



Level II Study Guide: Radiographic Testing

third edition



The American Society for Nondestructive Testing, Inc.



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ASNT exists to create a safer world by promoting the profession and technologies of nondestructive testing.

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The third edition of the *Level II Study Guide: Radiographic Testing* builds on the work of the previous editions written by William Spaulding and George C. Wheeler. The content has been subdivided into four chapters for ease of reference. Material has been added regarding ionization of matter, scatter radiation, image sharpness, film handling and storage, and replenishment of darkroom chemicals, among other topics. As with prior editions, the goal of this study guide is to provide basic information to prepare a candidate for Level II examinations in radiographic testing.

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Recommended References

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Chapter 1

Principles of Radiographic Testing

Radiographic testing unofficially began in 1895 when Wilhelm Conrad Röntgen, a German scientist, discovered that an unknown form of radiation emitted from a gas-filled electron tube was capable of penetrating objects that were opaque to light. After considerable investigation, Röntgen (Figure 1.1) named the rays *X-rays* to indicate their origin was unknown.

At about the same time, Antoine Henri Becquerel, a French scientist, found that radiation from certain uranium compounds had similar properties. This radiation was later determined by Ernest Rutherford to be two distinct types called *alpha* and *beta* radiation.

In 1900, Paul Ulrich Villard, also a French scientist, found that a third type of radiation emitted from some radioactive materials was similar to X-rays. This radiation was called *gamma rays*.



Figure 1.1: Wilhelm Conrad Röntgen.

X-Rays and Gamma Rays

X-rays and gamma rays are essentially the same, differing only in their origin. X-rays are produced artificially by accelerating or decelerating high-energy electrons using electronic equipment, while gamma rays are produced by the decay (disintegration of the nuclei) of radioactive isotopes.

Significant use of X-rays and gamma rays for industrial purposes began in the 1920s. Since then, industrial radiographic testing has become one of the most commonly used methods of nondestructive testing. Radiography is most often used for process control during manufacturing, to detect subsurface discontinuities in end products (e.g., castings, welds, ceramics, composite materials and electronic components) and for quality control inspections of electronic components (e.g., determining internal fits, alignments and/or gaps in

assemblies). Radiography is applied in building and bridge construction, aircraft aviation and aerospace, automotive and space components manufacturing, and aircraft overhaul, maintenance and repair. It is also used for inspecting piping and pipelines, refinery vessels, steel pressure vessels and storage tanks.

Advantages and Disadvantages of Radiographic Testing

Radiographic testing can be used to detect internal discontinuities in almost any material that is not too thick. X-ray machines capable of penetrating as much as 660 mm (26 in.) of steel, and greater thicknesses of other materials, are available. In addition to discontinuities, radiography can disclose internal structures, configurations, fluid levels and fabrication or assembly errors. In most applications, radiography provides an image of the test object that can be kept as a permanent record.

Isotopes are often used over X-ray machines because they are portable, don't need electricity and can access hard-to-reach places. Isotopes are also used in field testing because they have greater penetrating ability than the X-rays generated by most portable X-ray machines.

The major limitations of radiography are that the opposing sides of the test object must be accessible, precautions are required to prevent personnel exposure to radiation, and the configuration of the object must allow for the satisfactory formation of shadows of its internal structure.

Note: In ASNT Recommended Practice No. SNT-TC-1A: *Personnel Qualification and Certification in Nondestructive Testing* (2011), radiographic testing is considered a technique of the radiologic testing (RT) method.

Radiographic Principles

Radiographic testing is based on the detection of differences in the transmission/absorption of penetrating radiation by different parts of the

object being radiographed. The differences in transmission may be caused by differences in the thickness or composition of the absorbing material. Sensors that respond to the ionization produced when radiation is absorbed are used to detect the radiation that passes through the object.

Traditionally, special photographic film was the most commonly used detection medium. As with a photographic negative, the regions of the film where more radiation strikes the film will be blacker after the film is developed. In radiography, this produces an image of the part that includes its internal structure and discontinuities. Electronic sensors that react to ionization (e.g., geiger tubes and scintillation devices) also detect X-rays and gamma rays, and are used more often in radiographic testing applications.

Most discontinuities effectively reduce the thickness of the object, locally, so that more radiation is transmitted at that point. When film is the detector, the transmittal of more radiation results in greater darkening of the film (i.e., the discontinuity image is darker than the remainder of the object as in Figure 1.2). However, some discontinuities, such as tungsten inclusions in welds, may absorb more radiation than the surrounding material, which will appear as lighter images on a radiograph.

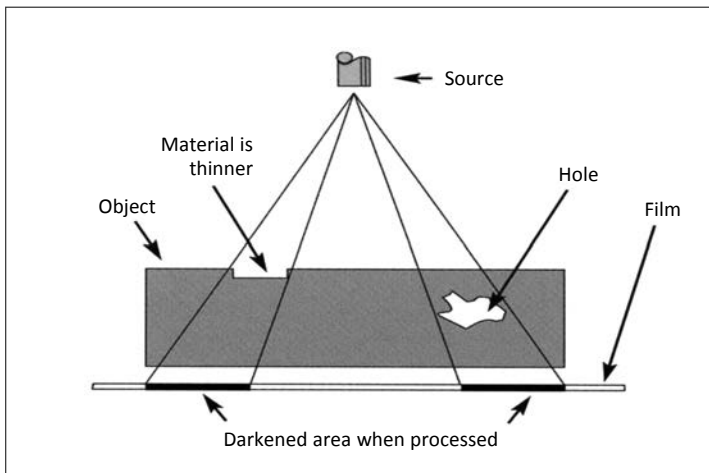


Figure 1.2: When film is the detector, the transmittal of more radiation results in greater darkening of the film.

Planar discontinuities that do not have any appreciable thickness, such as cracks and lack of fusion, are different. Because their small thickness causes little change in the amount of radiation that is absorbed, such discontinuities are difficult to

detect unless the plane of the discontinuity is nearly parallel to the radiation beam.

Images of higher quality and greater sensitivity are generated through the use of higher quality films with a larger variety of film grain sizes. Film processing has evolved to an automated state, producing more consistent image quality by removing manual processing variables.

Electronics and computers also allow technicians to capture images digitally (Figure 1.3). Digital radiography (DR) captures an image that can be presented for interpretation immediately. Images can also be digitally enhanced and sent anywhere in the world. An archived digital image will not deteriorate with time. The advantages of DR over film include immediate image preview, immediate availability and a wider dynamic range that makes it more forgiving of over- and under-exposure.

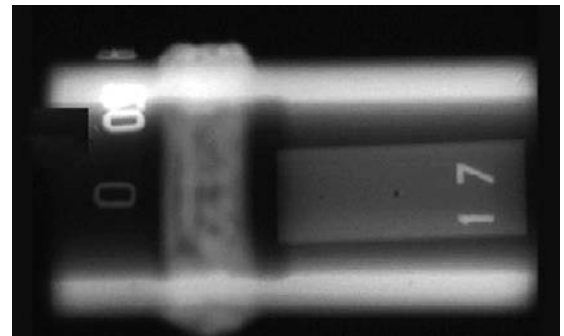


Figure 1.3: Digital image.

Nuclear Atomic Model

The nuclear atomic model describes the atom as consisting of a small, relatively heavy nucleus (protons and neutrons) with electrons revolving in orbit around the nucleus (Figure 1.4). The volume of that portion of an atom outside the nucleus is very large compared to the volume of the nucleus itself or of the individual electrons; therefore, the greatest part of any atom is empty space. The difference in atoms of different elements is the number of protons in the nucleus. Electrically, the atom is normally in balance, the number of protons in the nucleus being equal to the number of electrons in orbit.

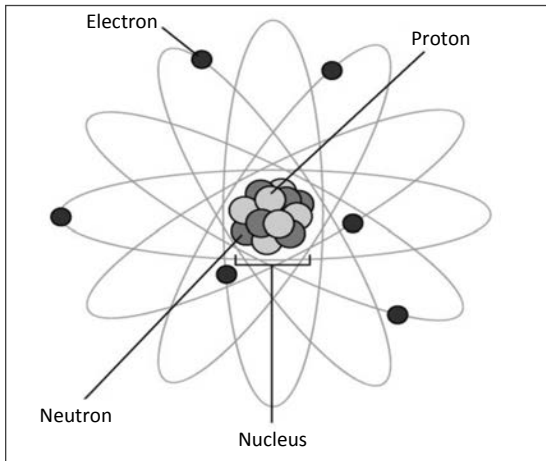


Figure 1.4: Atomic model.

Types of Penetrating Radiation

X-rays and gamma rays are a form of electromagnetic radiation like light, but their energy is much higher and their wavelengths are only about 1/10 000 that of light. The electromagnetic spectrum shown in Figure 1.5 compares the wavelengths and energies of various forms of radiant energy. The short wavelength and high energy of X-rays and gamma rays enable them to penetrate much more deeply into materials than light can.

The principal characteristics of X-rays and gamma rays are that:

1. the higher their energy, the shorter their wavelength, (wavelength is inversely proportional to energy);
2. they have no mass or electrical charge;
3. they travel at the speed of light;
4. when absorbed or deflected, they ionize matter;

5. the higher their energy, the greater the depth to which they can penetrate in a given material;
6. absorption is increased as the atomic number and density of the absorber increase;
7. they cannot be refracted (as by a lens) or reflected to any useful degree, but they can be diffracted by crystalline structures;
8. living tissue is damaged when it absorbs X-rays or gamma rays.

X-Rays

There are a number of advancements being made related to the generation and efficiency of X-rays, yet in general the principles are similar to conventional X-ray equipment. X-rays are produced when rapidly moving electrons are accelerated and then either stopped or changed in direction. Usually this is done in a vacuum (X-ray tube) by stopping the electrons with a barrier called a target (Figure 1.6).

This process produces characteristic X-rays, with energies/wavelengths that depend on the

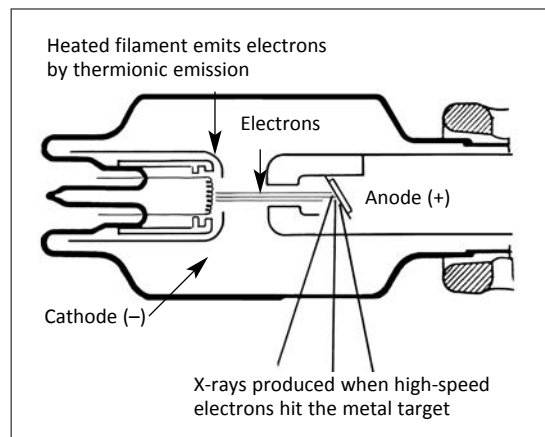


Figure 1.6: X-rays are generated in a vacuum tube.

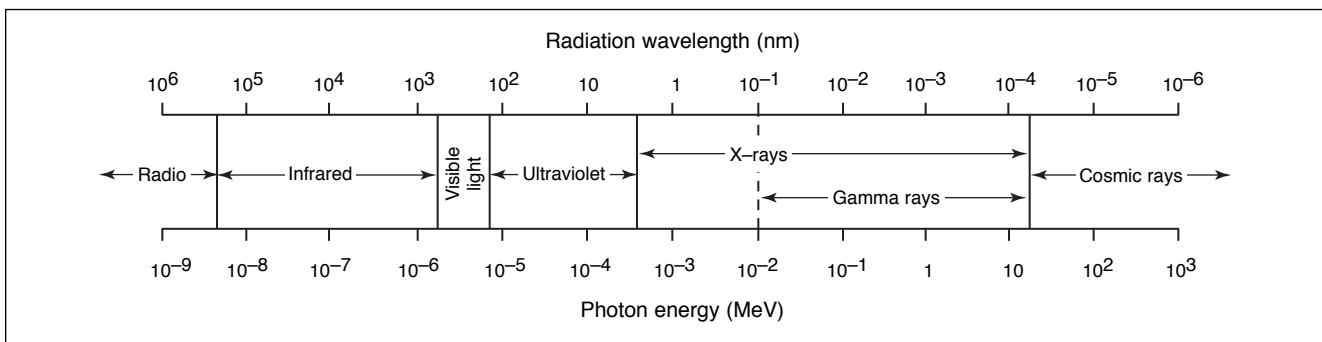


Figure 1.5: The electromagnetic spectrum.

target material, and bremsstrahlung X-rays with energies ranging from near 0 to the maximum energy of the electrons, the voltage at which the X-ray tube was operated (Figure 1.7). Bremsstrahlung X-rays are also called *white radiation* and make up most of the useful radiation in radiographic testing.

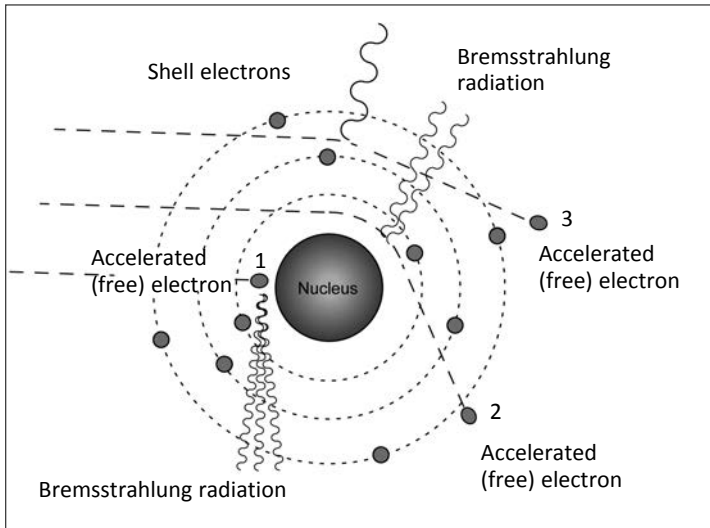


Figure 1.7: Generation of bremsstrahlung X-rays.

X-ray machines commonly used in radiography range in energy from 50 keV to 30 000 keV and in X-ray output from less than 0.05 Gy/min to as much as 250 Gy/min (5 rad/min to as much as 25 000 rad/min) measured at 1 m (3.3 ft) from the source. A typical X-ray tube consists of a source of electrons and a target in a vacuum chamber, with the means to apply high voltage across the source-target gap.

Electron Source

When electric current is passed through the wire filament coil in an X-ray tube cathode, the heat generated causes a cloud of electrons to be liberated from the coil. An increase in the current passing through the filament increases the number of free electrons, which increases the X-ray output of the tube. The focusing cup helps to keep the electrons bunched together to minimize the size of the focal spot, the area where the electrons strike the target. X-ray tubes contain two filaments that correspond to the focal spot sizes (Figure 1.8).

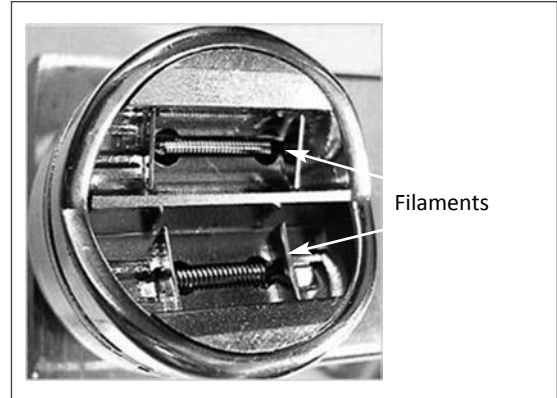


Figure 1.8: Filaments in an X-ray tube.

Electron Target

The target material must have a high melting point because it becomes very hot when bombarded by electrons from the filament. For the greatest efficiency in producing X-rays, the target should be made of a material with a high atomic number. Tungsten is generally used for the target material because it provides one of the best available combinations of high melting point and high atomic number, although other metals such as copper, iron and cobalt are used in tubes where special applications require a particular characteristic radiation.

Electron Acceleration

By applying a negative charge to the cathode and a positive charge to the anode, the negatively charged electrons are repelled by the cathode and attracted to the anode. The higher the voltage difference between the anode and cathode, the higher the velocity of the electrons when they strike the target, and the higher the energy of the X-rays that are generated. Higher energy radiation has greater penetrating power than lower energy radiation. In addition, as the energy of the electrons is increased, the quantity of X-rays generated increases.

In most X-ray machines, the X-ray output is measured indirectly by measuring the tube current (i.e., the flow of electrons from cathode to anode) usually in milliamperes or microamperes. In some machines, typically those with very high X-ray output, such as linear accelerators, the radiation intensity is measured directly in sievert (roentgen) per minute at 1 m (3.3 ft) from the target.

Because the production of X-rays is very inefficient, most of the tube current is converted into heat at the target. Consequently, the focal spot

size and the cooling of the anode to prevent the target from melting, are major design limitations. In addition, the ability of insulating materials to withstand high voltages greatly influences tube design. As a result, some machines have a duty cycle rating based on the kilovoltage, tube current and length of exposure. In many industrial X-ray tubes, a rotating anode is used in order to help distribute the heat allowing the target to cool (Figure 1.9).

X-ray machines are usually rated by their maximum voltage capability in kilovolts or megaelectronvolts.

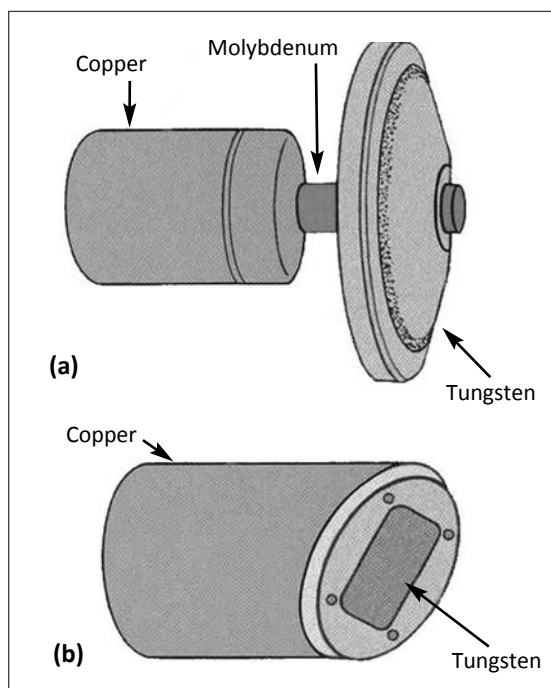


Figure 1.9: Anodes: (a) rotating anode; (b) stationary anode.

Gamma Rays

Gamma rays are similar to X-rays but are produced by the decay of naturally occurring or artificially produced radioactive isotopes referred to as *radioisotopes*. Iridium-192 and cobalt-60 are the most commonly used isotopes for radiographic testing and both are artificially produced by neutron bombardment in a nuclear reactor. Until these radioisotopes became available after World War II, naturally occurring radium was used extensively.

The wavelength (energy) of gamma rays depends on the isotope. Each isotope produces one or more fixed wavelengths, but no bremsstrahlung radiation.

Radiation Energy

Gamma-ray sources are available in many energy ranges from about 10 keV to 12 MeV. The most commonly used are iridium-192 with energies of 310 keV, 470 keV and 600 keV; and cobalt-60 with energies of 1.17 MeV and 1.33 MeV.

Source Activity

The activity of a gamma-ray source depends on the amount of radioactive material present and its rate of decay. The rate of decay is measured in becquerels (curies) and is a useful way of comparing the strength of various sources of the same isotope.

Specific Activity

Specific activity is the activity per unit quantity of the source, expressed as becquerels (curies) per gram. It is useful in radiographic testing because a source of a given strength with a high specific activity is physically smaller than one with a lower specific activity. The smaller source permits a smaller source-to-film distance than a larger source, everything being equal. Also, at the same distance, the smaller source produces sharper images. (See Sharpness on p. 12.)

Radiation Intensity

The intensity of radiation from an isotope source (or from a X-ray source) is measured in sievert (roentgen) per unit of time at a standard distance from the source. For isotopes, the units are usually sievert/h at 1 m (roentgen/h at 1 m) as compared to X-rays that are usually measured in sievert/min at 1 m (roentgen/min at 1 m). The intensity from an X-ray tube is also often expressed in terms of the tube current with units such as milliamperes.

Half-Life

The number of active atoms in a source diminishes with time because of radioactive decay. The time it takes the radioactive material to decay to one-half of its initial activity is called the half-life of the isotope.

- Half-life of Ir-192: 75 days.
- Half-life of Co-60: 5.3 years.

This means that 1.9 TBq (50 Ci) of iridium-192 will decay to 1 TBq (25 Ci) in 75 days, to 0.5 TBq (12.5 Ci) in the next 75 days and so on.

Interactions of Radiation with Matter

X-rays and gamma rays have no mass or weight; they are bundles of energy called photons that travel at the speed of light. They can be absorbed or deflected by matter in a number of ways, usually by causing atoms of the matter to become ionized (electrically charged). Electrons and/or lower energy photons are emitted from the atom in a different direction from that of the incident photons. These electrons or photons may, in turn, cause the ionization of other atoms in the absorber.

Ionization

Any action that disrupts the electrical balance of an atom and produces ions is called ionization. Atoms with a positive or negative charge are called ions. Free electrons are negative ions and free particles carrying positive charges, such as protons, are positive ions.

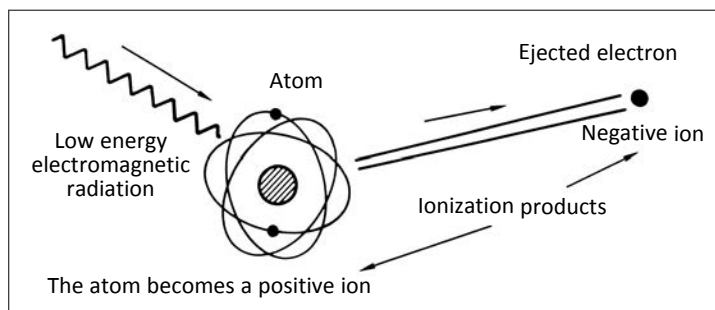


Figure 1.10: Ionization.

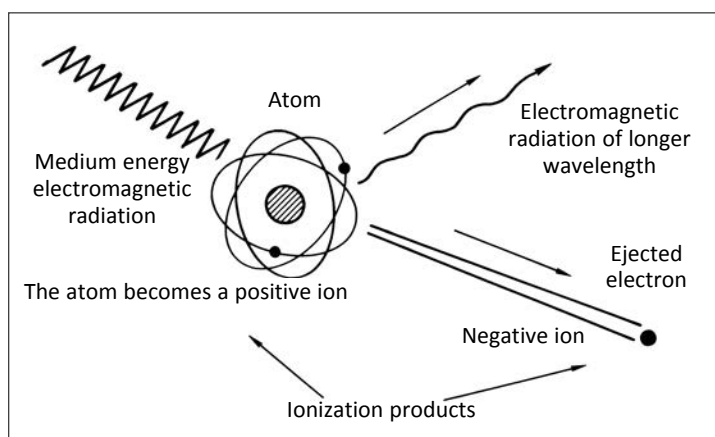


Figure 1.11: Compton effect.

X-rays passing through matter alter the electrical balance of atoms through ionization (Figure 1.10).

The energy of the ray may dislodge an electron from an atom and temporarily free an electron. The first atom (positively charged) and the electron (negatively charged) are, respectively, positive and negative ions, also known as an ion pair. In this manner, X-rays cause ionization in all material in their path.

In passing through matter, X-rays lose energy to atoms by ionization processes known as the *photoelectric effect*, the *compton effect* and *pair production*.

Photoelectric Effect

When X-rays (photons) of relatively low energy of 0.5 MeV or less pass through matter, the photon energy may be transferred to an orbital electron, ejecting it from its orbit. This phenomenon is known as the *photoelectric effect* or absorption. The remainder of the energy gives velocity to the electron. The photoelectric process absorbs all of the energy of the photon. It is this absorption effect that makes radiography possible.

Compton Effect

As shown in Figure 1.11, when higher energy photons of 0.1 MeV to 3 MeV pass through matter, scattering occurs due to the *compton effect*.

Part of the photon energy is expended in ejecting an orbital electron and imparting velocity to it. The remainder, as a lower energy photon, continues onward at an angle to the original photon path. This process, progressively weakening the photon, is repeated until the photoelectric effect completely absorbs the last photon.

Pair Production

Pair production occurs only with high-energy photons of 1.02 MeV or more, as shown in Figure 1.12. At these energy levels, when the photon approaches the nucleus of an atom, it changes from energy to an electron-positron pair. Positrons carry a positive charge, have the same mass as electrons and are extremely shortlived. They combine at the end of their path with an electron to emit one 0.51 MeV photon subject to the compton effect and the photoelectric effect.

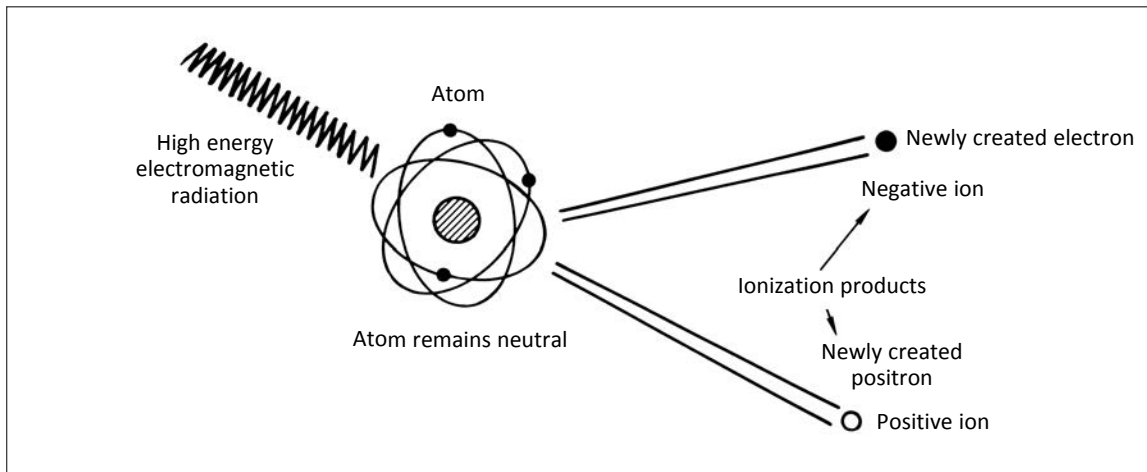


Figure 1.12: Pair production.

Scatter Radiation

The three processes — photoelectric effect, compton effect and pair production — all liberate electrons that move with different velocities in various directions. Because X-rays are generated whenever free electrons collide with matter, it follows that X-rays in passing through matter cause the generation of secondary X-rays. These secondary X-rays are a minor component of what is known as scatter radiation or scatter. The major component of scatter is the low-energy rays represented by photons weakened in the compton-effect process. Scatter radiation is of uniformly low-level energy content and of random direction.

Internal Scatter

The scatter that occurs in the object being radiographed, as shown in Figure 1.13, is called internal scatter. It is reasonably uniform throughout a test object of one thickness but affects definition by blurring the image outline. The scatter radiation shown in Figure 1.13 obscures the edges of the test object and the hole through it. The increase in radiation passing through matter caused by scatter in the forward direction is known as *buildup*.

Sidescatter

The scattering of rays from walls of objects in the vicinity of the test object or from portions of the test object that cause rays to enter the sides of the test object is sidescatter. As shown in Figure 1.14, sidescatter obscures the image outline just as internal scatter does.

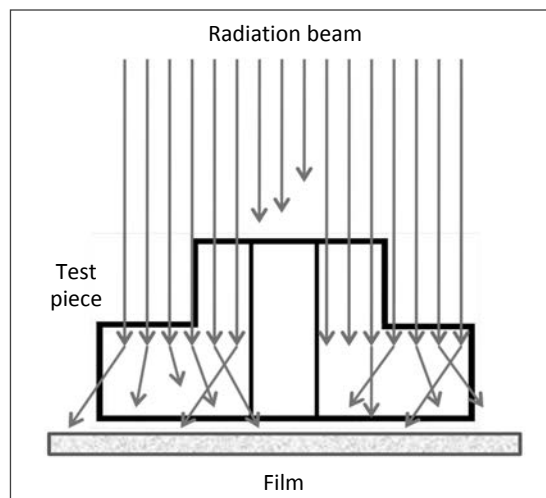


Figure 1.13: Internal scatter.

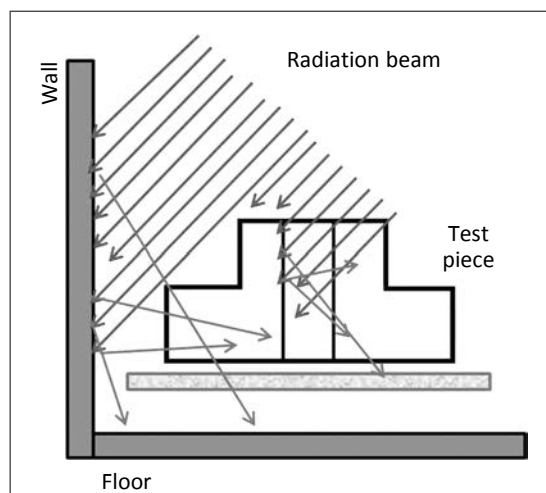


Figure 1.14: Sidescatter.

Backscatter

The scattering of rays from surfaces or objects beneath or behind the test object, as shown in Figure 1.15, is backscatter. Backscatter also obscures the test object image.

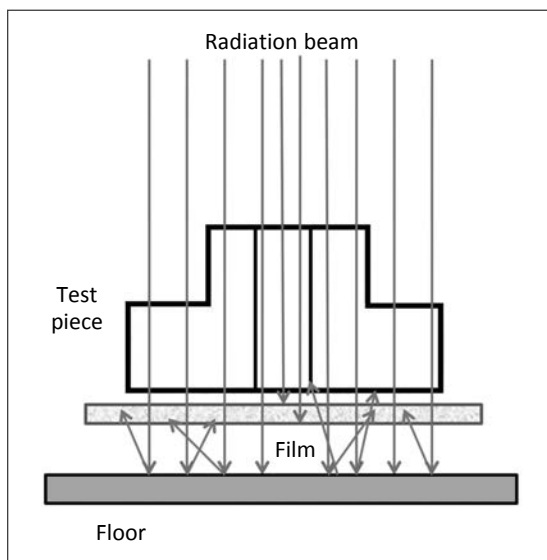


Figure 1.15: Backscatter.

Chapter 1: Review Questions

1. Which of the following is a false statement regarding the characteristics of X-ray and gamma rays?
 - a. Living tissue is damaged when it absorbs X-rays or gamma rays.
 - b. Absorption is decreased as the atomic number and density of the absorber increases.
 - c. The higher their energy, the greater the depth to which they can penetrate in a given material.
 - d. The higher their energy, the shorter their wavelengths.
2. What would be the result if the wavelength of the X-ray was to increase?
 - a. Only fine-grain film would be able to be used.
 - b. The heat on target would increase.
 - c. The penetration of the beam would increase.
 - d. The penetration of the beam would decrease.
3. Charged particles passing through matter lose energy primarily because of:
 - a. scatter radiation
 - b. ionization
 - c. secondary scatter
 - d. charged electrons
4. When electrons of many different energies strike a target, a continuous spectrum of X-rays is generated. These X-rays are known as:
 - a. bremsstrahlung
 - b. compton X-rays
 - c. scattering
 - d. slow electron emission
5. You have an Ir-192 source whose strength was 3.7 TBq (100 Ci) on July 1. What will be its approximate strength on Sept. 13 the same year if the half-life of Ir-192 is 75 days?
 - a. 1 TBq (30 Ci)
 - b. 1.9 TBq (50 Ci)
 - c. 2.6 TBq (70 Ci)
 - d. 3.3 TBq (90 Ci)
6. After three half-lives have elapsed, what will be the strength of an isotope source relative to its original strength?
 - a. 25% of the original
 - b. 33% of the original
 - c. 12.5% of the original
 - d. 11% of the original
7. What radioisotope has a gamma-ray energy emission that is approximately equal to 320 kV radiation from an X-ray tube?
 - a. Co-60
 - b. Ir-192
 - c. Cs-137
 - d. Ur-238
8. The specific activity of a gamma-ray source is important because it determines:
 - a. the size of source required for a given activity
 - b. the energy of the radiation that will be emitted
 - c. the rate at which the specific isotope decays
 - d. which type of radiation (alpha, beta or gamma) it will emit

Chapter 2

Radiographic Film Exposures

A radiograph is the shadow picture produced by X-ray or gamma radiation that has passed through an object and been partly absorbed by film. The radiation that is absorbed in the film sensitizes the silver halides in the emulsion in such a way that development converts them to silver particles.

In the film areas exposed to higher levels of radiation, more silver particles are produced by development, making the film darker. Film areas exposed to less radiation, due to a thicker or more absorptive object material, are lighter after processing, as shown in Figure 2.1.

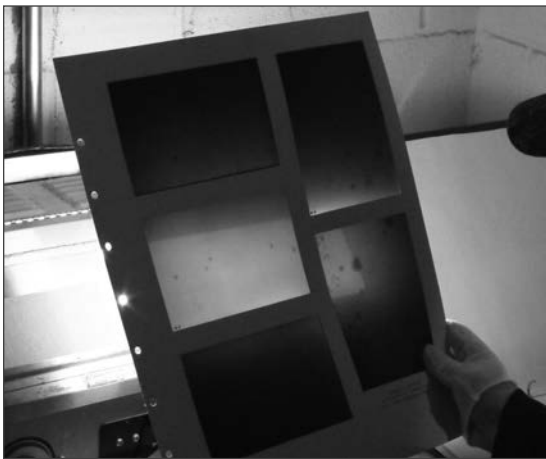


Figure 2.1: Radiographic image.

Film Density

The degree of film darkening is called *film density*. It is measured by the amount of visible light that can penetrate the film (Figure 2.2).

Density is defined as the logarithm of the amount of light incident on one side of the film divided by the amount of light transmitted through the film. Mathematically, density is presented as:

$$D = \log(I_o / I_t)$$

Equation 1

where:

D = density

I_o = light intensity incident on the film

I_t = light intensity transmitted

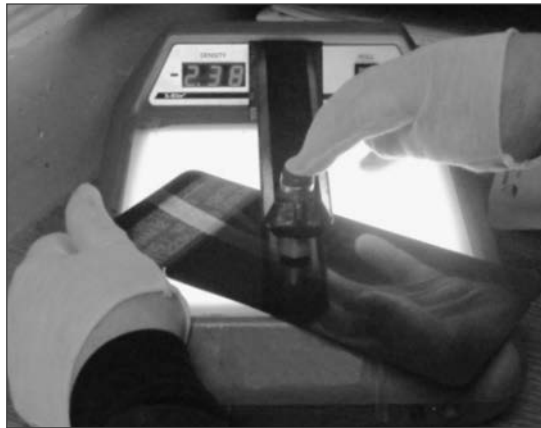


Figure 2.2: Measuring film density.

Film density and exposure time are related. Exposure is the intensity of radiation multiplied by the time it takes to produce a particular density. Thus, exposure is related to the time the film is exposed to penetrating radiation. All factors being equal, the longer the film is exposed to the penetrating radiation, the darker the density will be on the developed radiograph.

Image Quality

The usefulness of any radiograph depends on the quality of the image or the sensitivity. Sensitivity is defined as the smallest detail of the object that can be seen on the radiograph. It is a function of the contrast and the sharpness of the radiographic image.

Radiographic Contrast

Radiographic contrast refers to the amount of contrast observed on a radiograph and is affected by subject contrast and the contrast sensitivity of the film. Radiographic contrast can also be affected by the unsharpness of the detected image.

Contrast is affected by the radiation level. Most reference books recommend that a radiograph

should be made with the lowest-energy radiation or, in the case of X-rays, the lowest kilovoltage that will transmit adequate radiation intensities to the film. This is because long wavelengths tend to improve contrast. However, radiation energies that are too low produce excessive amounts of scattered radiation that washes out fine details. On the other hand, energies that are too high, although they reduce scattered radiation, may produce images having contrast that is too low to resolve small discontinuities.

Subject Contrast

Subject contrast is governed by the intensity of transmitted radiation through various parts of the object and by the amount of scatter radiation reaching the film. The amount of radiation transmitted through various regions of a test object depends on the thickness of those regions and on the radiation energy being used. Large differences in thickness produce high subject contrast; small differences in thickness produce little subject contrast.

Film Contrast

Each type of radiographic film has a characteristic relationship between the amount of exposure and the density that is produced by that exposure. The relationship is usually expressed as a graph or characteristic curve in which the density is plotted against the logarithm of the relative exposure, as shown in Figure 2.3. *Relative exposure* is used because there are no other measurement units that apply to all possible exposure conditions.

The log of the relative exposure is used to compress an otherwise long scale. A log scale has the added value that the same distance will separate the logs of any two exposures having the same ratio, regardless of the actual exposure values. This feature is useful in exposure calculations.

The slope of a film's characteristic curve is a measure of its contrast, while the curve's position left or right within the graph is a measure of film speed. The contrast is greatest where the greatest density difference is produced by a given difference in exposure, that is, where the slope of the curve is greatest.

Given the same degree of development, a film with a curve that lies to the left of another film is the faster film, because the left-most curve indicates that less exposure is required to produce a given density. The shape of the characteristic curve of a given film is not sensitive to radiation energy, but it

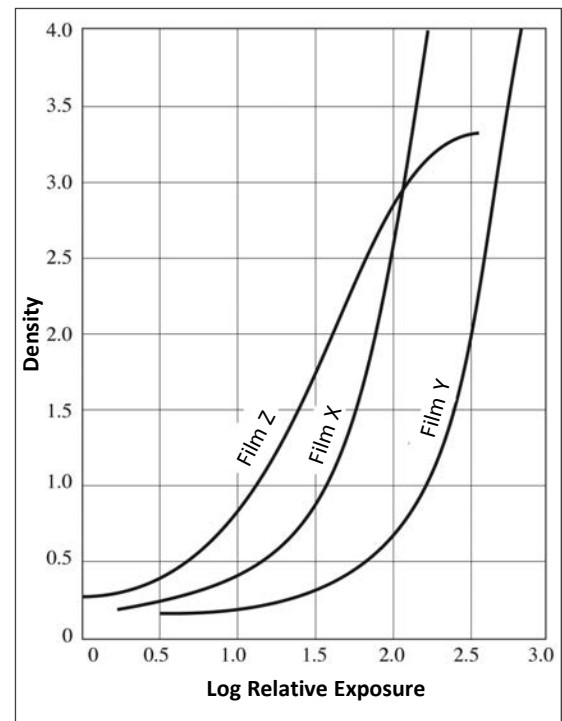


Figure 2.3: Characteristic curves of three typical X-ray films, exposed between lead foil screens.

is affected by the degree of film development, including time, temperature and composition of the developer. Within limits, an increase in degree of development increases the contrast exhibited by the radiograph.

Effect of Radiation Energy

Low-energy radiation produces high-contrast images because it is more easily absorbed than high-energy radiation. Therefore, only a small change in object thickness is necessary to achieve reasonable contrast. On the other hand, a large thickness difference is necessary to achieve reasonable contrast when using high-energy radiation.

Sharpness

The sharpness of a radiograph is usually judged from the image of known features such as edges, steps, or holes in the object. Sharpness is a function of geometric factors such as source size, source-to-film distance, object-to-film distance and screen-to-film contact, as well as the type of film and screens, and the radiation energy used. Unsharpness is also called geometric unsharpness, because that is the component of sharpness that can be calculated.

Geometric Exposure Principles

To create a radiograph there must be a source of radiation, a test object and film or some other type of imaging detector. A radiograph is a shadow picture of a test object placed between the film/detector and the X-radiation or gamma-radiation source. If the film/detector is placed too far from the test object, the discontinuity images will be enlarged. If the test object is too close to the source, any discontinuity images will be greatly enlarged, resulting in the loss of dimensional acuity. Proper placement of the film/detector minimizes enlargement and allows for more accurate representation of the size of the discontinuity.

The degree of enlargement varies according to the relative distances of the object from the film/detector. A certain degree of enlargement exists in every radiograph because some parts of the test object are always farther from the film/detector than others. The greatest enlargement is found when radiographic test objects are located at the greatest distance from the recording surface.

Enlargement cannot be eliminated entirely; however, with the use of an appropriate source-to-film/detector distance, enlargement can be minimized to a point where it will not be objectionable.

Figure 2.4 is a diagram of a radiographic exposure showing basic geometric relationships between the radiation source, the test object and the film/detector on which the image is recorded. These relationships are due to X-rays and gamma rays obeying the laws of electromagnetism. The ratio of the test object diameter D_o to the image diameter D_f is equal to the ratio of the source-to-object distance d_o to the source-to-film/detector distance d_f . For the radiographic image to be close to the same size as the test object, the film/detector must be placed as close to the test object as possible and the radiation source must be placed as far from the film or detector as is practical.

Film/Detector Image Sharpness

The sharpness of the image is determined by the size of the radiation source and the ratio of the object-to-film/detector distance and source-to-object distance. Figure 2.5(a) shows a small geometric unsharpness (penumbra) when the test object is close to the film/detector. The umbra (darkest part of the shadow) is the only part that is normally seen in a radiograph. The penumbra (unsharpness) is seldom seen.

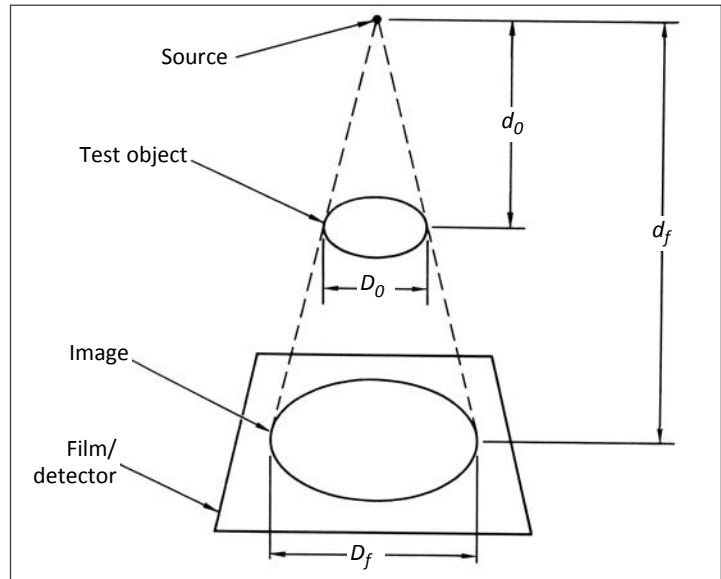


Figure 2.4: Image enlargement.

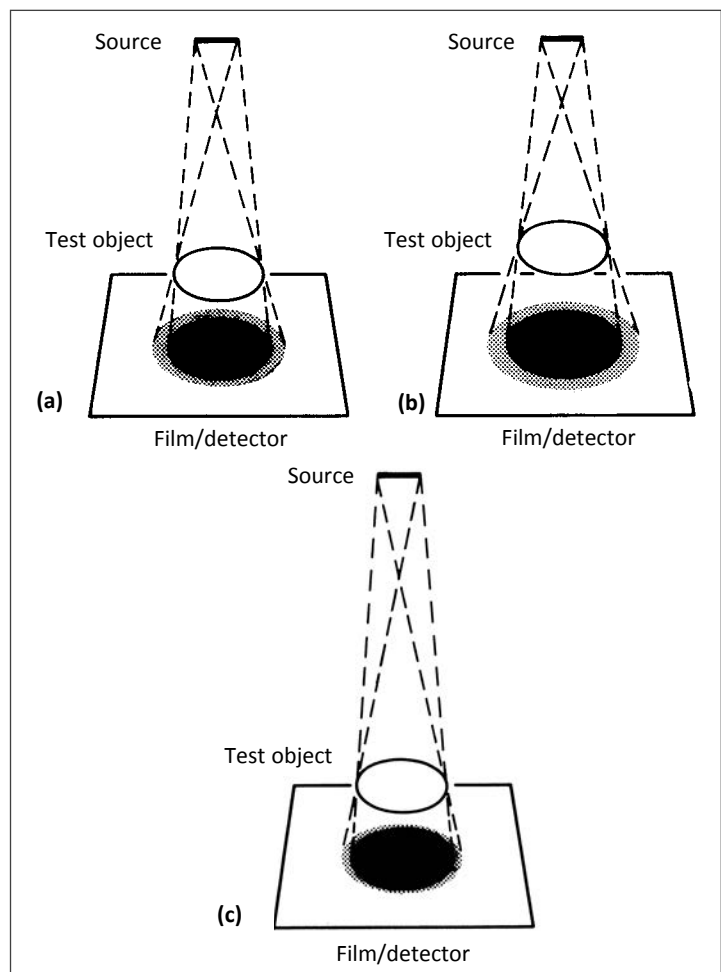


Figure 2.5: Image sharpness and penumbral shadow.

Figure 2.5(b) shows greater geometric unsharpness when the source-to-film/detector distance remains unchanged but the object-to-film/detector distance is increased. Figure 2.5(c) shows a smaller geometric unsharpness when the object-to-film/detector distance is the same as in Figure 2.5(a), but the source-to-film/detector distance is increased.

Most codes recommend maximum values for geometric unsharpness. To determine the geometric unsharpness, use the formula shown in Equation 2.

$$\frac{U_g}{F} = \frac{d}{D_o}$$

or

$$U_g = F \frac{d}{D_o}$$

Equation 2

where:

- U_g = geometric unsharpness
- F = the source size (the maximum projected dimension of the radiating source, or effective focal spot, in the plane perpendicular to the surface of the weld or object being radiographed)
- D_o = the distance from the source of radiation to the weld or object being radiographed
- d = the distance from the source side of the weld or object being radiographed to the film/detector.

Optimum geometric sharpness of the image is obtained when the radiation source is small, the distance from the source to the test object is relatively great and the distance from the test object to the film/detector plane is small. Figure 2.6 illustrates the decrease in geometric unsharpness with a decrease in source size.

Image Distortion

Two possible causes of film image distortion are shown in Figure 2.7. If the plane of the test object and the film/detector plane are not parallel, image distortion will result. Image distortion will also result if the radiation beam is not directed perpendicular to the film/detector plane.

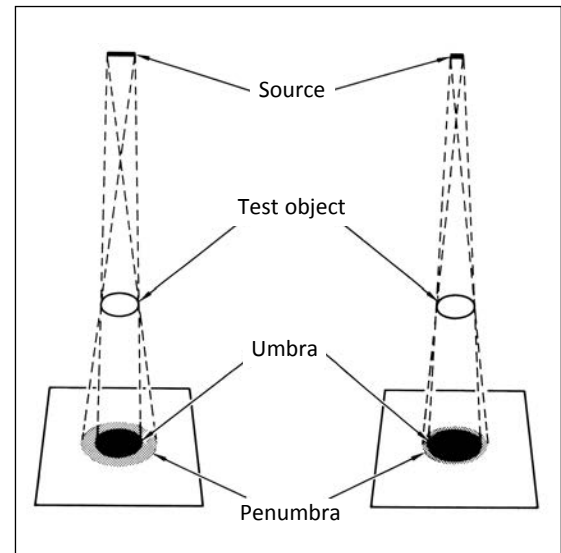


Figure 2.6: Effect of source size on image sharpness.

Nongeometric Factors Affecting Unsharpness

Unsharpness is also affected by the radiation energy, the type of film or other detector used, the type and position of screens and filters used, and the contact of the screens with the film. Increasing the radiation energy or increasing the speed of the film being used increases the unsharpness. Fluorescent screens increase unsharpness, while metallic screens vary in their effects depending on their composition, thickness and position relative to the film. All screens and filters that are within the film holder **MUST** be in intimate contact with the film or they will greatly increase unsharpness.

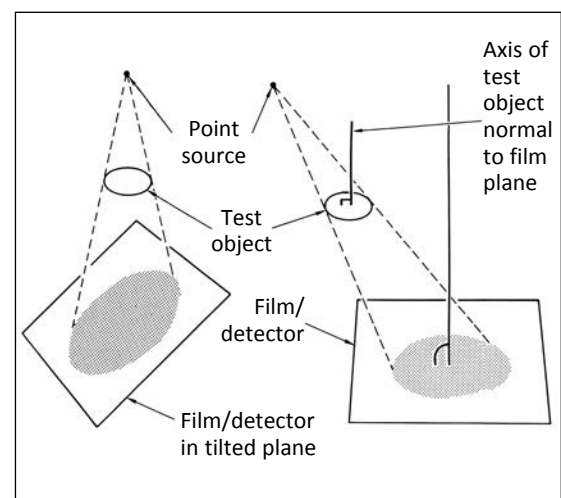


Figure 2.7: Image distortion.