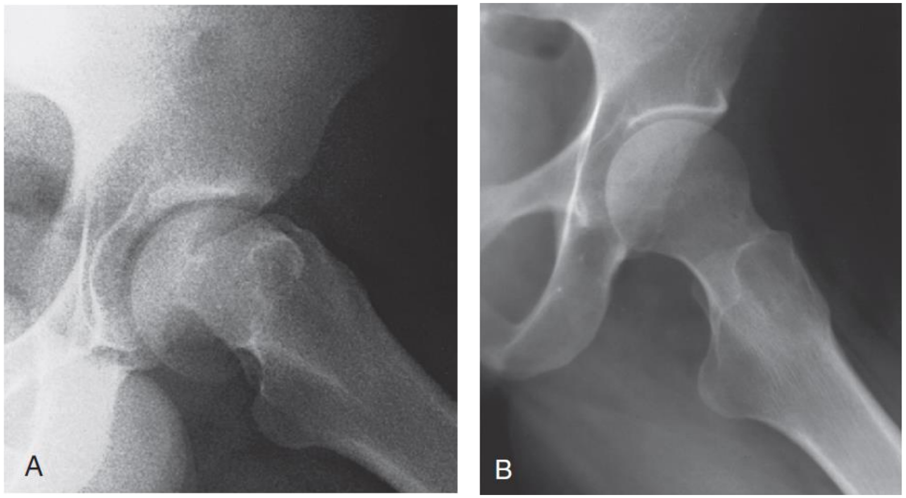
Focal Spot

- Focal spot is the area of target from which x-rays are emitted
  - The smaller the focal spot, the better the spatial resolution of the image
  - Unfortunately, as the size of focal spot decreases, heating of target is concentrated onto a smaller area (limiting factor to focal spot size
- Line-focus principle: angling target makes effective area of the target much smaller than actual area of electron interaction



Radiographic Image Quality

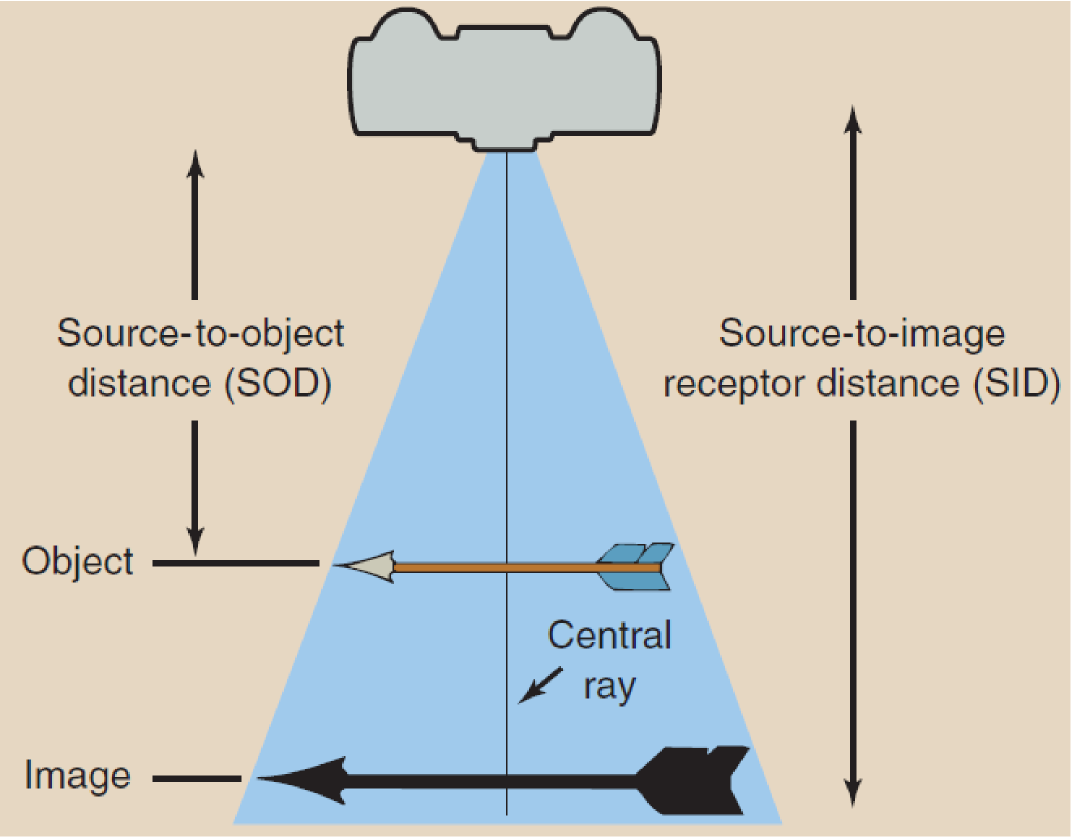
- Definition: fidelity with which anatomical structure being examined is rendered on radiograph
  - Spatial resolution: ability to image small objects
  - Contrast resolution: ability to distinguish anatomical structures
  - Radiographic noise: random fluctuation in intensity of image
    - Film graininess, structure mottle, quantum mottle, and scatter radiation



Radiographic Quality Rules

1. Fast image receptors have high noise and low spatial resolution and low contrast resolution.
2. High spatial resolution and high contrast resolution require low noise and slow image receptors.
3. Low noise accompanies slow image receptors with high spatial resolution and high contrast resolution.

Geometric Factors: Magnification



Magnification Factor

$$MF = \frac{\text{Image size}}{\text{Object size}} = \frac{SID}{SOD}$$

$$\text{Object size} = \text{Image size}\left(\frac{SOD}{SID}\right)$$

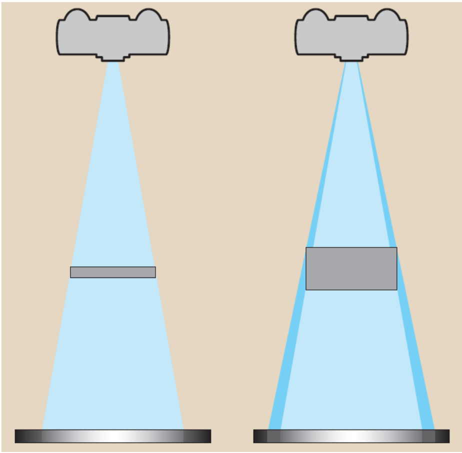
Minimizing Magnification

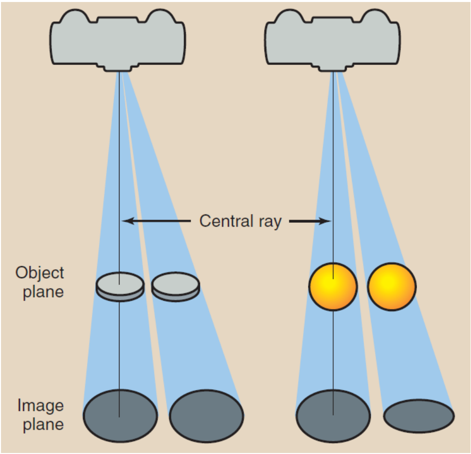
Large SID: Use as large a source-to-image receptor distance as possible.

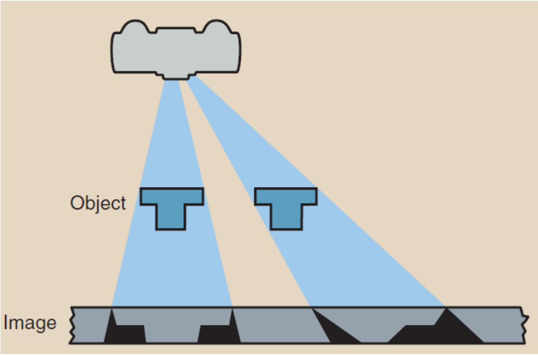
Small OID: Place the object as close to the image receptor as possible.

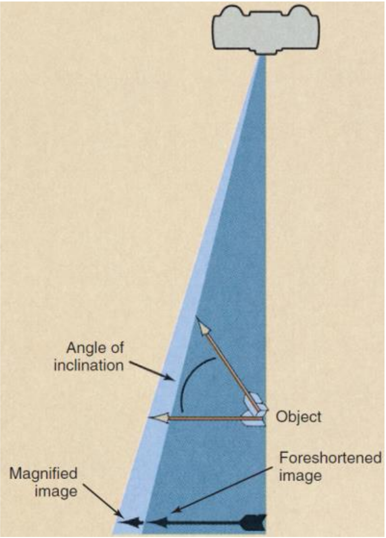
Geometric Factors: Distortion

- Unequal magnification of different portions of the same object is called shape distortion
  - Distortion depends on object thickness, position, and shape
  - Thick objects are more distorted than thin objects
  - If object plane and image plane are not parallel, distortion occurs



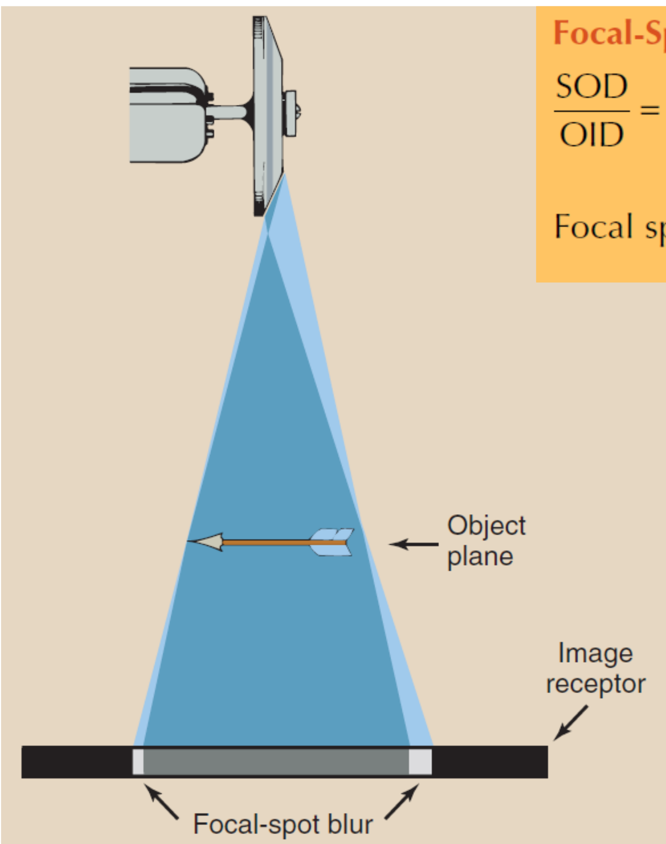






Geometric Factors: Focal-Spot Blur

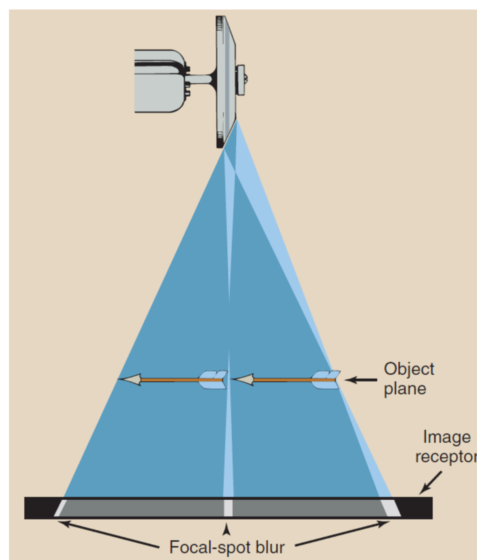
- Focal-spot blur is caused by effective size of focal spot
  - The most important factor for determining spatial resolution
  - Smaller on anode side than cathode side of the image (Heel effect)

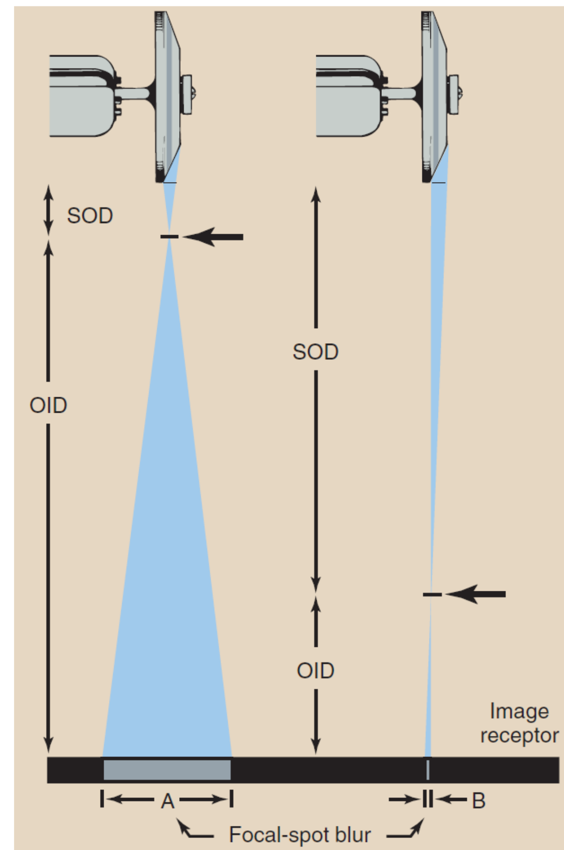


Focal-Spot Blur

$$\frac{SOD}{OID} = \frac{\text{Effective focal spot}}{\text{Focal spot blur}}$$

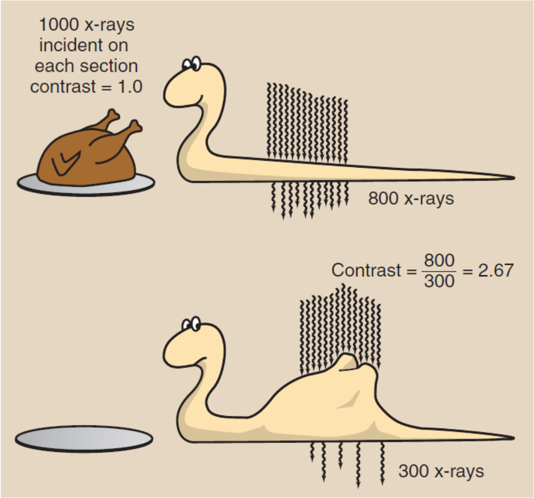
$$\text{Focal spot blur} = \frac{(\text{Effective focal spot})OID}{SOD}$$

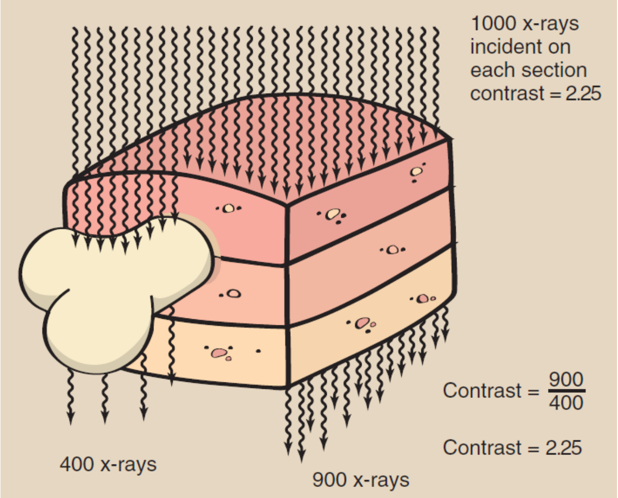


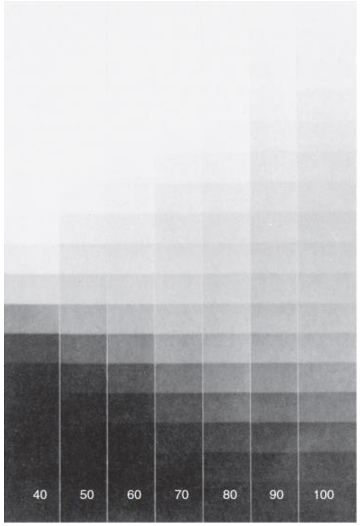


Subject Factors

- kVp is the most important influence on subject contrast







BOX 10-2 Subject Factors

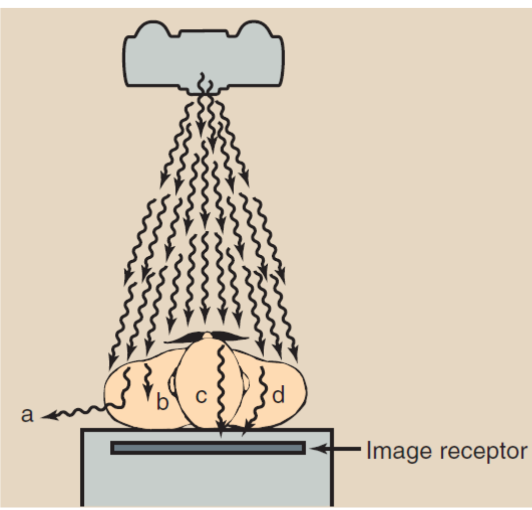
- Subject contrast
- Patient thickness
- Tissue mass density
- Effective atomic number
- Object shape
- Kilovolt peak

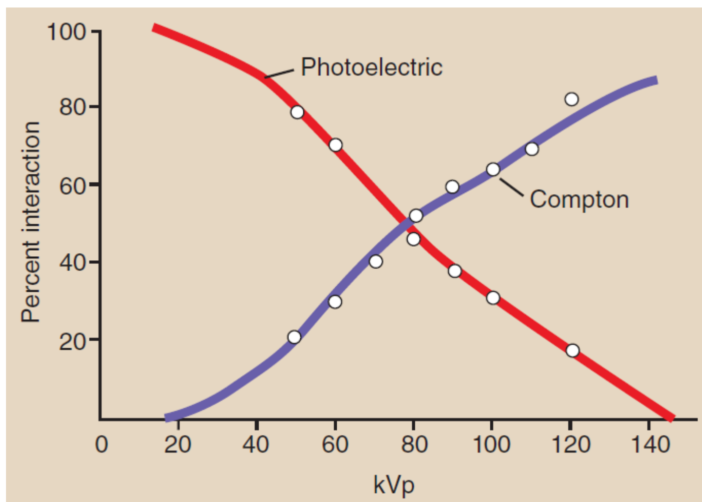
BOX 10-3 Procedures for Reducing Motion Blur

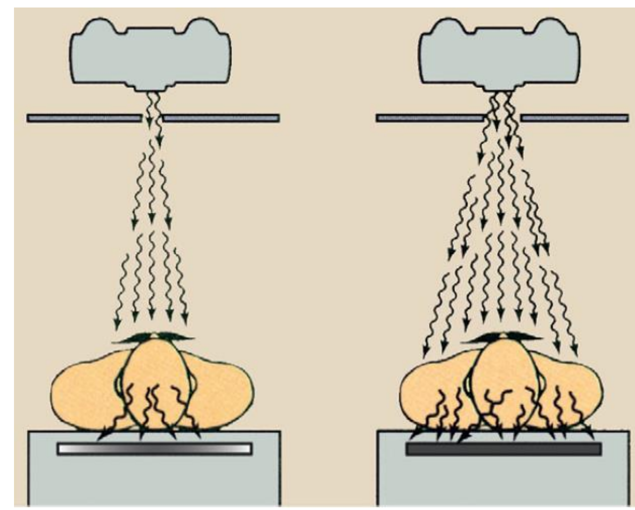
- Use the shortest possible exposure time.
- Restrict patient motion by providing instruction or using a restraining device.
- Use a large source-to-image receptor distance (SID).
- Use a small object-to-image receptor distance (OID).

Control of Scatter Radiation

- Reduced image contrast results from scattered x-rays
  - Restricting x-ray beam (collimation) reduces scattering

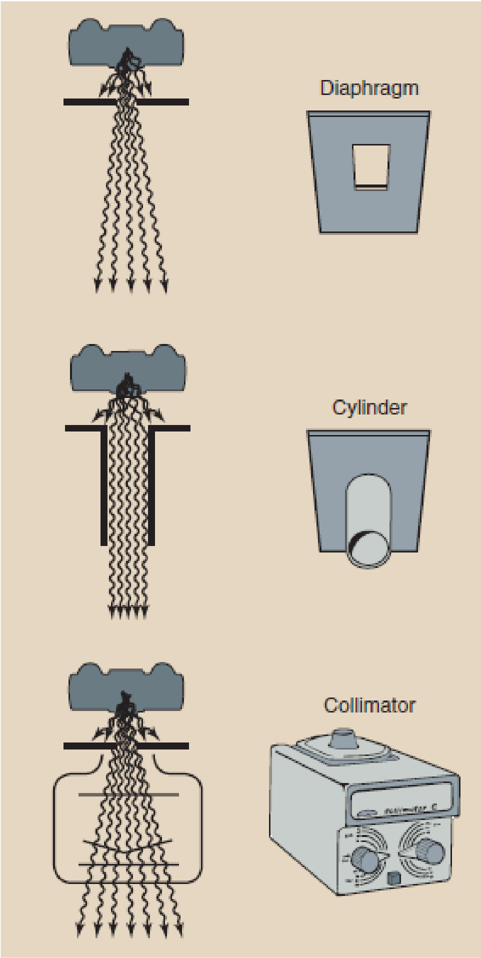


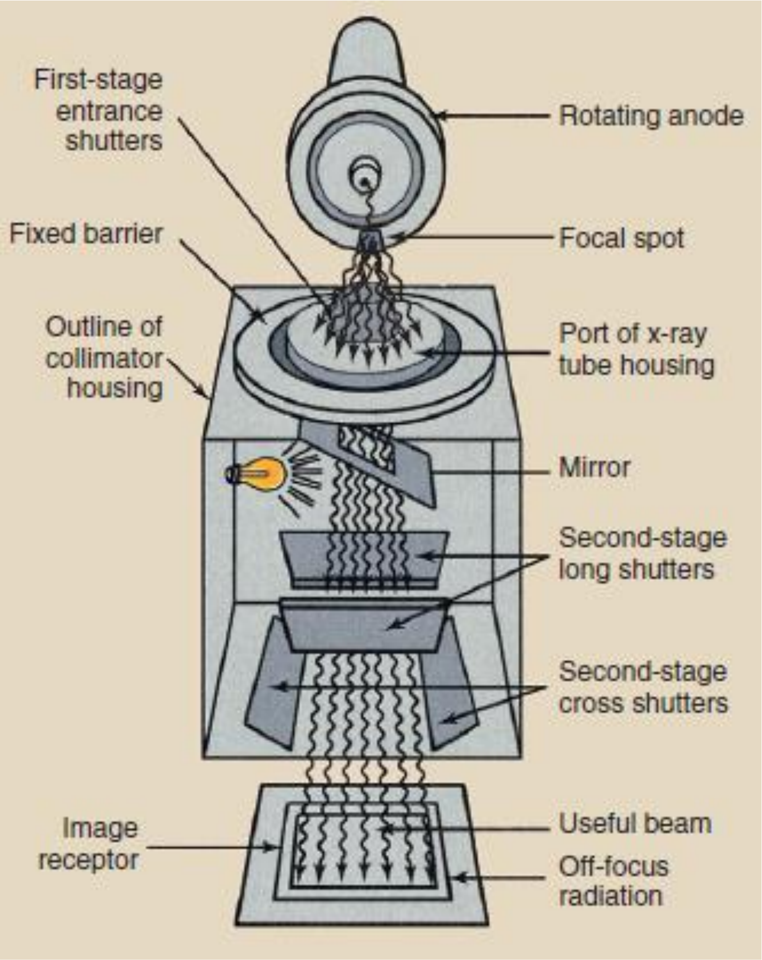




Beam Restricting Devices

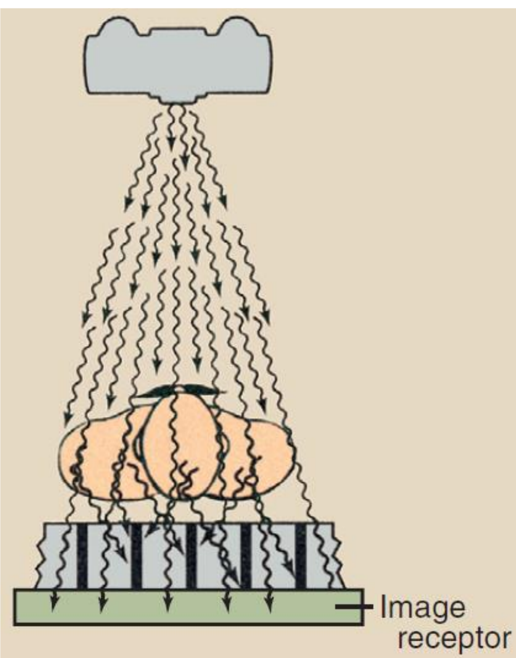
- Collimation reduces patient radiation dose and improves contrast resolution

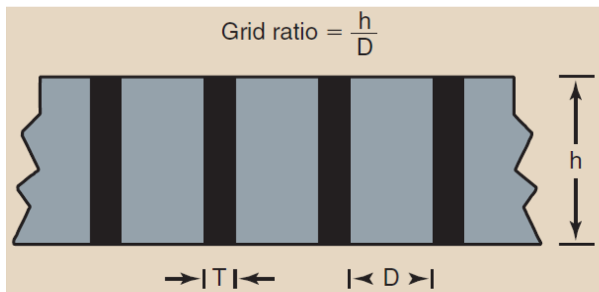


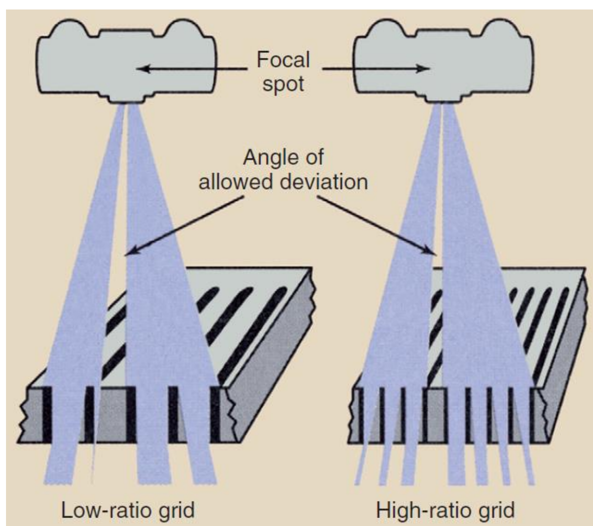


Radiographic Grids

- Effective device for reducing level of scatter radiation that reaches image receptor
  - The principal function of a grid is to improve image contrast







Grid Surface X-ray Absorption

$$\%\text{ x-ray absorption} = \frac{\text{width of grid strip}}{\text{width of grid strip} + \text{width of grid interspace}} \times 100$$

Grid Frequency

$$\text{Grid frequency} = \frac{10{,}000\ \mu\text{m/cm}}{(T + D)\mu\text{m/line pair}}$$

Contrast Improvement Factor

$$k = \frac{\text{image contrast with grid}}{\text{image contrast without grid}}$$

Radiographic Grids

- High-ratio and high-frequency grids increase patient radiation dose
- When grid is used, radiographic technique must be increased to produce same image receptor signal by a factor called Bucky (Grid) factor (B)
  - As Bucky factor increases, radiographic technique and patient dose increases
  - The higher the grid ratio, the higher is the Bucky factor
  - The Bucky factor increases with increasing kVp

Bucky Factor

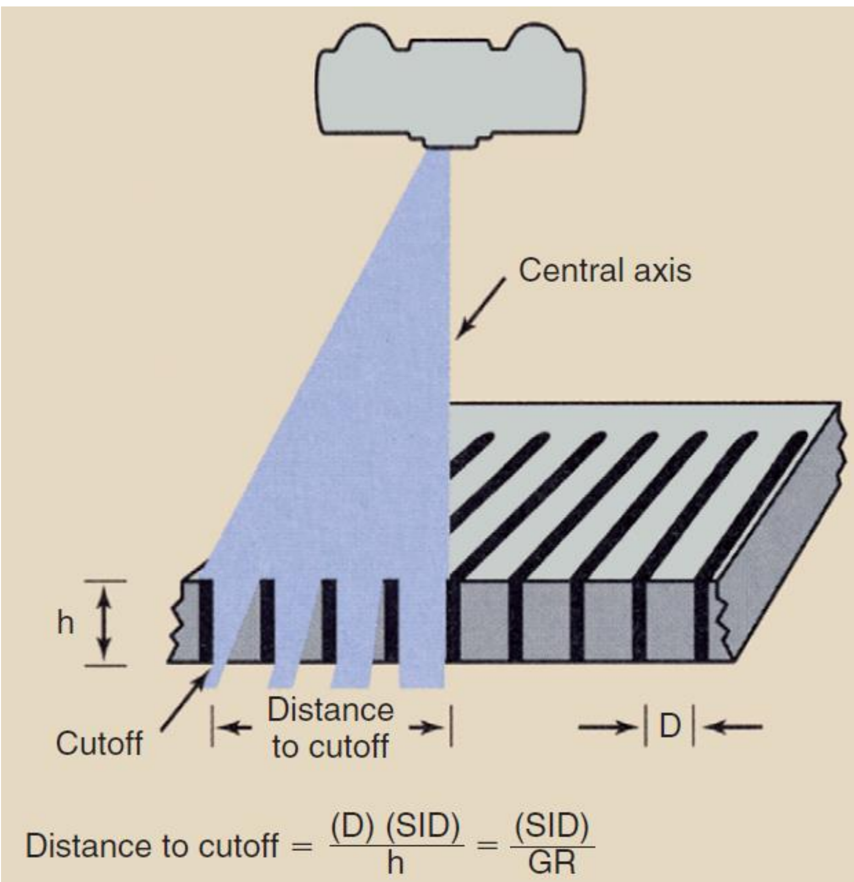
$$B = \frac{\text{Incident remnant x-rays}}{\text{Transmitted image–forming x-rays}} = \frac{\text{Patient dose with grid}}{\text{Patient dose without grid}}$$

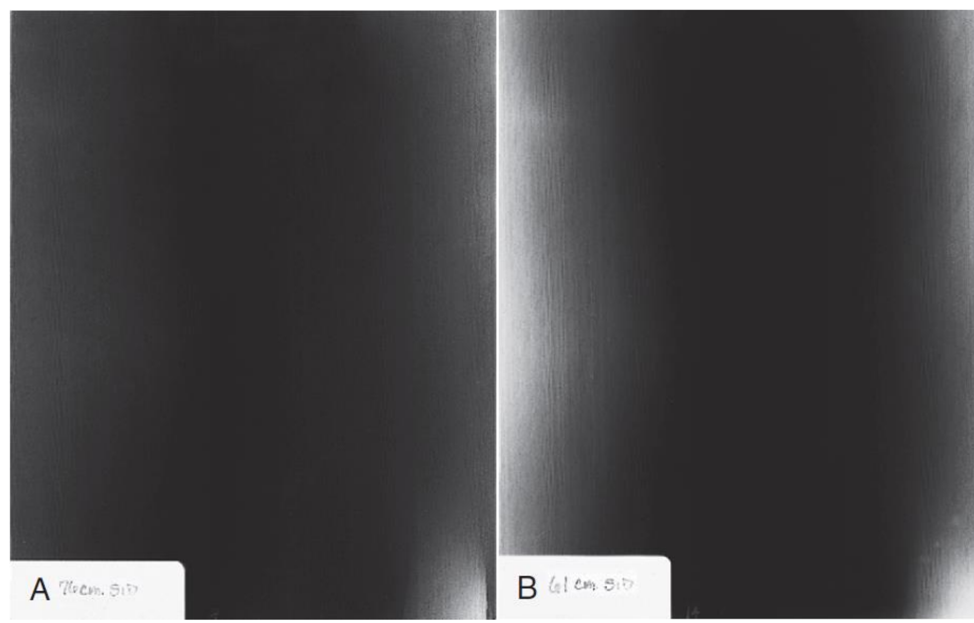
TABLE 11-2 Approximate Bucky Factor Values for Popular Grids

Grid Ratio	BUCKY FACTOR AT 70 kVp	90 kVp	120 kVp	Average
No grid	1	1	1	1
5:1	2	2.5	3	2
8:1	3	3.5	4	4
12:1	3.5	4	5	5
16:1	4	5	6	6

Radiographic Grids

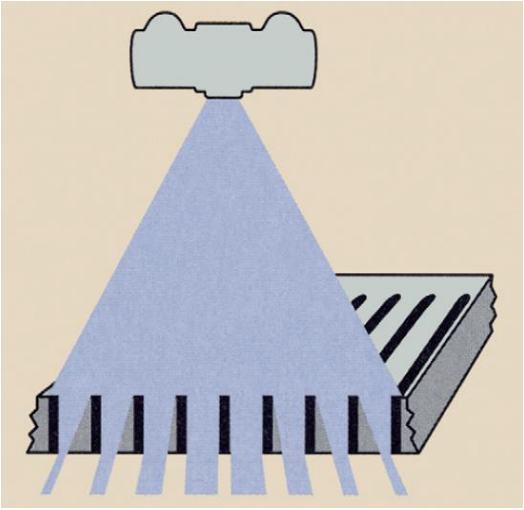
- Grid Cutoff: undesirable absorption of primary x-rays by grid
  - Greater Attenuation of primary x-rays near edges of image receptor

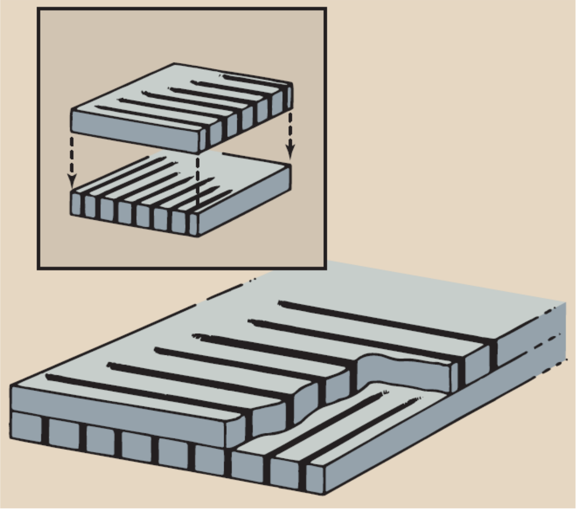


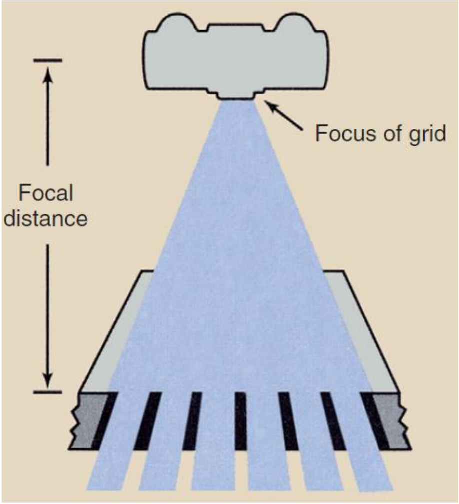


Radiographic Grids Types

- Parallel, Crossed and Focused
- Moving Grid (Bucky): reciprocating and oscillating
  - (-) Require a bulky mechanism that is subject to failure
  - (-) Distance between patient and the image receptor is increased
  - (-) Moving grids can introduce motion into cassette-holding device
  - Advantages of moving grids far outweigh disadvantages

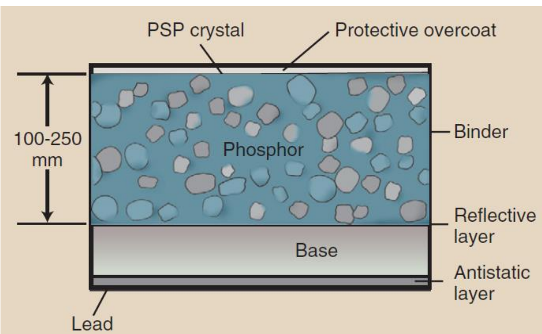


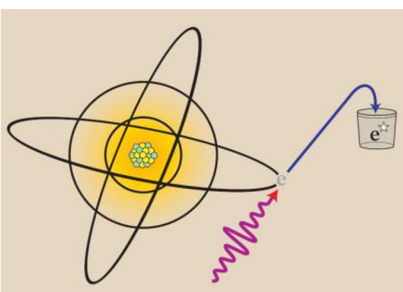


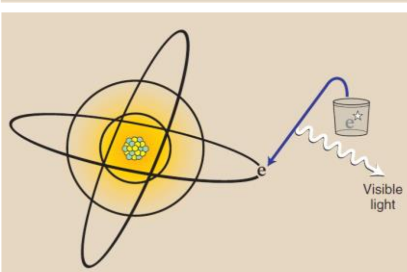


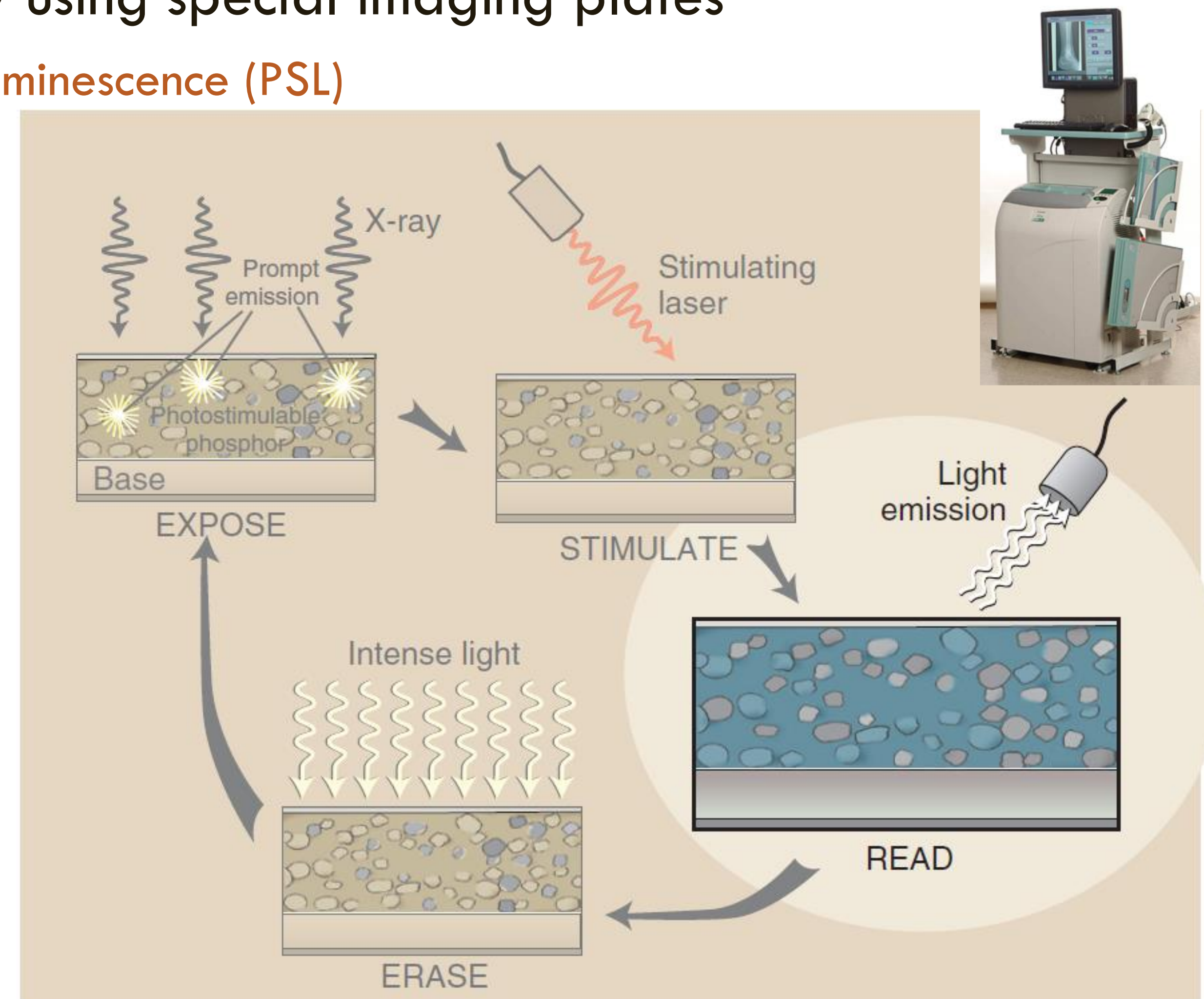
Computed Radiography (CR)

- Filmless radiology using special imaging plates
  - Photostimulable luminescence (PSL)





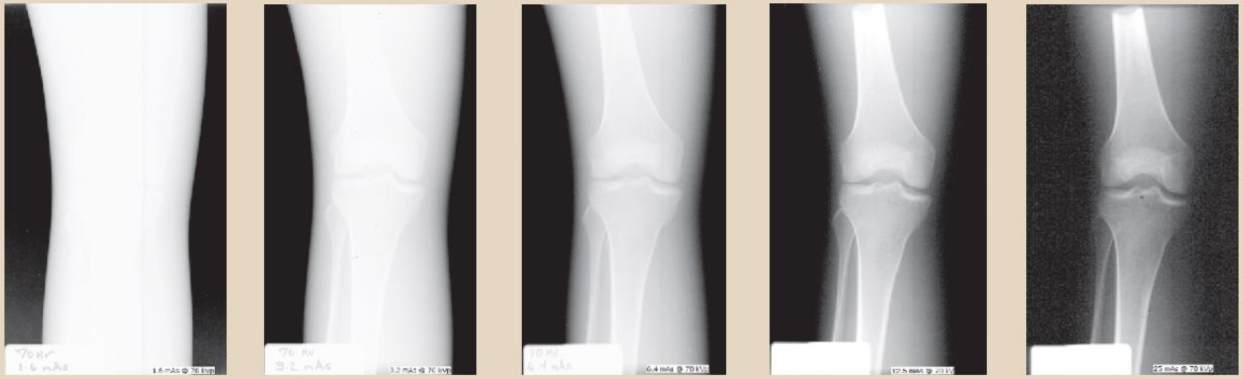




Computed Radiography (CR)

Screen-Film Radiography

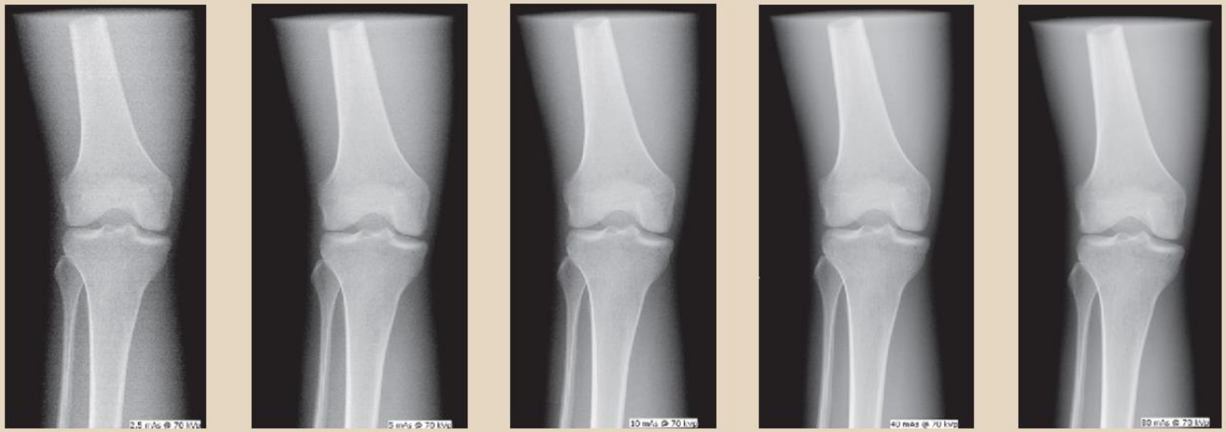
Proper radiographic technique and exposure are essential



1.6 mAs/70 kVp | 3.2 mAs/70 kVp | 6.4 mAs/70 kVp | 12.5 mAs/70 kVp | 25 mAs/70 kVp

Computed Radiography

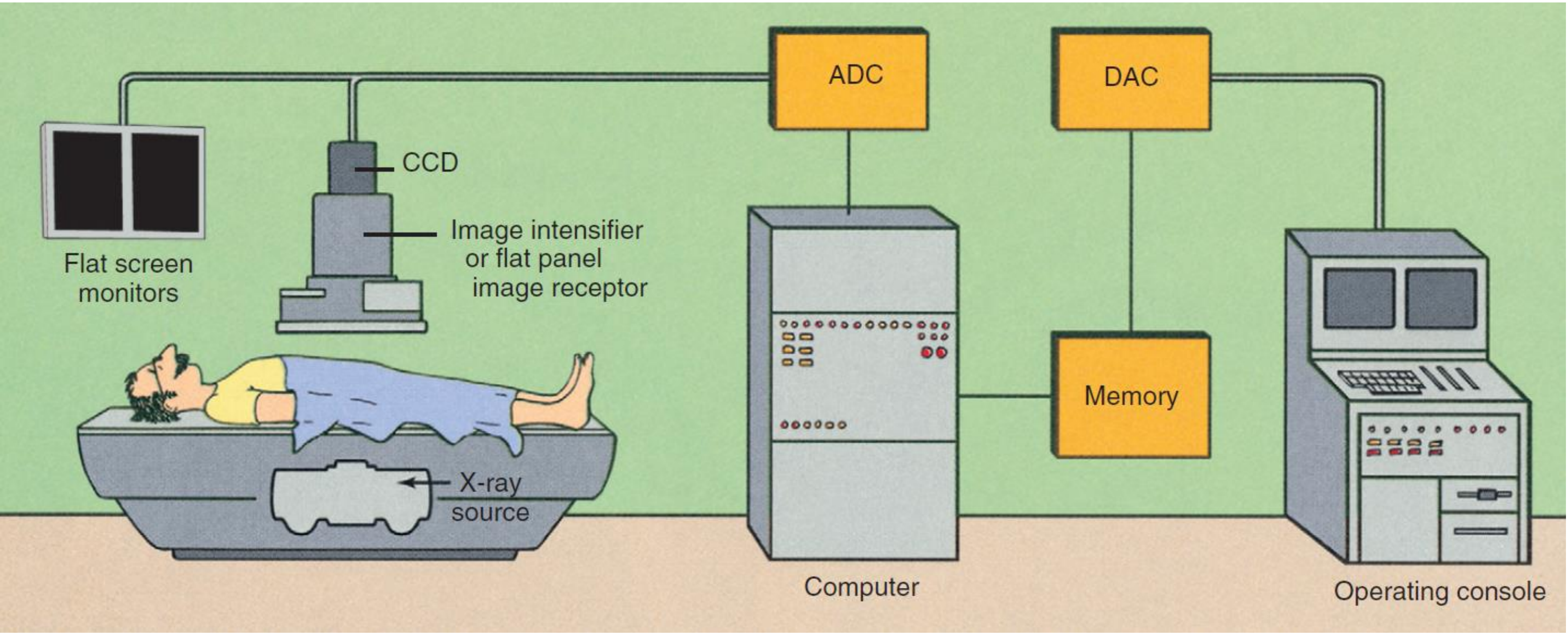
Radiographic technique is not so critical



2.5 mAs/70kVp | 5 mAs/70kVp | 10 mAs/70kVp | 40 mAs/70kVp | 80 mAs/70kVp

Digital Fluoroscopy (DF)

- Fluoroscopy: real-time dynamic viewing of anatomic structures
  - Advantages of DF include the speed of image acquisition and postprocessing to enhance image contrast



Interventional Radiology

- Performing surgical procedures under guidance from radiographic equipment

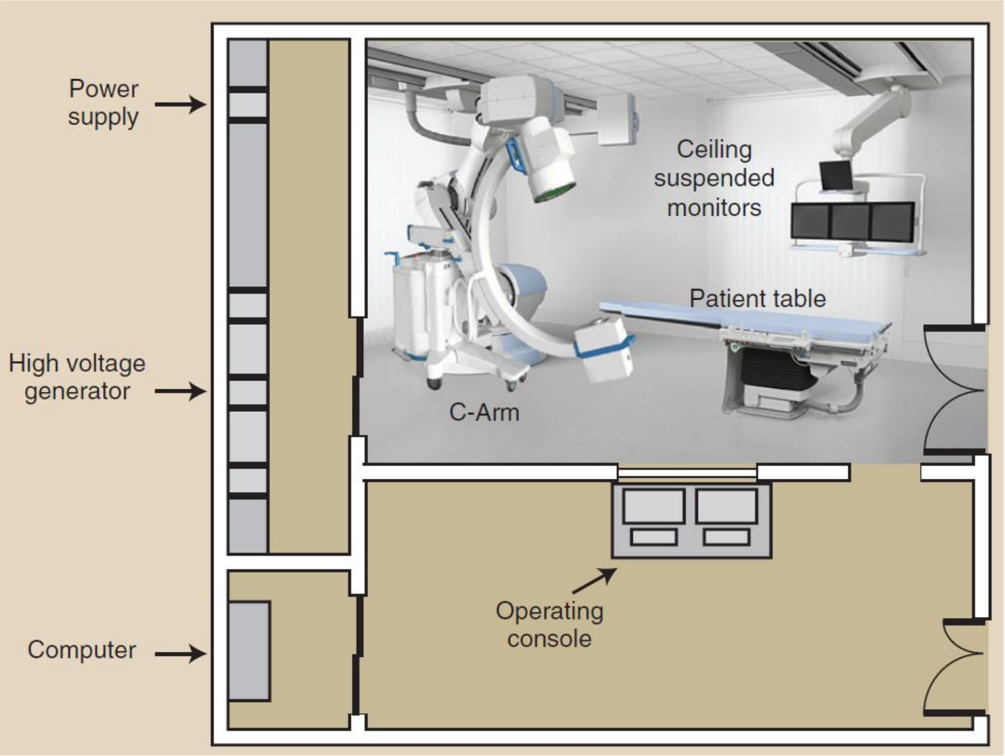


TABLE 27-1 Representative Procedures Conducted in an Interventional Radiology Suite

Imaging Procedures	Interventional Procedures
Angiography	Stent placement
Aortography	Embolization
Arteriography	Intravascular stent
Cardiac catheterization	Thrombolysis
Myelography	Balloon angioplasty
Venography	Atherectomy
	Electrophysiology

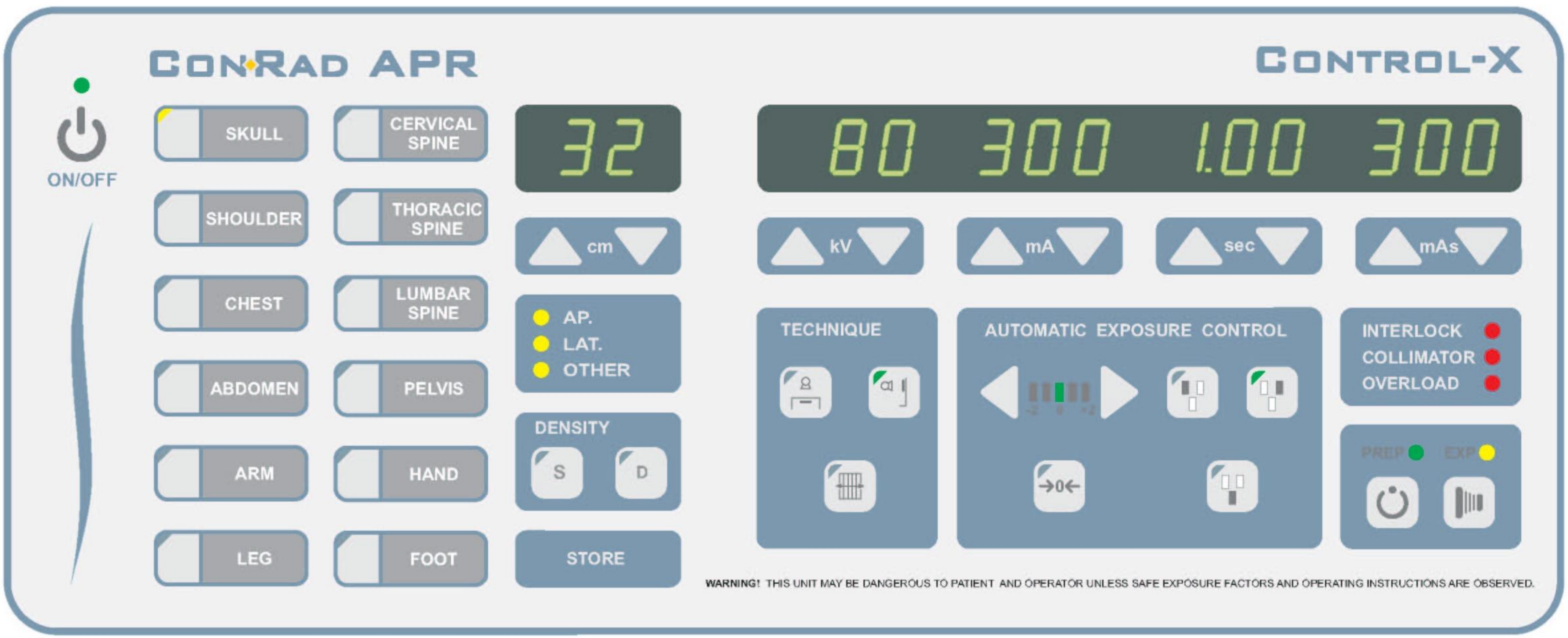
Digital Mammography

- Radiographic examination of the breast
- Digital Mammography spatial resolution limited by pixel size
  - Superior contrast resolution principally because of postprocessing

TABLE 23-3	Mammographic Technique Chart	
Compressed Breast Thickness (cm)	Target–Filter	Kilovolt Peak
0–2	Mo–Mo	24
3–4	Mo–Mo	25, 26
5–6	Mo–Rh	28
7–8	Mo/Rh	32
7–8	Rh–Rh*	30*

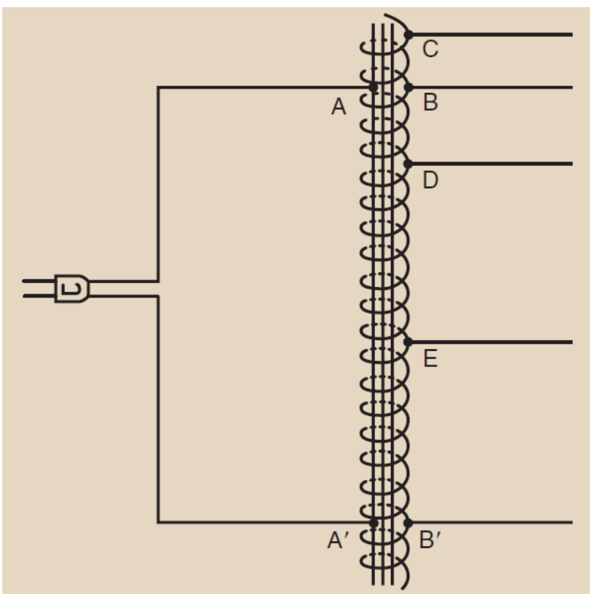
Operating Console

- Allows radiologist to control x-ray tube current and voltage so that useful x-ray beam is of proper quantity and quality
  - *Radiation quantity* refers to number of x-rays or intensity of x-ray beam
  - *Radiation quality* refers to penetrability of x-ray beam and is expressed in kilovolt peak (kVp) or, more precisely, half-value layer (HVL)



Autotransformer

- Power supplied to x-ray imaging system is delivered first to autotransformer where it provides controlled but variable voltage to high-voltage transformer
  - It is much safer and easier to control a low voltage and then increase it than to increase a low voltage to the kilovolt level and then control its magnitude



Autotransformer Law

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

where

V_P = the primary voltage

V_S = the secondary voltage

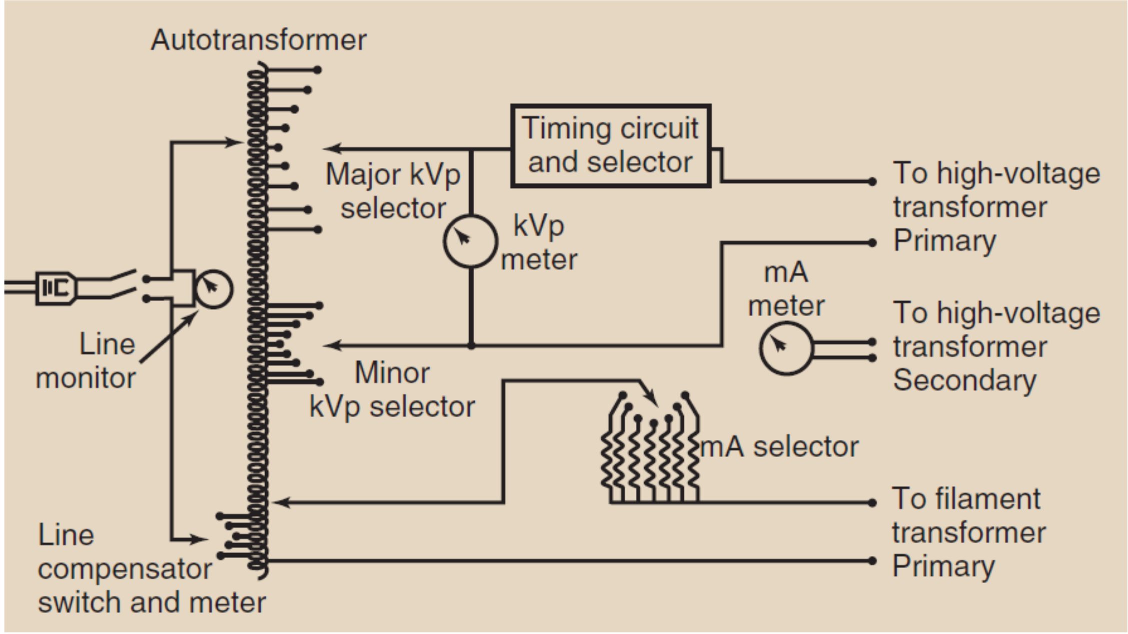
N_P = the number of windings enclosed by primary connections

N_S = the number of windings enclosed by secondary connections

Adjustment of Kilovolt Peak (kVp)

- kVp determines the quality of the x-ray beam
- Appropriate autotransformer connections can be selected with an adjustment knob, a push button, or a touch screen
  - This low voltage from autotransformer becomes the input to high-voltage step-up transformer that increases voltage to chosen kilovolt peak

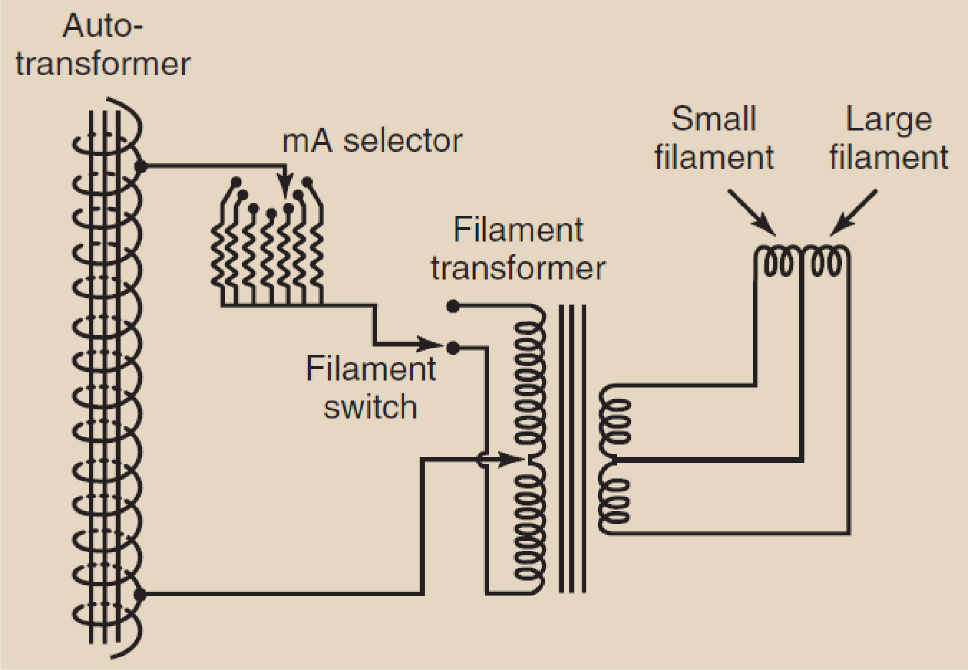
Note: kVp meter placed across output terminals of autotransformer actually reads voltage, not kVp. It registers kilovolts because of the known multiplication factor of high voltage transformer



Control of Milliamperage (mA)

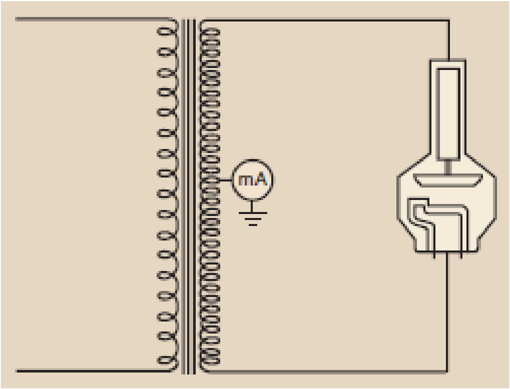
- The x-ray tube current, crossing from cathode to anode, is measured in milliamperes (mA)
  - Number of electrons emitted by filament is determined by filament temperature (controlled in turn by filament current)
  - *Thermionic emission* is the release of electrons from a heated filament

Space Charge Effect: As the kVp is raised, anode becomes more attractive to electrons that would not have enough energy to leave the filament. Hence, this effectively increases mA with kVp and hence should be corrected for by special circuit



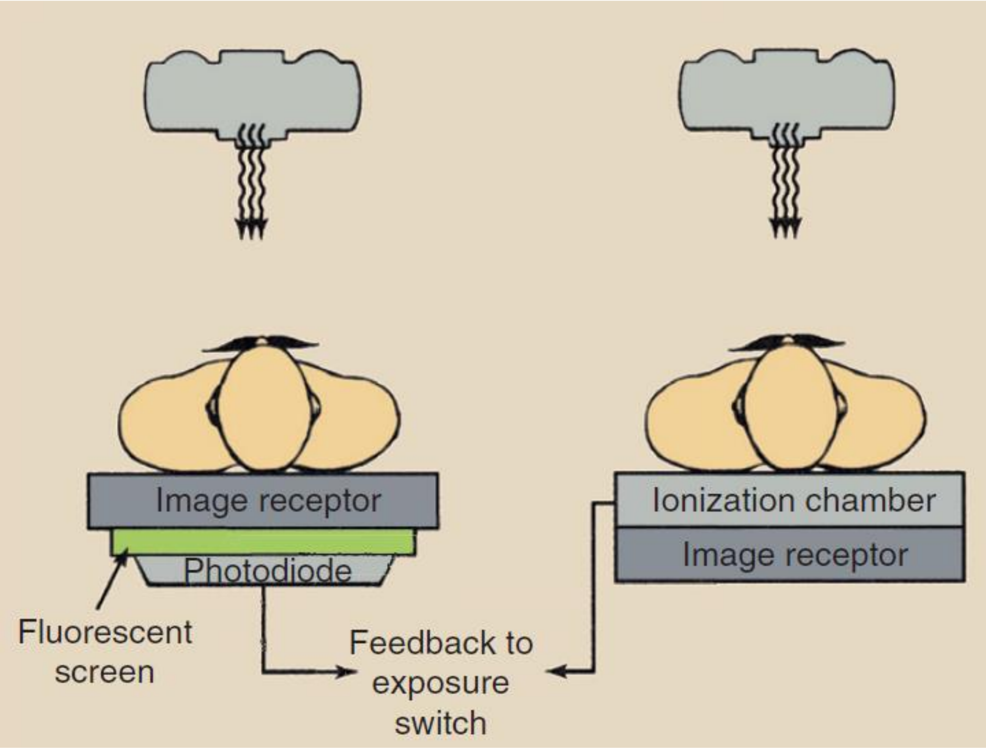
Exposure Timer

- Most exposure timers are electronic, controlled by microprocessor
  - Allow wide range of time intervals to be selected and are accurate to intervals as small as 1 ms
- Special kind of electronic timer, called an *mAs timer*, monitors product of mA and exposure time and terminates exposure when desired mAs value is reached
  - Because the mAs timer must monitor actual tube current, it is located on the secondary side of the high-voltage transformer



Automatic Exposure Control (AEC)

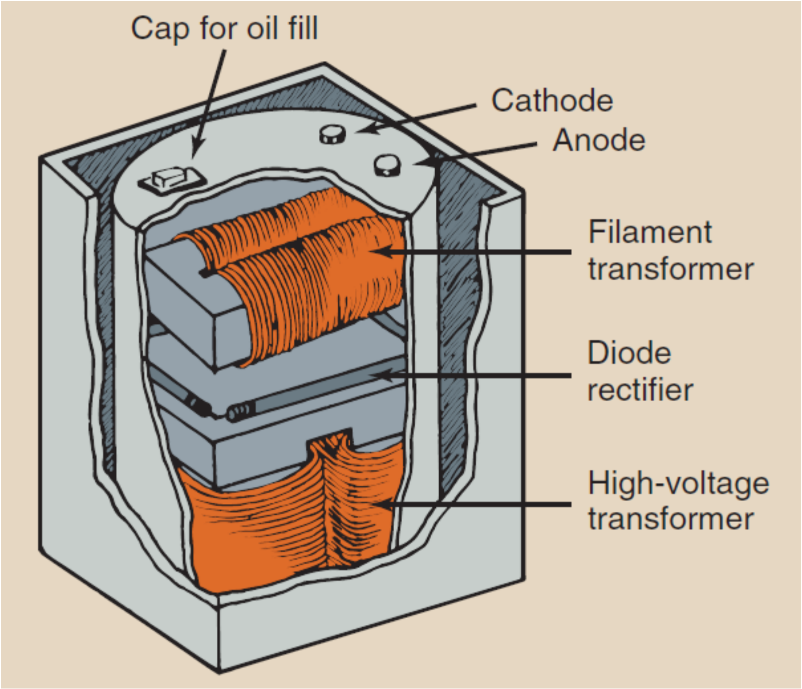
- AEC is a device that measures quantity of radiation that reaches image receptor and automatically terminates exposure when image receptor has received required radiation intensity



High-Voltage Generator

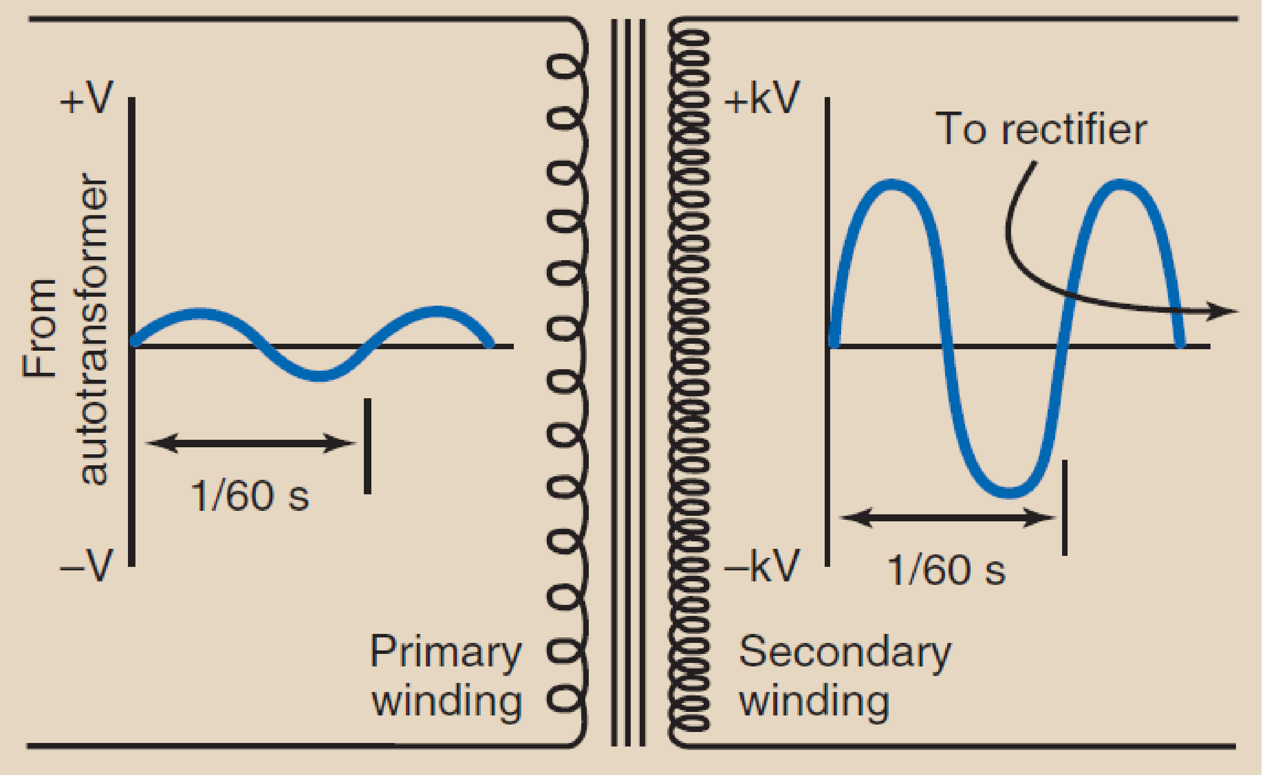
- Function: increases output voltage from autotransformer to the kVp necessary for x-ray production
- High-voltage generator contains three primary parts: *high-voltage transformer*, *filament transformer*, and *rectifiers*

Note: Although some heat is generated in the high-voltage section and is conducted to oil, the oil is used primarily for electrical insulation



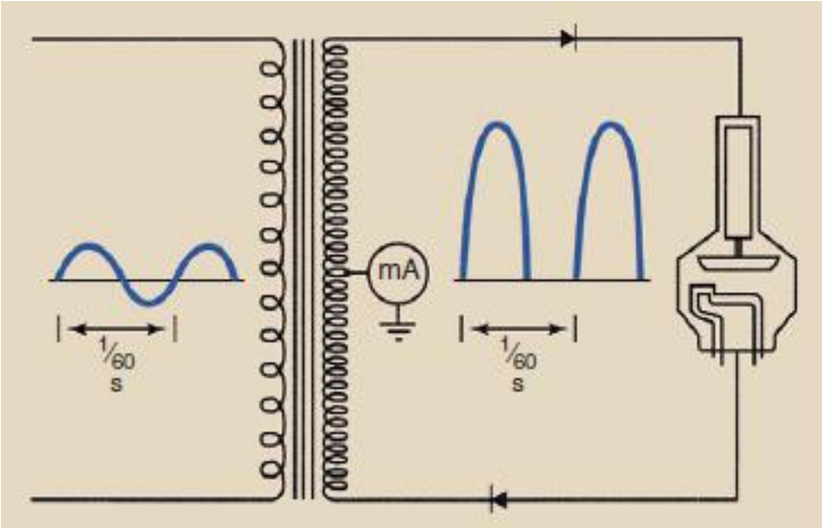
High-Voltage Transformer

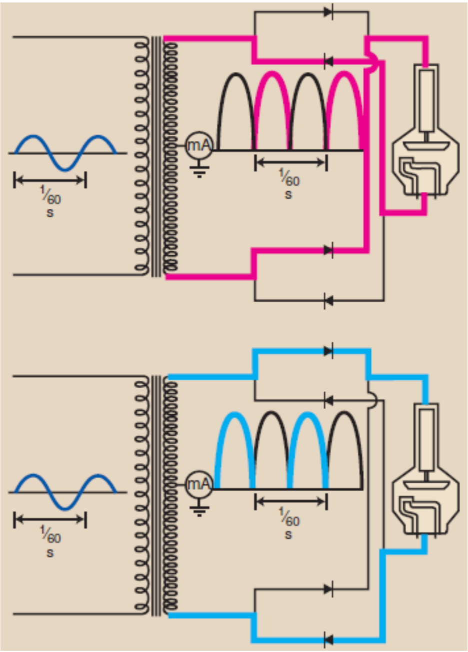
- High voltage transformer is a step-up transformer
  - Turns ratio of is usually between 500:1 and 1000:1



High-Voltage Rectification

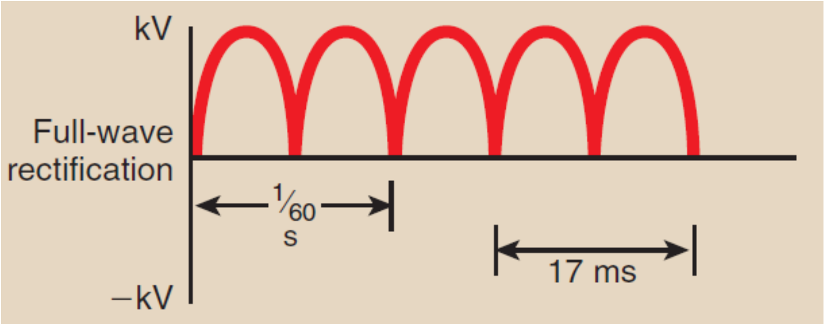
- Rectification is the process of converting AC to DC
  - Rectification is accomplished with diodes
- Transformers operate AC while x-ray tubes need DC
  - X-rays are produced by acceleration of electrons from cathode to anode and cannot be produced by electrons flowing in reverse

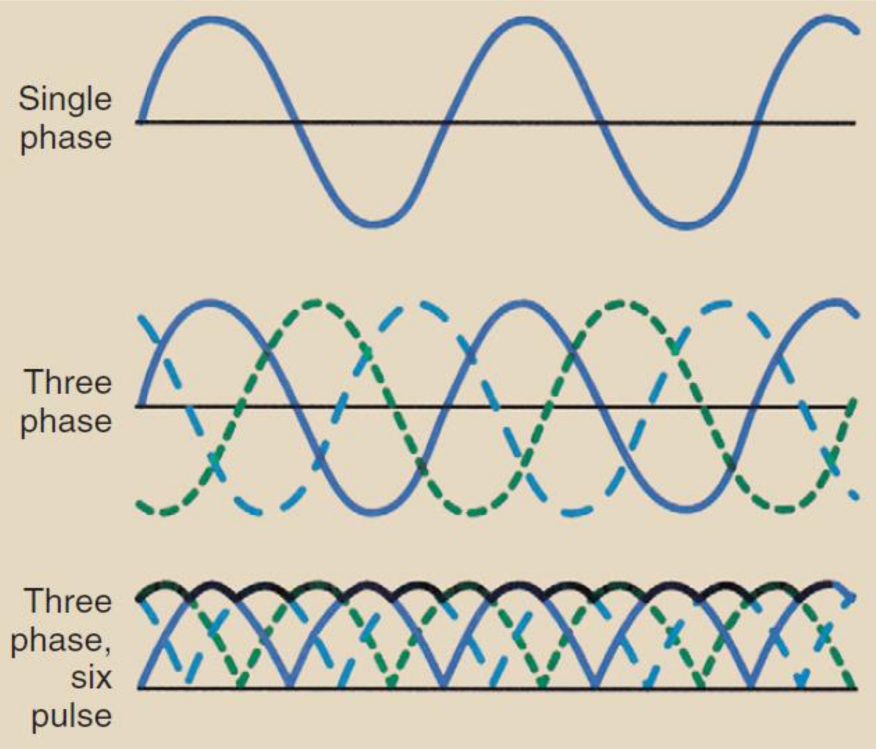




Single-Phase vs. Three-Phase

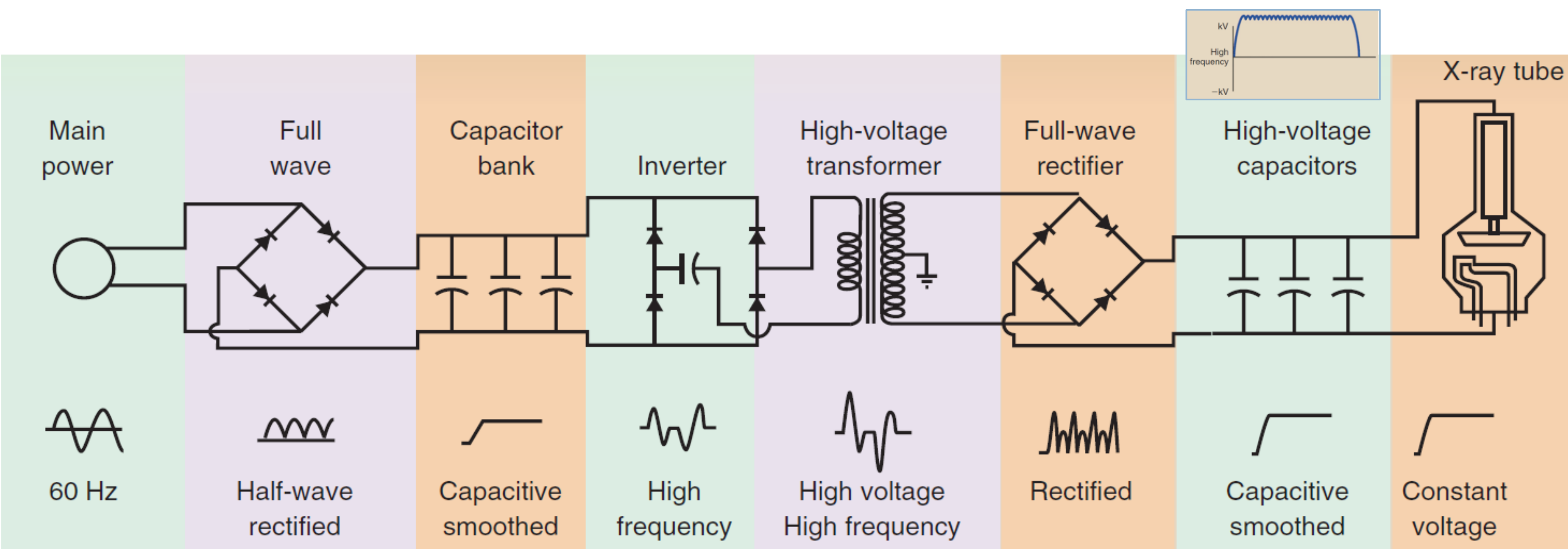
- Three-phase power is a more efficient way to produce x-rays than is single-phase power
  - With three-phase power, voltage applied across the x-ray tube is nearly constant, never dropping to zero during exposure.





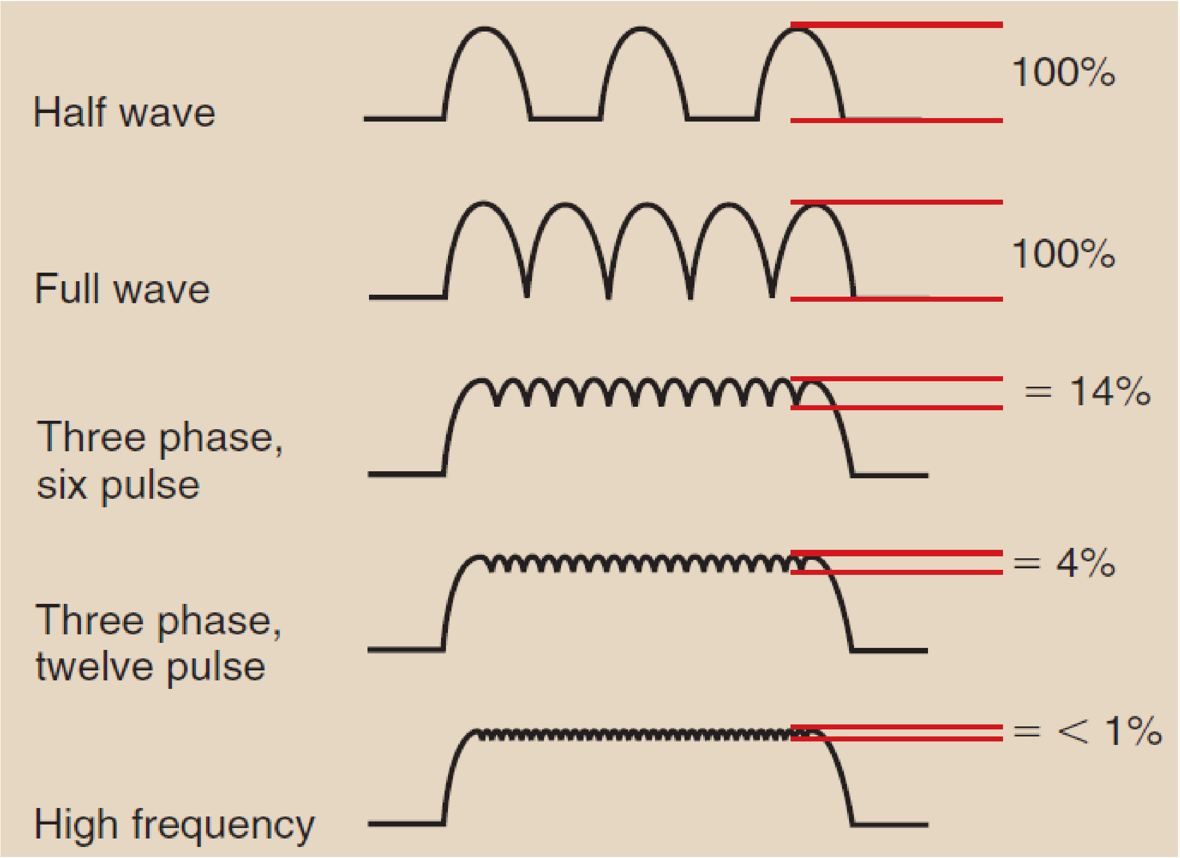
High-Frequency Generator

- High-frequency generators produce nearly constant potential voltage waveform, improving image quality
- Rectified power at 60 Hz is inverted to a higher frequency, from 500 to 25,000 Hz, then transformed to high voltage
  - Advantage: much smaller size than 60-Hz high-voltage generators



Voltage Ripple Comparison

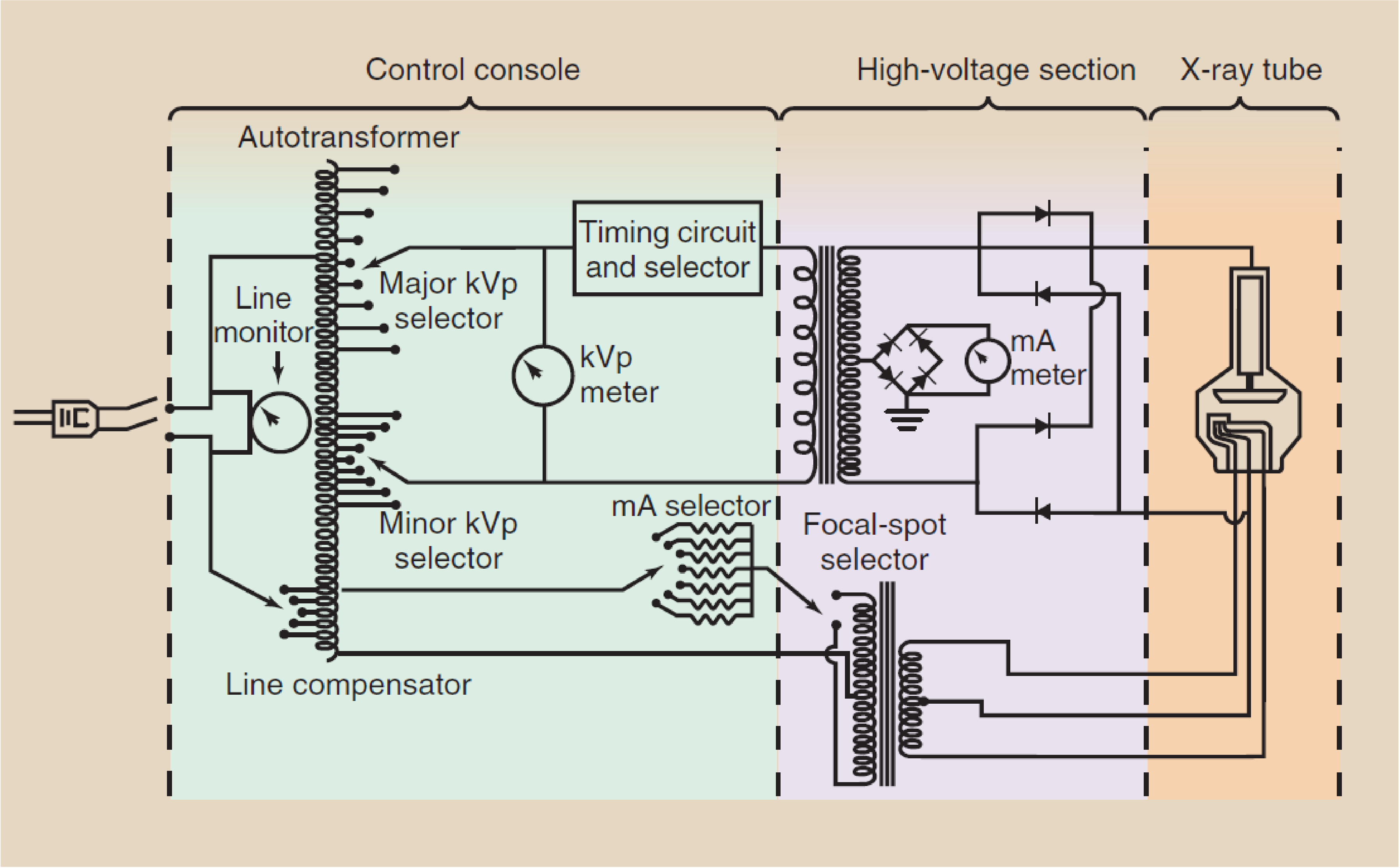
- Less voltage ripple results in greater radiation quantity and quality



Power Rating

- Transformers and high-voltage generators usually are identified by their power rating in kilowatts (kW)
  - Power (W) = Current (A) × Potential (V)
- For specifying high-voltage generators, the industry standard is to use the maximum tube current (mA) possible at 100 kVp for an exposure of 100 ms
  - This generally results in the maximum available power
- Use RMS voltage factor to account for voltage ripples
  - 0.7 of peak in single phase generators
  - Close enough to 1 in three-phase and high-frequency generators

X-Ray Circuit



Cardinal Principles for Radiation Protection

- Simplified rules designed to ensure safety in radiation areas for occupational workers

BOX 35-1 Cardinal Principles of Radiation Protection

Keep the time of exposure to radiation as short as possible.

Maintain as large a distance as possible between the source of radiation and the exposed person.

Insert shielding material between the radiation source and the exposed person.

Cardinal Principles for Radiation Protection

- Minimize Time
  - Dose is directly related to duration of radiation exposure
  - Exposure = Exposure rate × Exposure time
- Maximize Distance
  - As distance between source of radiation and person increases, radiation exposure decreases rapidly by inverse square law
  - If distance from source exceeds 5 times source diameter, it can be treated as point source (assume true and apply inverse square law)
- Use Shielding
  - Positioning shielding between radiation source and exposed persons greatly reduces level of radiation exposure
  - Shielding used in diagnostic radiology usually consists of lead, although conventional building materials also are used

Shielding

- Estimate dose reduction using half-value layer (HVL) or tenth-value layer (TVL) of barrier material (1 TVL = 3.3 HVL)
- Protective apparel
  - Protective aprons usually contain 0.5 mm Pb (2 HVL – reduction to 25%).
  - Actual measurements show reduction to approximately 10%

TABLE 35-1 Approximate Half-Value and Tenth-Value Layers of Lead and Concrete at Various Tube Potentials

	HVL		TVL	
Tube Potential	Lead (mm)	Concrete (cm)	Lead (mm)	Concrete (cm)
40 kVp	0.03	0.33	0.06	1.0
60 kVp	0.11	0.64	0.34	2.2
80 kVp	0.19	1.1	0.64	3.6
100 kVp	0.24	1.5	0.80	5.1
125 kVp	0.27	2.0	0.90	6.4
150 kVp	0.28	2.2	0.95	7.1

Effective Dose

- Effective dose is the equivalent whole-body dose
  - When only part of body is exposed, as in medical x-ray imaging, risk is proportional to effective dose (E)
  - Equivalent whole-body dose is the weighted average of the radiation dose to various organs and tissues

$$E = \Sigma D_i W_t$$

TABLE 35-2 Weighting Factors for Various Tissues

Tissue	Tissue Weighting Factor (W_t)
Gonad	0.20
Active bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Esophagus	0.05
Liver	0.05
Thyroid	0.05
Bone surface	0.01
Skin	0.01

Patient and Occupational Effective Dose

BOX 35-2 Effective Dose During Computed Tomography

Computed tomography of the abdomen and pelvis results in a tissue dose of 20 mGy_t (2000 mrad). What is the effective dose?

$E = \Sigma(D_iW_i)$

$= (20)(0.2)$ gonads

$+ (20)(0.12)$ colon

$+ (20)(0.05)$ liver

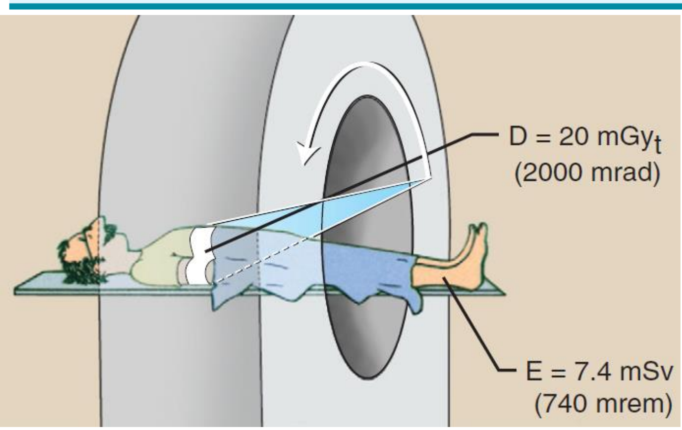
All other organs listed in Table 35-2 receive essentially zero dose.

$= 4$ gonads

$+ 2.4$ colon

$+ 10$ liver

$= 7.4$ m Sv



BOX 35-3 Effective Dose during PA Chest Radiography

A PA chest radiograph results in an entrance skin dose of 0.1 mGy_t, an exit dose of 0.001 mGy_t (1 μGy_t), and an average tissue dose of 0.05 mGy_a (50 μGy_a). What is the effective dose?

$E = \Sigma(D_iW_i)$

$= (50)(0.12)$ lung

$+ (50)(0.05)$ breast

$+ (50)(0.05)$ esophagus

$+ (50)(0.05)$ thyroid

All other tissues receive essentially zero dose.

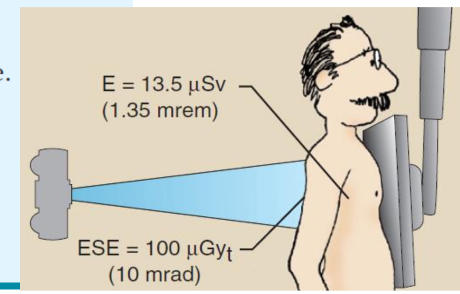
$= 6.0$ lung

$+ 2.5$ breast

$+ 2.5$ esophagus

$+ 2.5$ thyroid

$= 13.5$ µ Sv



BOX 35-4 Occupational/Radiation Effective Dose

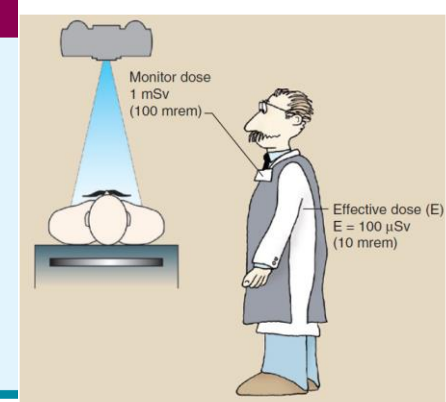
An occupational radiation monitor records a dose of 1 mSv. What is the effective dose if the occupational dose is received during fluoroscopy when a protective apron is worn?

$E = \Sigma(D_iW_i)$

$= (1)(0.05)$ thyroid

All other tissues receive essentially zero dose.

$= 0.01$ mSv $= 10$ µSv



Covered Material and Suggest Problems

- Chapters 1, 5, 6, 7, 8, 9, 10, 11, 35 of textbook
- Attempt questions at the end of each chapter