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MILITARY HANDBOOK

RADIOGRAPHIC TESTING

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5.0 SAFETY NOTICE

Radiographic testing requires the use of radiation beams with energies sufficient to penetrate material objects.

It is the potential exposure to these penetrating radiations that makes radiographic testing the greatest safety concern of all the nondestructive testing methods covered in this handbook. Normally, these radiating beams can not be detected by any of our five senses. When radioactive sources are present, they are always "on." Therefore, strict compliance with safety regulations is required. Modern X-ray machines use high voltages and therefore safety procedures for electrical hazards must also be employed. Section 5.8 presents a more thorough coverage of the safety precautions and rules associated with this test method.

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5.1 INTRODUCTION

Radiographic testing provides a nondestructive method of inspecting the internal continuity of a specimen. It is truly a modern miracle that allows us to see "through" a piece of steel or almost any other material. Even though radiography can be relatively expensive and may involve extensive safety considerations, its uniqueness and applicability find it in wide use in manufacturing, research, and in medical diagnostics and therapy.

Although a study of radiographic testing might include only x-rays and their uses, this chapter includes both natural and artificial radiation sources with coverage of x-ray, gamma (γ-ray) and neutron (N-ray) radiography.

This chapter provides the fundamental principles and guides associated with radiographic testing. It includes the theory of operation, the type of equipment, the advantages and disadvantages of the method, various applications and standards, and guides for specific disciplines. The information contained in Chapter 1 should be included with this chapter for general guidelines to the employment of all NDT methods and for a more complete understanding of radiographic testing as it compares with other basic methods.

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5.2 BASIC PRINCIPLES

Radiographic testing involves three basic concepts. First, there must be a beam of radiating energy that can penetrate a specimen. Second, the beam must be selectively attenuated by the variables of the specimen as penetration occurs. Last, the results of this selective attenuation must be detected and/or displayed. Therefore, we will study penetrating radiation beams, their attenuations due to the absorption characteristics of materials, and present-day detection and display systems.

5.2.1 PENETRATING RADIATION

Radiographic testing normally involves two types of penetrating radiation: electromagnetic radiation of high-energy photons or a collimated beam of neutrons. Some of the principles presented in the following subsections are applicable to both types of penetrating beams, but the discussions in this and some of the following subsections are specifically directed to X-rays and γ-rays, the radiation of high-energy photons.

Figure 5.2(1) shows the electromagnetic spectrum. Gamma rays and X-rays comprise the high energy, short wavelength portion of the spectrum. The boundaries shown in Figure 5.2(1) between the areas listed are fairly arbitrary. There are no sharp, natural boundaries or exact, or fixed, limits. The visible range might provide the greatest exceptions to these statements, but even here the exact limits of the boundaries are often debated.

The low energy, low frequency, long wavelength X-rays are called "soft" X-rays, and the high energy, high frequency, short wavelength X-rays are called "hard" X-rays.

It has been found that an electromagnetic radiation field can always be divided into fixed-sized energy bundles called photons. The energies of these single units, or bundles, are fixed by their wavelengths, or frequencies. The characteristics of an ultraviolet, X-ray or a gamma ray photon, can be identical if they have the same wavelength. In other words, all photons are essentially the same except for their wavelengths, or equivalent frequencies or energies. The proper differentiation between X-ray and γ-ray photons is their source of origin. An X-ray photon is produced from a man-made device (an X-ray tube), while a γ-ray photon is produced by a radiation from a naturally radioactive isotope.

The total energy in an electromagnetic beam is dependent upon the energy of the individual photons and the total number of photons that are present. It is the energy of the individual photons in the ray that determines the penetration capabilities of the rays. The total number of photons, however, determines if the amount of penetration is sufficient for detection. Two beams can have the same total amount of energy, but one will penetrate a specimen and the other will not because of differences in energies of their individual photons. Therefore, to properly work with radiography, one must know both the frequency or wavelength spectrum of a beam and its total

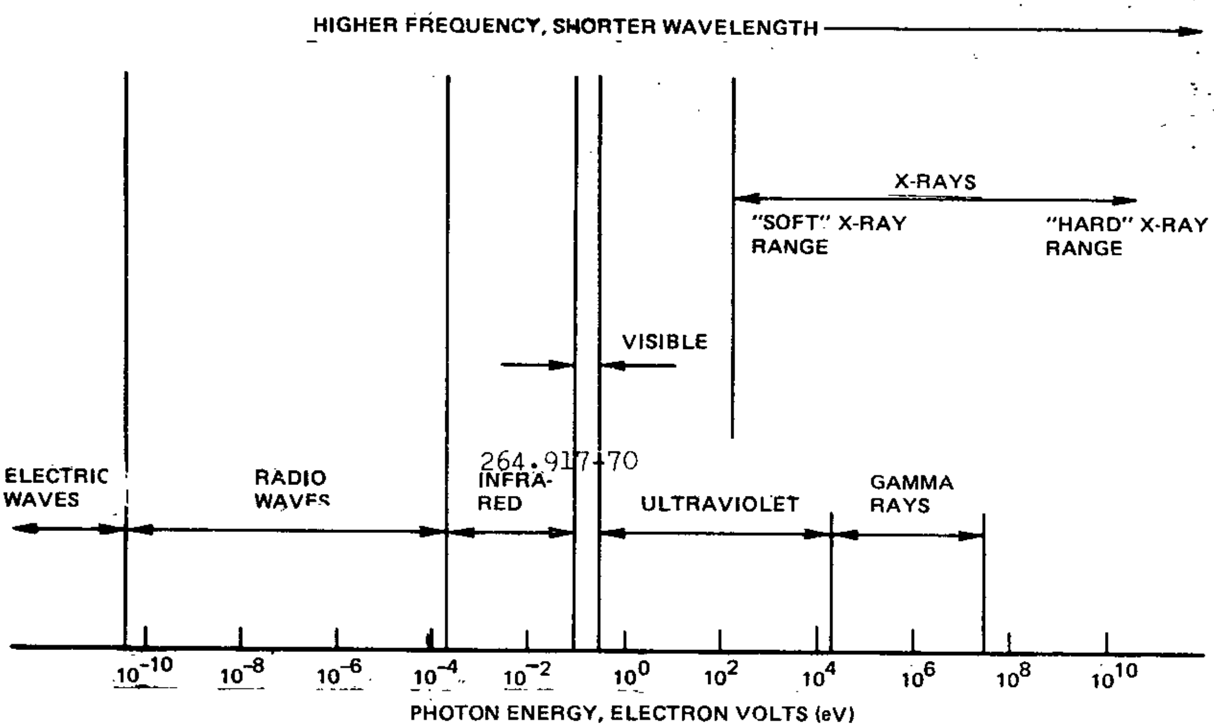

Figure 5.2(1). The electromagnetic spectrum.

energy. When a chart or table shows the energy of a beam, it must be determined if the chart is showing the energies of the individual photons, or the total energy of the beam. These differences are not always clearly indicated and yet both are important.

The spectrum of an X-ray beam differs greatly from that of a radioactive source. A radioactive source can have a single frequency, single energy photon emission. (In most cases, there is more than one radioactive process involved, and so more than one frequency of radiation is present, but those that are present are each of one fixed photon energy level.) The spectrum of an X-ray beam, however, includes a continuous spectrum, along with fixed frequency characteristic rays, as shown in Figure 5.2(2).

Table 5.2(1) lists some common radioactive gamma ray energy levels (10^6eV = 1 MeV).

For gamma ray sources, the individual photon energies can be high or low, depending on the specific isotope, but the total energy of the beam will depend on the amount of the isotope present and its overall activity.

The maximum energy level of a photon in an X-ray spectrum is limited by the voltage applied to the X-ray tube (the voltage used to accelerate the electron beam). (See Paragraph 5.3 for an X-ray tube description.) The total amount

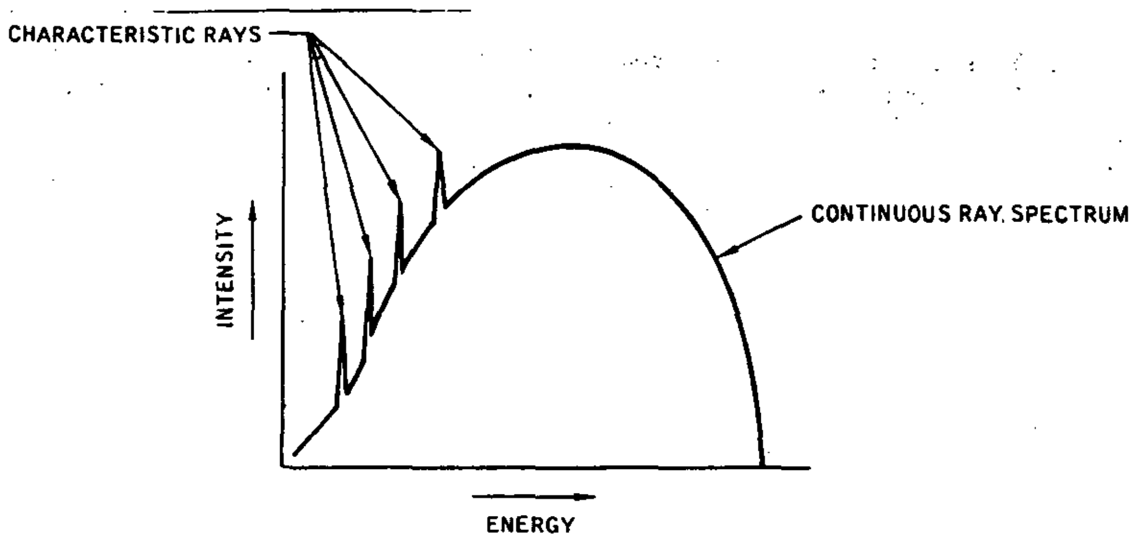

Figure 5.2(2). X-ray spectrum.

Table 5.2(1). Gamma ray energy (energy of the individual photons).

ISOTOPE	GAMMA RAY ENERGY MeV
COBALT 60	1.33, 1.17
IRIDIUM 192	0.31, 0.47, 0.60, ETC.
THULIUM 170	0.84, 0.052
CESIUM 137	0.66

of energy in the beam, however, is dependent upon the current of the electron beam. Therefore, both current values and voltage values are important when X-rays are involved.

The characteristic rays of an X-ray tube (see Figure 5.2(2)) are determined by the atoms that make up the X-ray tube's anode and are the excitation levels of these atoms. Tungsten is a common anode material and tungsten characteristic rays do not begin until an energy of about 70 KeV is reached. Since these characteristic rays are narrow, single frequency spectrums, they contain very little of the total energy of the ray and are not of direct use in most X-ray work.

Figure 5.2(3) shows how the spectrum can be varied by changing the current and voltage applied to the tube. With the same applied voltage, an increase in X-ray tube current produces more total energy even though the individual photons have the same energy limits and distributions. When the current remains the same but the tube voltage is increased, both the total amount of energy and the energy limits of the photons increase. When the voltage is increased, a new energy range of photons appears. All those above point a of Figure 5.2(3) have higher energies than those that were present at the lower voltage. It can be noted that the photon energy levels of the characteristic rays remain fixed and do not shift (on the horizontal axis) with changes in either the voltage or the current.

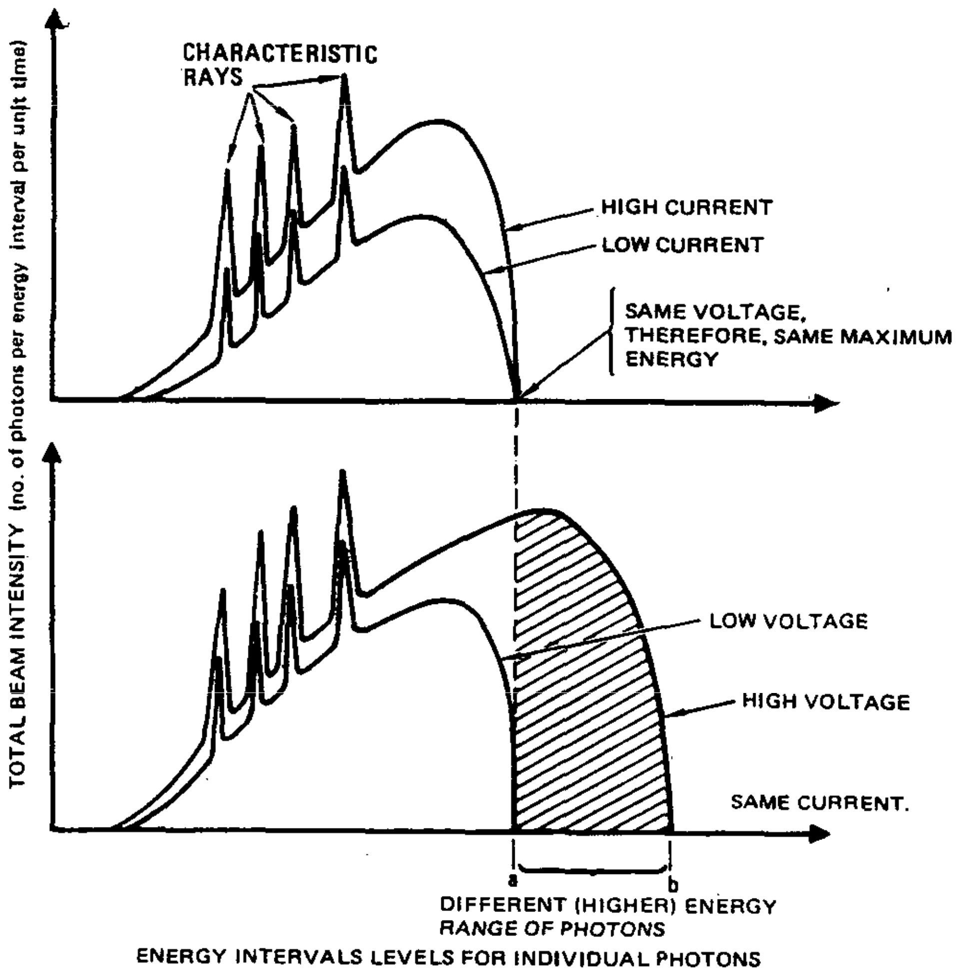

Figure 5.2(3). Varying energy spectrums.

Mathematical relationships useful for some of these variables are:
For photons,

$$E = hf = hc/\lambda, \qquad (1)$$

where

E = energy of photon (ergs)

h = Planck's constant (6.626×10^{-27} erg-sec)

f = frequency of radiation energy (Hz or cycles/sec)

c = speed of light (2.998×10^{10} cm/sec)

λ = wavelength of radiation energy (cm).

or

$$E \quad \frac{12,400}{\lambda} \qquad (2)$$

where E = energy in electron volts (eV) (same magnitude as the volts, V, applied to the X-ray tube) and λ = wavelength in angstroms (10^{-8} cm).

The maximum energy photon from an X-ray tube is eV, and thus the minimum wavelength and maximum frequency from an X-ray tube, will be:

$$\lambda_{min} = \frac{12,400}{V}, \qquad (3)$$

and

$$f_{max} = 2.42 \times 10^{14} V, \qquad (4)$$

where

λ = wavelength in angstroms

f = frequency in hertz

V = Volts applied to X-ray tube.

(e = electronic charge carried by an electron, 1.6×10^{-19} coulombs or 1.6×10^{-12} ergs/volt)

The total power of an X-ray beam (P):

$$P \approx K_1 A Z V^{K_2} \qquad (5)$$

where

P = Energy per unit time

K_1 = Constant which varies with tube design, etc.

A = Tube current

Z = Atomic number of tube's anode material

K_2 = Constant, almost always greater than 2, often around 2.5.

The constant K_1 is very small, so small that only a small percent of the total energy applied to the tube is ever seen as X-ray energy. The vast majority of the energy appears as heat. An analyses of Equation 5 will show that the efficiency of an X-ray tube increases with increased voltage, being at least proportional to the voltage raised to the first power or more.

5.2.2 BEAM ATTENUATION AND MATERIAL ABSORPTION CHARACTERISTICS

Several factors affect the attenuation of a beam. Any beam that radiates from a localized source will exhibit an intensity loss because of the geometric increase in the area of the distribution as radiation proceeds from the source. Theoretically, for a point source, this geometric factor will be proportional to d^{-2}, where d is the distance from the source. For electromagnetic beams, there are other losses in intensity due to interaction with matter that may be located in the path of the beam. There are several kinds of interactions between photons and matter: simple scattering, photoelectric absorption, Compton scattering, pair production, and X-ray generation. These interactions are described as follows:

a. Scattering (includes Rayleigh scattering). When photons approach close to charged particles (normally the "orbital" electrons around a nucleus) the directions of some of the photons can be changed with no measurable loss in their energies. The amount and degree of direction changes made depends on the number of particles present and their relative size as functions of wavelengths. The interaction involves what could be termed reflection and/or refraction.

b. Photoelectric Absorption. When a photon passes through matter, its entire energy can be transferred to an orbital electron. The photon thus ceases to exist. Part of the photon energy is expended in ejecting the electron from its orbit and the remainder imparts velocity to the electron. This phenomena is known as photoelectric effect or absorption (see Figure 5.2(4)). Radiography is most often dependent upon this absorption process which is usually the most predominant relationship for photons with energies of 0.5 MeV or less. Photoelectric absorption is an ionization effect that can result in the release of negligibly small-energy photons when the atom returns to its normal state.

c. Compton Scattering. A photon can interact with an orbital electron and transfer only a portion of its energy to the electron. This effect is called Compton scattering (see Figure 5.2(4)) and often occurs when the photon energy ranges from about 0.1 to 3.0 MeV. Part of the photon energy is expended in dislodging the orbital electron and imparting velocity to it. The remainder of the photon energy continues on as a lower energy photon at an angle to the original photon path. This process can be repeated, progressively weakening "the photon" until a photoelectric effect completely absorbs the final photon.

d. Pair Production. (Figure 5.2(4)) Pair production occurs only with very high energy photons of 1.02 MeV or more. At these energy levels, usually when the photon approaches the nucleus of an atom, the photon can be changed to an electron-positron pair. Positrons carry a positive charge, have the same mass as electrons, and are extremely short lived. They combine at the end of their path with electrons to emit two 0.51 MeV or greater photons which can then again be subject to Compton scattering and photoelectric effect.

e. Secondary X-ray Generation. The last three processes, photoelectric absorption, Compton scattering, and pair production, all liberate free electrons that move with different velocities in various directions. Since X-rays are generated whenever free electrons collide with matter, it follows that X-rays in passing through matter can cause the generation of secondary X-rays. These secondary X-rays, or photons, can then repeat any of the first four processes, depending upon their respective energies, etc.

Most of these interactions result in losses in the X-ray intensity. The last interaction, e, results in a regaining of some of these losses. This "gain" is normally a minor part of the whole, and because there is a large amount of randomness in its directions, it is usually of no value and can actually cause a blurring of the X-ray image along with the rest of the scattering that occurs. It is possible, however, to use this process, along with others, to some advantage when it occurs in the immediate vicinity of the film, and can at that point result in an enhanced intensity of the image with negligible blurring.

In general, all these effects of attenuation, alone or combined together, follow an exponential relationship such that:

$$I_x = I_o e^{-\mu x} \qquad (6)$$

where

I_x = beam intensity after penetrating a distance x

I_o = original beam intensity (at x = 0)

μ = attenuation coefficient (cm^{-1})
(a function of photon energy and material)

x = distance of penetration travel (cm)

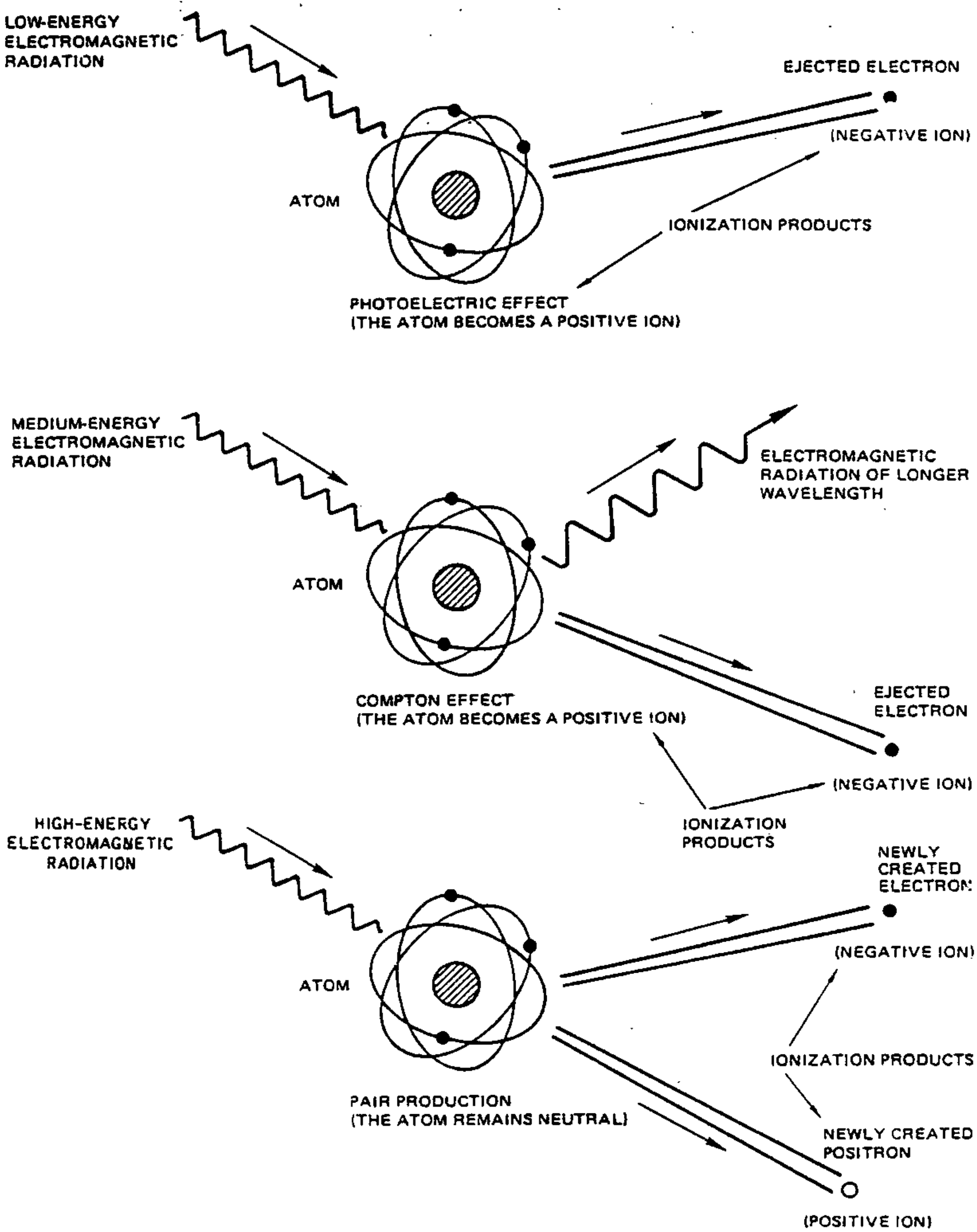

Figure 5.2(4). Ionization interactions of photons with matter.

This law is seldom exactly applicable. It is theoretically correct only when the beam is a narrow, parallel beam, with only one wavelength or photon energy present, with no selective absorption or scattering, and the material is of uniform density, etc. It basically is the law, however, upon which X-ray images are established. It shows the changes in the energy or the intensity of the beam that accounts for the contrast seen in recorded images.

In place of the attenuation coefficient, the absorption coefficient is often used. The absorption coefficient relates to actual photons lost and does not include those photons which leave the beam due to scattering. Therefore, the attenuation coefficient is always slightly more than the absorption coefficient.

The amount (thickness) of material that reduces the intensity of a beam to one-half of its original value is called the half-value layer. This thickness can be related to the absorption coefficient :

$$t_{HVL} = \frac{0.693}{\mu} \qquad (7)$$

where

t_{HVL} = thickness of the half-value layer (cm),
μ = absorption coefficient (cm^{-1})

It must be kept in mind that the attenuation or absorption varies greatly with the energy levels (or wavelength spectrum) of the photons and the type material, and they are exact for only idealized conditions. These "coefficients" are statistical relationships, and short term deviations are "expected" even when conditions are perfect.

These coefficients are often expressed as a mass absorption or mass attenuation coefficient, μ_m, derived by dividing μ by ρ, the density of the material. This allows these equations to be used where variances in material densities are expected. Also, separate elements combined either chemically or physically into material compounds can be considered.

These relationships are:

$$I_x = I_o e^{-\mu_m \rho x} \qquad (8)$$

or

$$I_x = I_o e^{-(\mu_{m1} \rho_1 + \mu_{m2} \rho_2 + \ldots.)x} \qquad (9)$$

where

μ_{m1} = mass attenuation coefficient for element 1
ρ_1 = mass density of 1, as part of the total density of the compound, etc.

In almost all practical situations, the amount of radiation that comes through a material is greater than that amount represented by Equations 6, 8 or 9, and this increase in penetration over that theoretically estimated is called "buildup." It is due to the gain obtained from photons being scattered into (or back into) the beam path, re-radiation from ionized atoms, energy from combining electrons-positrons, or new radiations from the energetic electrons that were ejected in the original absorption process. It must be noted that, because the absorption or attenuation is an exponential function, no amount of shielding can ever stop all the radiation even from a weak source. Therefore, while a safe level of radiation can usually be achieved or maintained, it is never totally eliminated. Table 5.2(2) shows typical half-value layers for different energy levels for different materials.

Table 5.2(2). Approximate half-value layers for certain x-ray tube potentials and gamma-ray sources.

SHIELDING MATERIAL IN INCHES	HALF-VALUE LAYER FOR TUBE POTENTIAL IN KILO-VOLTS PEAK (KVP)							
	50 KVP	70 KVP	100 KVP	125 KVP	150 KVP	200 KVP	250 KVP	300 KVP
LEAD (IN.)	0.002	0.007	0.01	0.011	0.012	0.02	0.03	0.06
CONCRETE (IN.)	0.2	0.5	0.7	0.8	0.9	1.0	1.1	1.2

SHIELDING MATERIAL IN INCHES	HALF-VALUE LAYER FOR RADIOISOTOPE SOURCE		
	IRIDIUM-192	CESIUM-137	COBALT-60
LEAD (IN.)	0.19	0.25	0.49
STEEL (IN.)	0.61	0.68	0.87
CONCRETE OR ALUMINUM (IN.)	1.9	2.1	2.6

If two half-value layers are penetrated, the exiting intensity is 1/4 of the initial intensity since one-half of the intensity is lost through the first layer, then one-half of the remaining half is lost in the second layer.

If three half-value layers are traversed, then only $1/2 \times 1/2 \times 1/2 = (1/2)^3 = 1/8$ of the original intensity is able to penetrate. To repeat, some radiation will always be able to penetrate no matter how many layers are present.

5.2.3 DETECTION SYSTEMS

The most common detection system is the "exposure" of a film negative to the radiating beam as it exits the specimen. The negative becomes "sensitized" by the degree of radiation exposure so that when it is "developed," a particular chemical rate of reaction will be faster for the more exposed areas than for the less exposed areas. The differences in these chemical rates of reactions can be used to produce an image of the original beam intensity gradient. This image is basically a two-dimensional image, resulting in a shadow-graph of the specimen.

The usefulness of a radiograph is usually measured by the response it can produce on the human eye. When the radiographer interprets a radiograph, he is seeing the details of the specimen image in terms of the amount of light passing through the processed film. Areas of high density (areas exposed to relatively large amounts of radiation) will appear dark gray; areas of light density (areas exposed to less radiation) will appear light gray. The density difference between any two film areas is known as contrast. The sharpness of the film image is known as definition. Successful interpretation of any radiograph relies upon contrast and definition detectable by the eye.

The ability of film to record different radiation exposures as differences in density is called film contrast. Radiographic film is fabricated with a variety of emulsions which give different film contrasts and other properties such as speed and graininess.

The film contrast for any particular film is usually determined from a plotted relationship between the film exposure and the resulting film density. This relationship is expressed in the form of film characteristic curves, often called H & D curves. Figure 5.2(5) is an example of one of these curves. It shows film density on a linear, vertical scale and the relative exposure as a horizontal, log scale. Each type and make of film has a different curve. The film contrast is proportional to the slope of the curve.

These H & D curves cannot give exact exposure factors for every particular setup or equipment, but once a point is established on a curve with a particular setup, the change in the exposure required to reach another point on the curve can be determined. For X-rays, the "exposure" variable is proportional to tube current times the time of exposure, usually measured in milliampere-minutes. For γ-rays, the "exposure" is proportional to source strength times the time of exposure, usually measured in millicurries-hours.

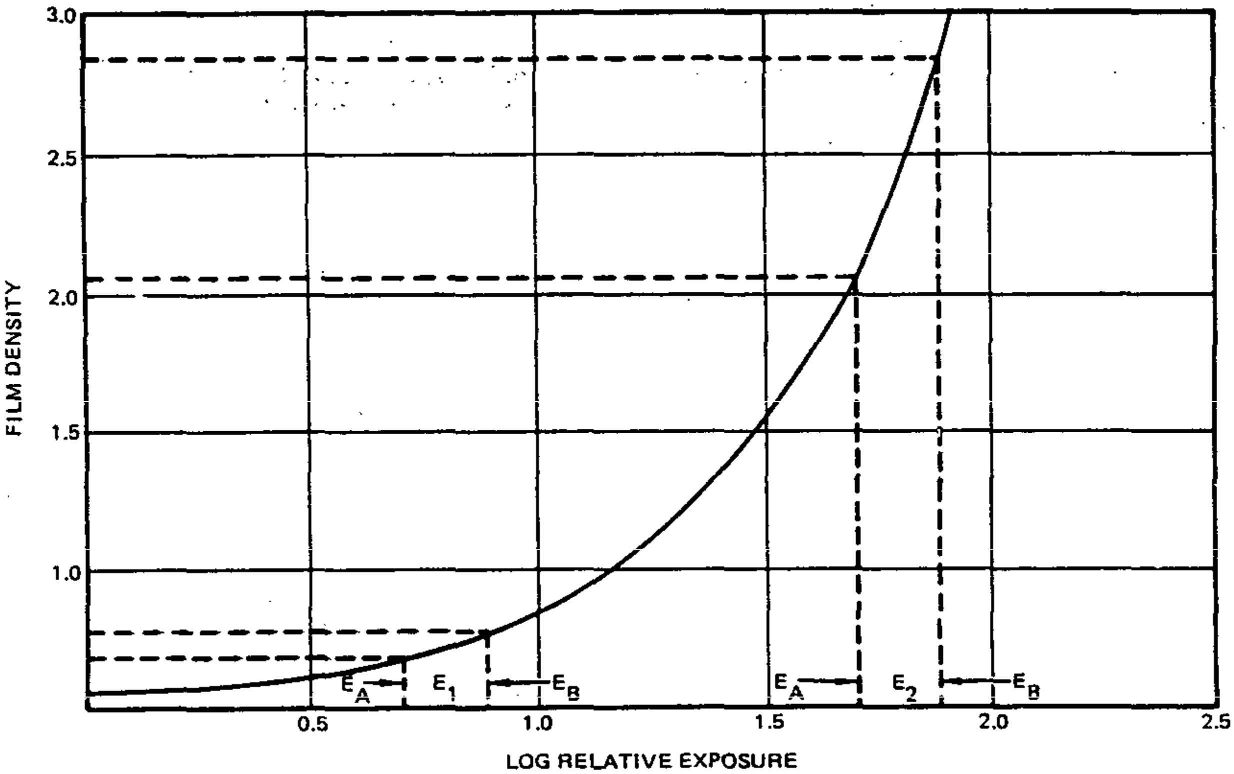

Figure 5.2(5). Film characteristic (H & D) curve.

The "density" variable is the common logarithm of the ratio of visible light incident upon one side of a radiograph to the visible light transmitted through the radiograph. Expressed mathematically,

$$D = \log_{10} \frac{I_o}{I} , \qquad (10)$$

where D is the film density, I_o the intensity of the incident light, and I the intensity of the transmitted light.

It is difficult for the eye to distinguish between small density differences, and there is a lower limit of contrast that the eye cannot detect. The H & D curves for most films make it readily apparent that as exposure increases, overall film density increases and, more importantly, film contrast (the slope of the curve) increases. Referring to Figure 5.2(5) it is obvious that film exposure E_A is less than E_B and that it is the difference between the two that the radiographer must be able to observe. For a low exposure E_1, the difference in density between E_A and E_B due to the low slope of the curve, is relatively small, and will probably not be discernible by the eye. By increasing the exposure to the value represented by E_2, not only is the overall density of the radiograph increased, but the density difference (radiographic contrast) between E_A and E_B is greatly increased. The resulting contrast is easily detectable by the eye. Selection of a correct exposure can use the film's contrast characteristics to amplify the subject contrast, resulting in a useful radiograph. In industrial radiography, films should always be exposed for a density of at least 1.5. The highest desirable density is limited only by the light intensity available for reading the radiograph, usually no greater than 4.

Film speed is measured by the exposure required to obtain a desired film density. High-speed film needs only low exposure while slow-speed film requires more exposure to attain the same film density. Figure 5.2(6) illustrates H & D curves for three different speed films. The shape of each curve and its position on the log relative exposure axis is determined by the design of the film. Film speed is a consideration of importance since time is a cost factor in any industrial operation. Whenever other considerations permits, such as being able to accept increased graininess, fast film may be used.

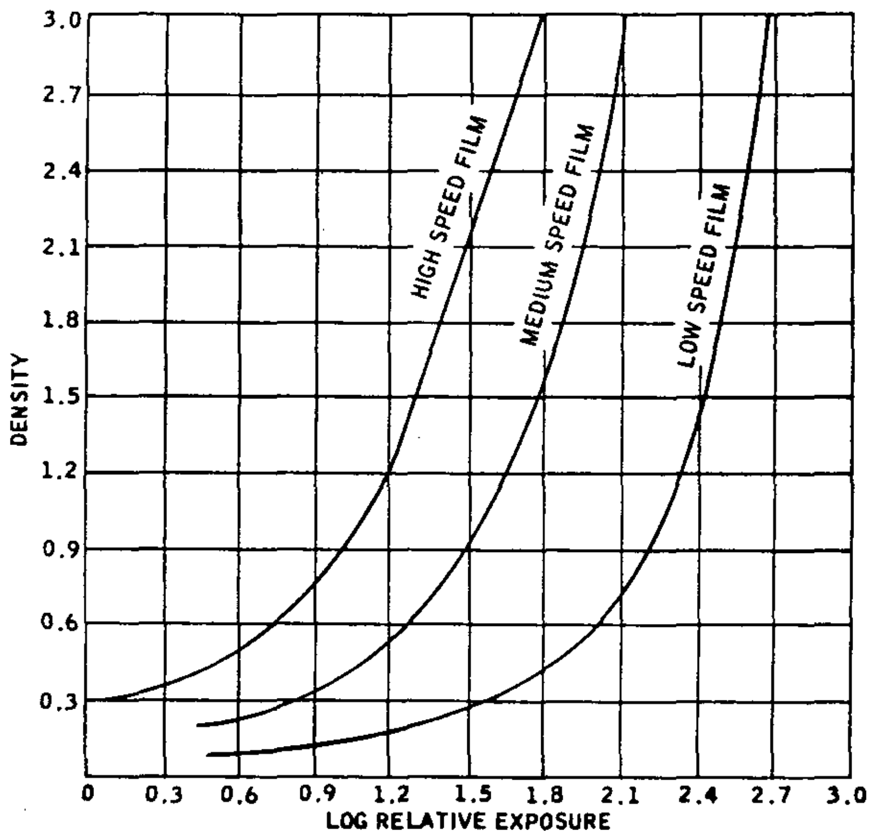

Figure 5.2(6). Relative film speed.

Graininess is the visible evidence of the grouping into clumps of the minute silver particles (grains) that form the image on radiographic film. Graininess affects film contrast and image definition, and all film is subject to it (see Figure 5.2(7)). The degree of graininess of any film is dependent upon:

a. The fine or coarse grain structure of the original film emulsion.

b. The quality of the radiation to which the film is exposed (an increase in the penetrating quality of the radiation will cause an increase in graininess).

c. Film processing. (Graininess can be directly affected by the development process. Under normal conditions of development, any increase in development time is accompanied by an increase in film graininess.)

d. The use of fluorescent screens. (Fluorescent screens also amplify the increased graininess with increase in radiation energy.)

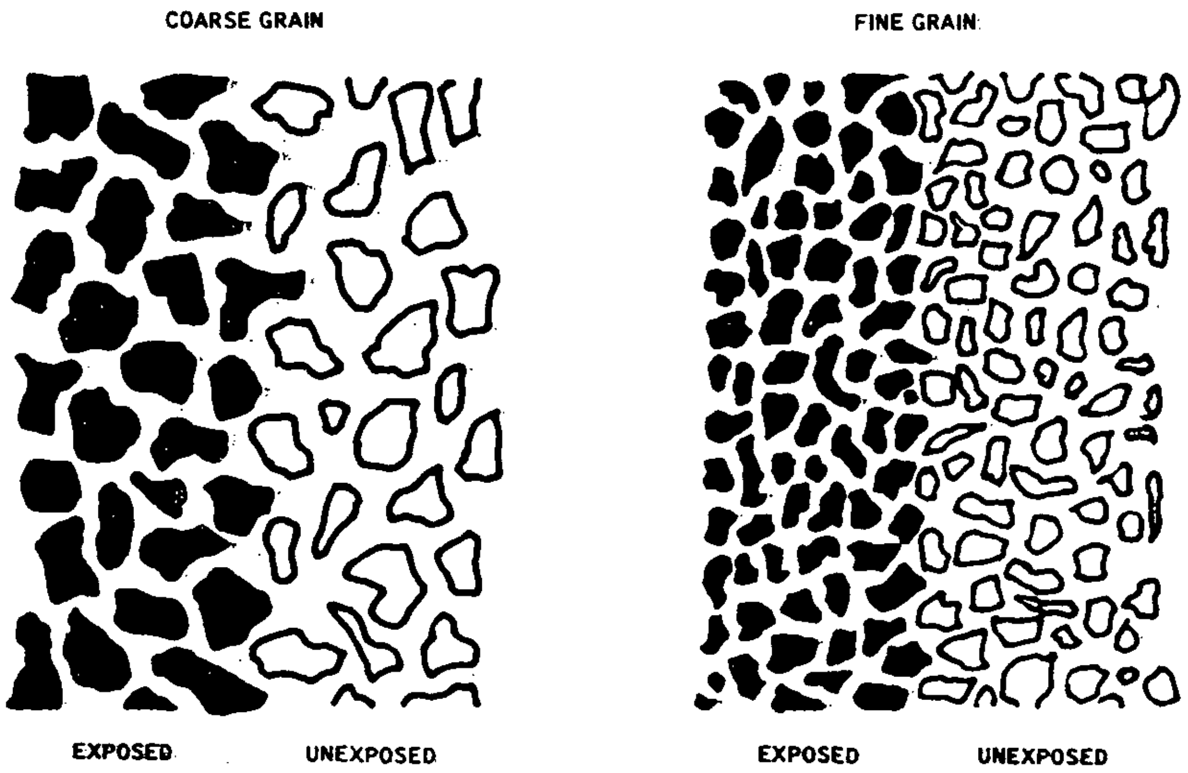

Figure 5.2(7). Film grain (greatly magnified).

The selection of film by the radiographer is based on the need for radiographs of a certain contrast and definition quality. Film contrast, speed, and graininess are interrelated and fast films usually have large grains and poor resolution, whereas slow films have fine grain and good resolution. Therefore, though it is economically advantageous to make exposures as short as possible, the use of fast film is limited by the graininess that can be tolerated in the radiograph. Film manufacturers have created films of various characteristics, each designed for a specific purpose. Their recommendations as to film usage should be considered.

Other detection systems are used. They are:

(1) Fluoroscopy uses a screen that becomes proportionally fluorescent when exposed to different intensities of X-rays to produce a direct image on the screen. In this detection method the screen must be viewed indirectly; e.g., by a mirror, to prevent direct exposure of the viewer to the X-rays. Image amplifiers can be used to increase the intensity and size of the fluorescent image.

(2) A special television camera can be used that is X-ray sensitive rather than photo-sensitive.

Other special detection methods (ionization detectors, photolithographic processes, and others) are also in use. In all these cases, simple two-dimensional images can at most be recorded, all obtained from straight line (ray) data. Through mathematical analysis and/or multiple exposures, three-dimensional information can be constructed (as is done in tomography), but the direct imaging is at best two dimensional. X-ray lasers, if and when available, might provide three-dimensional holographic recordings, but for the present, three-dimensional information must be by overt reconstruction processes.

5.2.4 GAMMA RAYS

Since gamma rays are high-energy photons, then all previous comments about photons, their interaction with matter, their absorption and scattering, etc., are applicable to gamma rays. There are several concepts and definitions, however, that are applicable just to gamma ray sources.

Gamma rays are produced by the nuclei of isotopes which are undergoing natural disintegration. Isotopes are varieties of the same chemical element having different atomic weights. A parent element and its isotopes all have an identical number of protons in their nuclei but a different number of neutrons. Among the known elements, there are more than 800 isotopes of which more than 500 are radioactive.

There are natural radioactive isotopes and man-made radioactive isotopes. Radium is one of the best known and most used natural radioactive sources. Man-made radioactive sources include Cesium 137, Cobalt 60, Thulium 170, and

Iridium 192. The first of these is obtained as a fission by-product; the others are obtained by neutron bombardment. Both natural and artificially produced isotopes produce gamma rays, alpha particles and/or beta particles.

In radiography, the more penetrating gamma rays are, except for safety, the only radiations of direct interest. The intensity of an isotope source is measured in roentgens per hour at a distance of one meter (rhm) or at a distance of one foot (rhf). This is a measure of radiation emission over a given period of time at a fixed distance. The activity (amount of radioactive material) of a gamma ray source determines the intensity of its radiation. The activity of artificial radioisotope sources is determined by the effectiveness of the neutron bombardment that created the isotopes. The measure of activity is the curie (3.7×10^{10} disintegrations per second).

Specific activity is defined as the degree of concentration of radioactive material within a gamma ray source. It is usually expressed in terms of curies per gram or curies per cubic centimeter. Two isotope sources of the same material with the same activity (curies) but different specific activities will have different dimensions. The source with the greater specific activity will be the smaller of the two. For radiographic purposes, specific activity is an important measure of radioisotopes, since the smaller the radioactive source the greater the sharpness of the resultant film image (see Figure 5.4(2)).

The length of time required for the activity of a radioisotope to decay (disintegrate) to one-half of its initial strength is termed "half-life." The half-life of a radioisotope is a basic characteristic and is dependent upon the particular isotope of a given element. In radiography, the half-life of a gamma ray source is used as a measure of activity in relation to time, and dated decay curves, similar to that shown in Figure 5.2(8), are supplied with radioisotopes upon procurement.

Radioactive decay follows an exponential relationship, and therefore a straight line plot occurs on a semi-log graph, as shown in Figure 5.2(8).

5.2.5 NEUTRON RAYS

Figure 5.2(9) indicates one reason why N-rays are used and why they are important. The mass absorption of X-rays follow fairly uniformly the atomic number of the elements, being largely affected by the number of orbital electrons that are present with which the X-ray photons can interact. The absorption of neutrons, however, is much different. As Figure 5.2(9) shows, some of the lowest atomic number elements, where X-rays are the least absorbed, have great absorptivity for neutrons. It is this great difference in relative absorption capabilities that can make N-rays useful when X-rays cannot do the job. For one example, when explosives (explosives usually contain a large number of hydrogen atoms) must be viewed within a steel case, X-rays are fairly useless since the X-rays are almost entirely absorbed by the steel and are relatively unaffected by the explosive. Neutron rays, however, will normally give good results, going easily through the steel, but absorbed

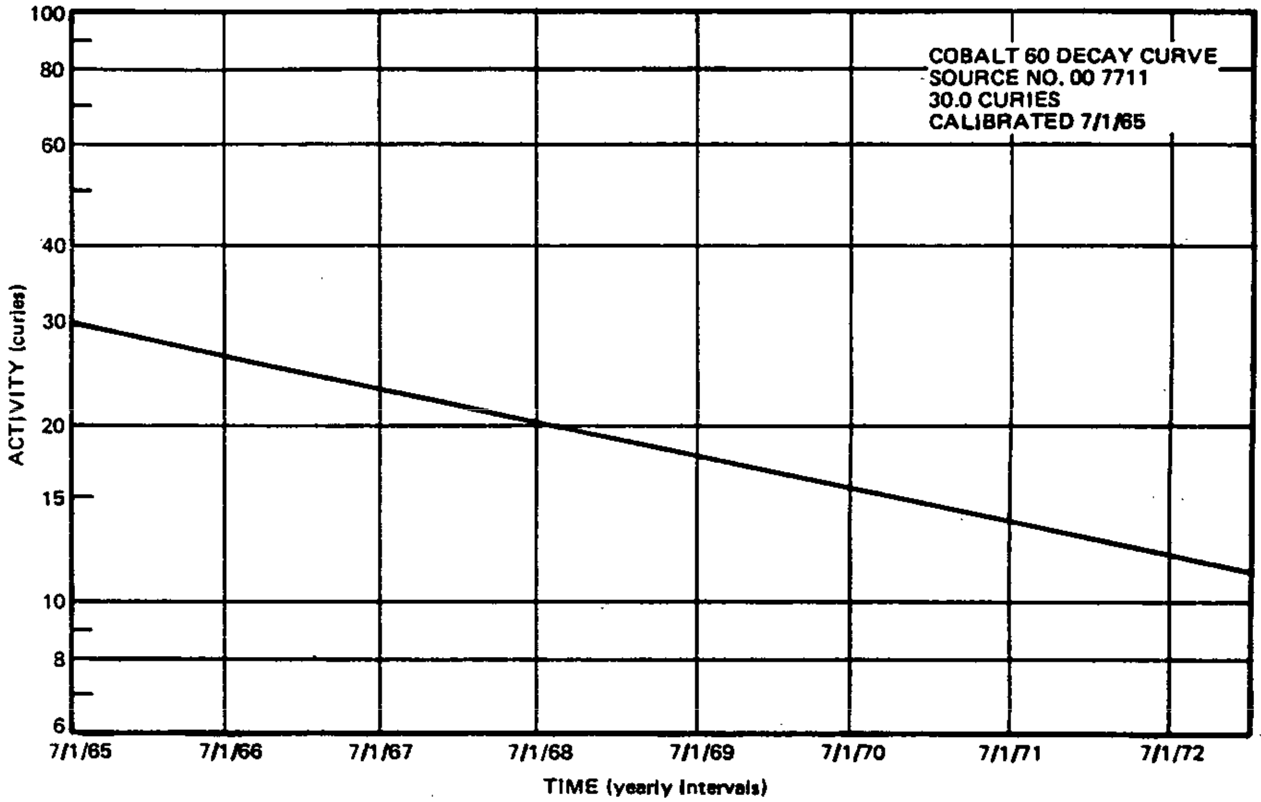

Figure 5.2(8). Dated decay curve.

by the least amount of explosive that might be present. The degree of usefulness of N-rays depends upon these differential absorptivities. Therefore, the proper choice of an N-ray method requires knowledge of the atomic numbers of the elements that are present and their relative absorption as shown in Figure 5.2(9).

It should be noted that both X-rays and N-rays are often used on the same task. They each show different variables, and it is not always a choice of which is best. The choice of whether X-rays alone, or N-rays alone, or both are to be used depends upon each individual problem and the differences in absorptivities that may be required.

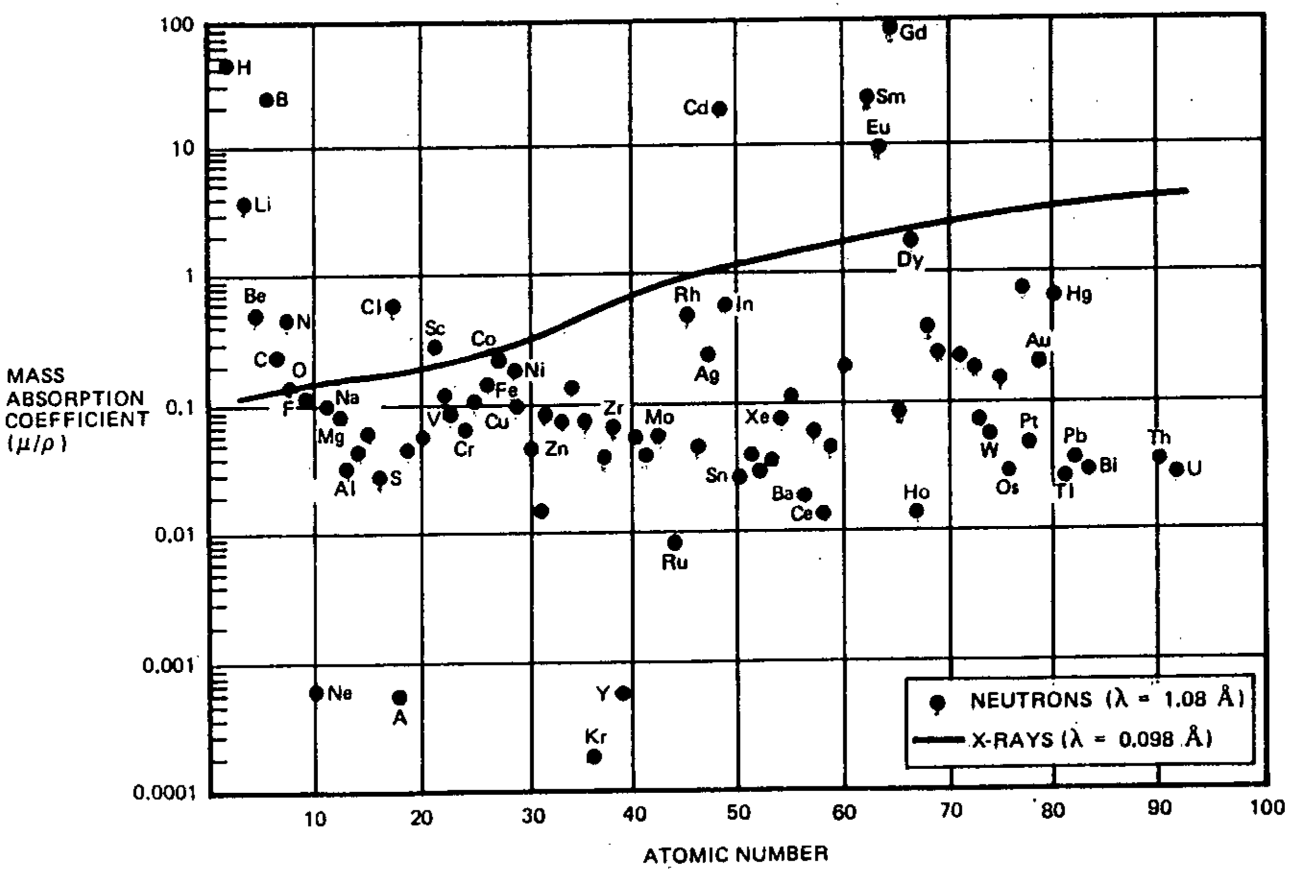

Figure 5.2(9). Absorption comparisons between X-rays and N-rays.

5.3 EQUIPMENT AND MATERIALS

Radiographic equipment includes portable or mobile systems, laboratory systems, and large, fixed installations. There are electronic controls that can provide automatic exposures. Automatic film development is common. The selection of equipment, materials, and facilities available is extensive.

5.3.1 X-RAY EQUIPMENT

In selecting X-ray equipment, one of the most important factors to be considered is the maximum thickness and type of material to be examined. The material and its thickness will essentially dictate the necessary peak voltage rating of the equipment. X-ray equipment must be especially designed to operate at the low kilovolt range. Usually a Beryllium window is included to allow the long wavelengths to exit the X-ray tube and expose the specimen. When equipment is designed to operate at the high voltage range, it is difficult to provide adequate heat sinks and radiation protection is usually massive and expensive. Because of these factors, the same equipment is not normally used for all voltage ranges.

Table 5.3(1) shows relationships between voltage ratings and thicknesses of steel that can be inspected. Table 5.3(2) shows different applications for different voltage ratings. Each application or material to be inspected could require a different rating, or range in rating, of peak voltage.

Other important choices might be the size of the specimen to be examined, safety aspects, mobility requirements, and the ability of the floor and foundations to support the weight of the equipment. Other equipment characteristics that can be mentioned are radiation quality, radiation output, and source size. A description of these three items follows.

(1) Radiation Quality. One must normally make a compromise between high energies resulting in short exposure times, and the greater radiation absorption at lower energies which results in better contrast and improved radiographic quality. When selecting X-ray equipment, it is best to obtain a unit which will emit a radiation spectrum containing a large portion of the short wavelengths indicative of the maximum or peak voltage. With such a unit, it is usually possible to operate, if and when necessary, over a limited range of lower energies to get the longer wavelength X-rays which improve radiographic contrast. However, if the unit does not deliver a good quantity of the more penetrating X-rays indicated by the peak potential rating, the exposure time can be less than that of other equipment of similar peak voltages. To assess the quality of an X-ray source, we must know the characteristic half-value layer which it produces. When comparing two X-ray machines at the same current and voltage, the machine which produces the larger half-value thickness in a given material has the highest quality beam.

Table 5.3(1). Relationship between voltage ratings and steel thickness.

VOLTAGE RATINGS	THICKNESS FOR PRODUCTION PARTS STEEL (INCHES)
175 KV	1/8 - 1
250 KV	1/4 - 2
1000 KV	1/2 - 4
2000 KV	3/4 - 8
15 MeV	3/4 - 14

Table 5.3(2). Relationship between voltage ratings and application.

VOLTAGE RATING	GENERAL APPLICATION
50 KV	RADIOGRAPHY OF WOOD, PLASTICS, NONMETALIC COMPONENTS, TEXTILES, LEATHER; DIFFRACTION AND MICRORADIOGRAPHY.
100 KV	RADIOGRAPHY OF LIGHT METALS AND ALLOYS. FLUOROSCOPY OF FOOD STUFFS, PLASTIC PARTS AND ASSEMBLIES, AND SMALL LIGHT ALLOY CASTINGS.
150 KV	RADIOGRAPHY OF HEAVY SECTIONS OF LIGHT METALS AND ALLOYS, AND OF THIN SECTIONS OF STEEL OR COPPER ALLOYS. FLUOROSCOPY OF LIGHT METALS.
250 KV	RADIOGRAPHY OF HEAVIER SECTIONS OF STEEL OR COPPER. FLUOROSCOPY IS NOT GENERALLY USED AT THIS VOLTAGE.
1000-2000 KV RADIOACTIVE ISOTOPES	RADIOGRAPHY OF VERY HEAVY FERROUS AND NON-FERROUS SECTIONS. (3 IN. STEEL OR GREATER)

(2) Radiation Output. The conversion of electrons into X-rays is an inefficient process. Over 90 percent of the power consumed by an X-ray machine is wasted in the production and dissipation of heat. This heat problem is a most significant economic factor in the design and construction of X-ray equipment and is directly related to the X-ray output. To reduce heat, the X-ray output is often curtailed. A second factor which influences the X-ray output is the effective potential applied in accelerating the electrons. This is the same characteristic mentioned in connection with the quality of radiation, but it is a different influence of this characteristic. The quantity of X-rays generated increases with the 2.5 power of the applied potential; i.e., conversion of the electron energy to X-rays becomes more efficient as the applied potential increases. Therefore, the larger percentage of electrons which are accelerated at the higher or near to peak potential, the greater the output of the X-ray machine. A third factor which affects the output is the quantity of X-rays absorbed in the material of which the

machine is constructed. This is termed inherent absorption. To assess the radiation output or productivity from an X-ray machine, we must know the roentgen output. The roentgen output is a measure of the number of X-ray photons developed, based upon the ionization effect produced when these photons are absorbed in air. When comparing two X-ray machines which are generally equal in design, the machine with the highest output in roentgens is the more suitable. For comparison purposes, all factors concerned with the roentgen measurement must be equivalent. Roentgen output can be expressed in terms of roentgens per hour at a distance of one meter (rhm).

(3) Source Size. The sharpness of a radiographic film image is partly determined by the size of the radiation source (focal spot). The electron beam in most X-ray tubes is focused so that a small area of the target is bombarded by the beam. Usually the target (anode) is set at an angle (Figure 5.3(1)) and the projected size of the bombarded area, as viewed from the specimen, is smaller than the actual focal spot. This projected area of the electron beam is the effective focal spot. In theory, the optimum tube would contain a pinpoint focal spot. In practice, the size to which the focal spot can be reduced is limited by the heat generated in target bombardment. If the actual focal spot is reduced beyond certain limits the heat at the point of impact destroys the target.

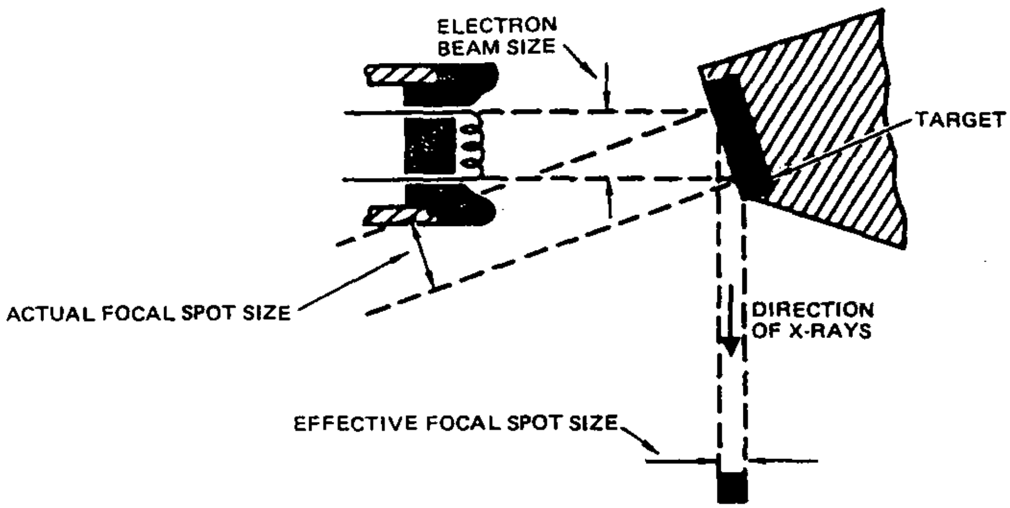

Figure 5.3(1). Effective versus actual focal spot size.

Many accessories are necessary for X-ray work. They are:

a. Diaphragms, Collimators, and Cones. Diaphragms, collimators, and cones are thicknesses of lead, fitted to the tubehead of X-ray equipment, or built to limit the area of radiation (see Figure 5.3(2)). They decrease the amount of scatter radiation by limiting the beam to the desired test area. Many X-ray machines have built-in adjustable diaphragms designed so that the beam at a fixed distance covers a standard film size area.

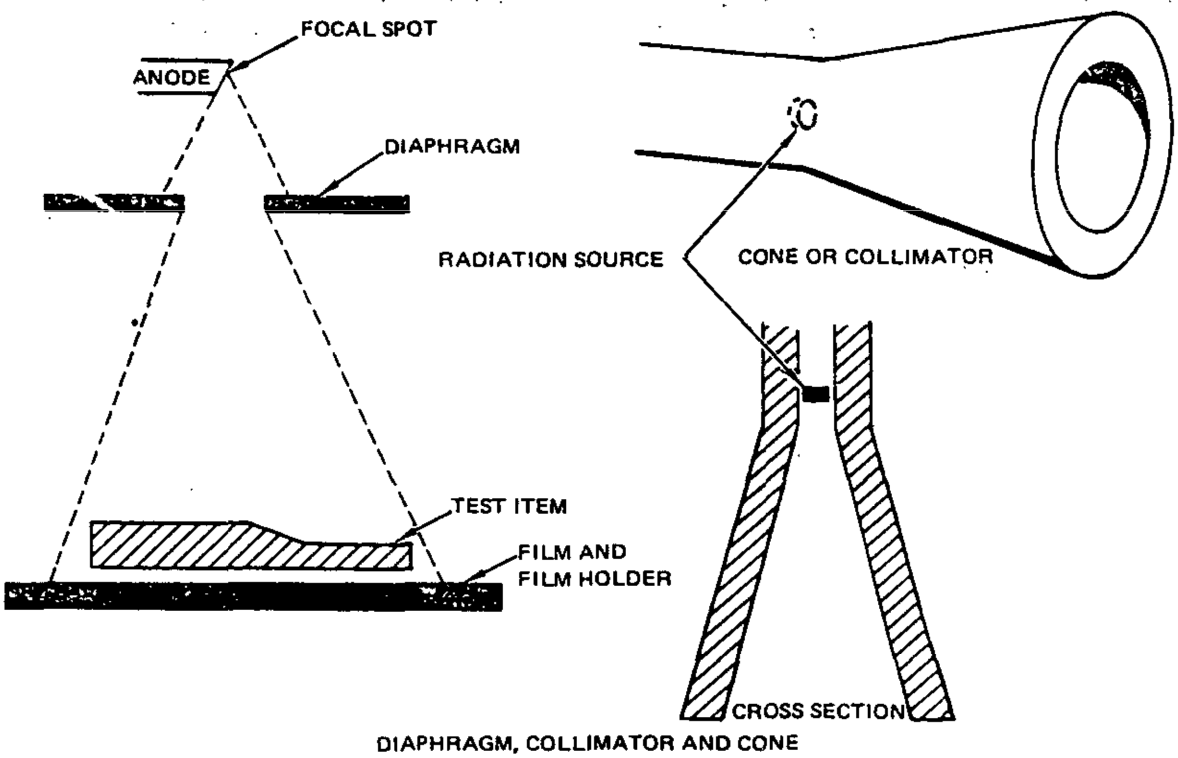

Figure 5.3(2). Accessories for radiographic testing.

b. Filters. Filters are sheets of high atomic number metal, usually brass, copper, steel, or lead, placed in the X-ray beam at the tubehead (see Figure 5.3(3)). By absorbing the "soft" radiation of the beam, filters accomplish two purposes: they reduce subject contrast permitting a wider range of test item thicknesses to be recorded with one exposure; and they eliminate scatter caused by soft radiation. Filters are particularly useful in radiography of items with adjacent thick and thin sections. The material and thickness of the test item and its range of thicknesses determine the filter action required. In radiographing steel, good results are usually obtained by using: lead filters 3 percent of the maximum test item thickness; or copper filters 20 percent of the maximum test item thickness. Particular care must be exercised in the use of such filters since defects in the filter may be mistakenly interpreted as test item defects.

c. Screens. When an X- or gamma-ray beam comes in contact with film, less than one percent of the radiation energy available is absorbed by the film in producing an image through photographic effect. To convert the unused energy into a form that can be absorbed by film, fluorescent or lead radiographic screens may be used on the front and/or the back of the film. The intensification factor of lead screens is much lower than that of fluorescent

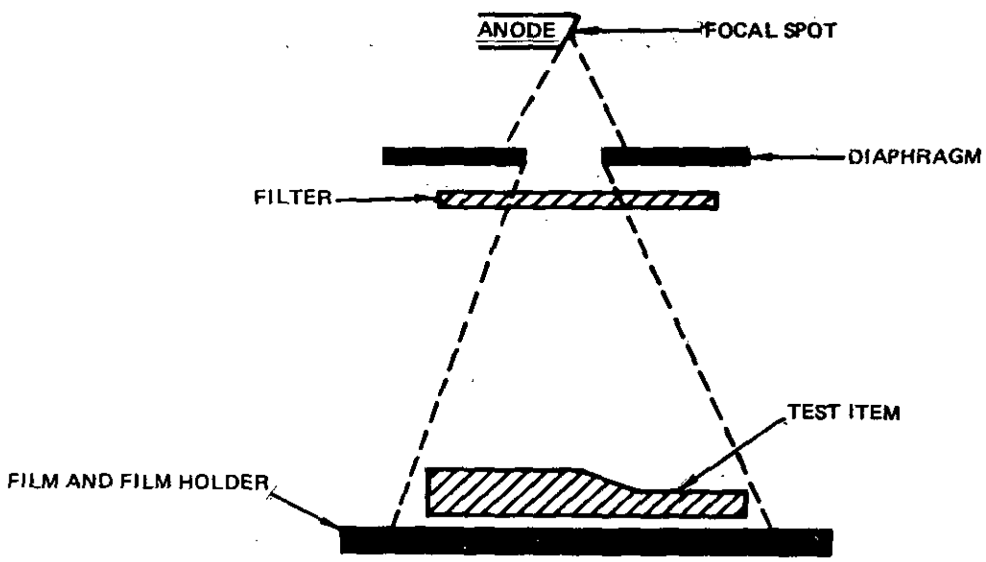

Figure 5.3(3). Filters.

screens. When exposed to low energy photons, it is possible for the front screen absorption effect to be of such magnitude that required exposure is greater than that without screens. However, because of their capability for reducing the effects of scattered radiation and the resultant better contrast and definition of the radiographic image, lead screens can still be practical. They are used in almost all gamma ray applications and for most X-ray work above 100 KVP.

To ensure the intensification action of lead screens, they must be kept free from dirt, grease, and lint since these materials have high electron absorption qualities and can absorb the "intensifying" electrons emitted by the screens. The screens may be cleaned with 1,1,1-trichloroethane or other commercial cleaners that are nontoxic and nonflammable. If a more thorough cleaning is desired, fine steel wool can sometimes be used. The fine abrasion marks caused by gently rubbing with steel wool leave no harmful effects. Scratches can be a problem in very fine detailed radiography. Deep scratches, gouges, wrinkles, or depressions that affect the flatness of the screen surface will cause poor radiographic results. It is important that intimate contact be maintained between the lead screens and film surfaces. Small air gaps can cause a fuzzy image. This is due to scatter of the photo electrons by the air. The photo electrons are knocked off the surface of the lead by the x-ray photons.

d. Masking Material. Masking is the practice of covering, or surrounding, portions of the test item with highly absorbent material during exposure.

Masking reduces the test item exposure in the masked areas, eliminating much scatter. Commonly used masking materials are lead, barium clay, and metallic shot (see Figure 5.3(4)). When barium clay is used as a mask material, it should be thick enough so that radiation absorption of the clay is appreciably greater than that of the test item. Otherwise, the clay will generate noticeable scatter. In any circumstance, the sole purpose of masking is to limit scattered radiation by reducing the area of the test item exposed to the primary beam.

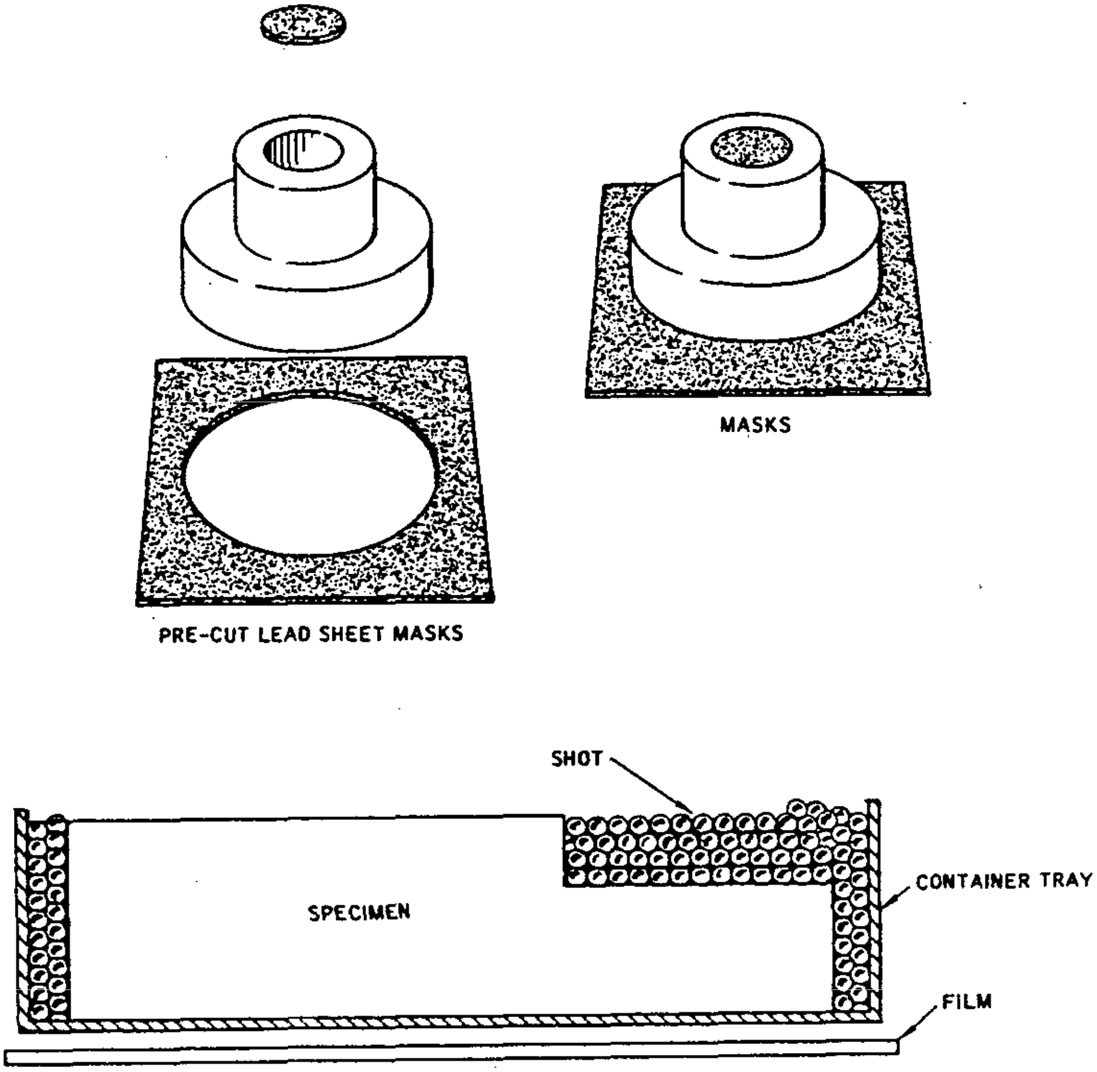

Figure 5.3(4). Masking techniques for radiography.

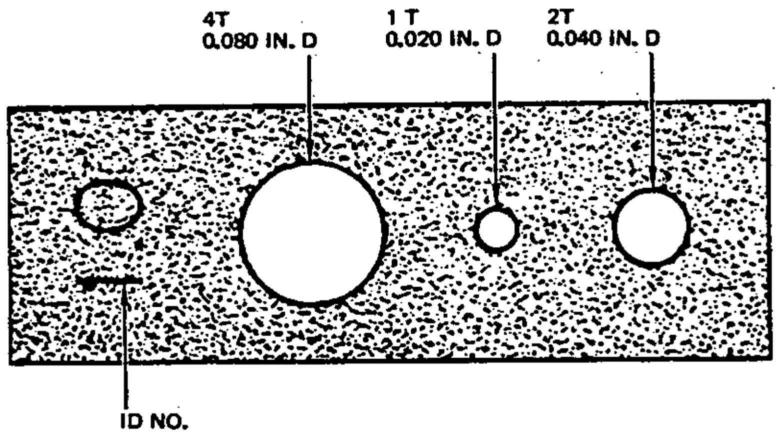

Figure 5.3(5). Standard penetrameter for one-inch material.

e. Penetrameters. The penetrameter, for indicating image quality, is composed of material identical, or radiographically similar, to the specimen being radiographed and whose thickness is a percentage of the specimen thickness. It may also contain steps, holes or slots. When placed in the path of radiation, its image provides a check on the radiographic technique used. (Figure 5.3(5) shows a penetrameter for one-inch material.)

Penetrameters are used to indicate the contrast and definition which exist in a given radiograph. The type generally used in the U.S. is a small rectangular plate of the same material as the object being X-rayed. The construction of film holders and cassettes should be of such design as to insure intimate contact between films and screens. It is of uniform thickness (usually two percent of the object thickness) and has holes drilled though it. Hole diameters of one, two, and four times the thickness of the penetrameter are specified by ASTM. In addition to the type of penetrameter just described; step, wire, and bead penetrameters are also used. These are described in the literature and in ASTM Specification E-94. When a set-up is vertical, the heavy lead screens tend to sluump or bulge.

The degree of sharpness evidenced by the detail of the outline of the penetrameter is referred to as the contrast sensitivity. If the outline is clearly defined, the contrast sensitivity is referred to as two percent or better. Detail is defined as the degree of sharpness of outline of the image. If the radiograph does not show a clear definition of the test item or a flaw in the test item, it is of little value, although it may have adequate contrast and density. Penetrameters of different types have been devised for special uses; e.g., special small wire penetrameters are used in the radiography of small electronic components.

f. Shim Stock. Shim stock for radiographic testing may be defined as thin pieces of material identical to test item material. They are used in radiography of welds, etc., where the area of radiographic interest is thicker than the test item thickness. Shims are selected so that the thickness of the shim equals the thickness added to the test item (by the weld) in the area of interest (see Figure 5.3(6)).

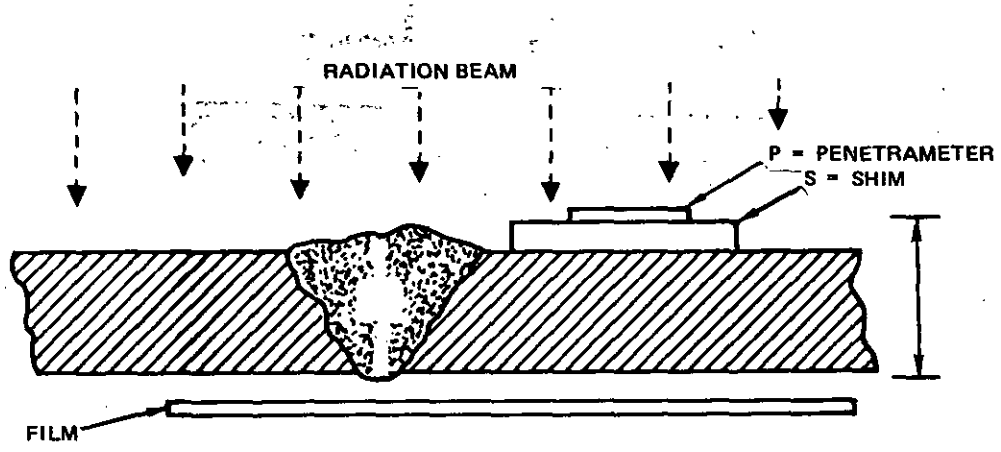

Figure 5.3(6). Use of shim stock.

The shim is placed underneath the penetrameter (between the penetrameter and the test item). In this way, the image of a penetrameter is projected through a thickness of material equal to the thickness in the area of interest. In use, the length and width of the shim should always be greater than the similar dimensions of a penetrameter as indicated in Figure 5.3(6).

g. Film Holders and Cassettes. Film holders are designed to shield film from light and to protect it from damage. Film holders are made from a variety of materials including rubber and plastic. The holders are flexible and permit molding the film to the contours of the test item, thereby holding item-to-film distance at a minimum. Cassettes are specially designed, rigid, usually two-piece hinged, film holders that spring-clamp tightly together. Cassettes are of use when flexibility is not required since their clamping action holds screens and film together, and firmly in place.

h. Linear and Angular Measuring Devices. Correct source-to-film distance and knowledge of test item thicknesses are required for any radiographic setup. For these measurements, a six-inch machinist's scale and a tape measure are often tools of the radiographer. When a task requires radiography at an angle other than that normal to the plane of the test item, a plumb bob and protractor may be used to determine the correct angular setup.

i. Positioning Devices. For quality radiography, the position of the source, the test item, and the film should remain fixed during exposure. For both X- and gamma-ray equipment, the floor, a table, or any stable surface may suffice to support the test item. Specifically designed holders (usually tripods) are used to position the cable containing the source. Any positioning arrangement complying with safety considerations and not causing excess scatter radiation is generally acceptable.

j. Identification and Orientation Markers. To permit correct interpretation of the finished radiograph, the test item and the radiograph must be marked so that the test item and its orientation can be identified with the radiograph. This may be accomplished by affixing lead numbers or letters to (or adjacent to) the test item during exposure, and marking the test item in identical fashion with a marking pen, or by scribing. The lead numbers or letters, which are attached with masking tape, appear on the radiograph. Comparison of the radiograph with the marked test item eliminates any possibility of wrong identification.

k. Area Shielding Equipment. The control of scatter radiation can be accomplished by proper use of shielding. Areas in which radiography takes place must be adequately protected against both side and back scatter. In permanent installations, this is accomplished by use of lead shielded rooms or compartments. When permanent installations are not available, lead screens may be placed so that areas reached by the primary radiation are shielded. The area immediately beneath (or behind) the film should always be covered with lead.

l. X-ray Film. Basically there are three grades of film for industrial radiography: coarse grain, fine grain, and extra-fine grain film. The extra-fine grain film gives the highest contrast or quality, but requires relatively long exposure times. The coarser grain films do not quite give the good quality results that the finer grain films do, but they need only relatively short exposure times. Since there is a wide variety of films to choose from, one is able to select the optimum film for a given job. (See Section 5.2(3) for basic film considerations.) Note that the grading of industrial x-ray film is rather arbitrary and is mainly determined by the film manufacturers. Therefore, any candidate x-ray film should be tested and evaluated before applying it to a particular inspection job.

Commercial radiographic film is normally sold in sheet film of various standard dimensions (which may be coated with the photosensitive emulsion on only one side or on both sides of the film) or in rolls of various widths and practically unlimited length. The roll form is especially useful for radiographing circumferential areas. Most radiographic films are relatively insensitive to red or yellow light. For this reason, films may be handled in a dark room which is properly illuminated with red or yellow safelights of low intensity. Several types of such lights are commercially available with special filters for use in the processing of radiographic film.

m. X-Ray Exposure Charts. X-ray exposure charts show the relationship between material thickness, kilovoltage, and exposure. Each chart applies only to a specific set of conditions: a certain X-ray machine; a certain target-to-film distance; a certain type of film; certain processing conditions; and the density upon which the chart is based. Exposure charts are adequate to determine exposures of test items of uniform thickness, but should be used only as a guide when radiographing a test item of wide thickness variations. Charts furnished by manufacturers are accurate only within ±10 percent (since no two X-ray machines are identical). For quality radiography, X-ray exposure charts should be based on: (1) the material most often radiographed; (2) the film most commonly used; and (3) a reasonably chosen target-to-film distance. These should be prepared for each X-ray machine in use.

Exposure charts can also be prepared to show film latitude (which is defined as the variation in material thickness which can be radiographed with one exposure) while maintaining film density within acceptable limits. These limits are fixed by the lowest and highest densities that are acceptable in the finished radiograph.

n. Gamma Ray Exposure Charts. The variables in gamma radiography are the source strength and the source-to-film distance. These are related on the chart to each of different speed films. By selecting a given film type, the radiographer can determine exposure time for desired image density. Gamma ray exposure charts are similar to X-ray exposure charts, and are adequate to determine exposures of test items of uniform thickness. However, they should be used only as a guide when radiographing a test item of wide thickness variation. Charts are available from film manufacturers and are generally accurate when used with film processed in compliance with the manufacturer's recommendations. These exposure charts must be used in conjunction with dated decay curves (see next item).

o. Dated Decay Curves. Dated decay curves are supplied with radioisotopes. By use of the curve, the source strength may be determined at any time. Since the source strength must be known before exposure calculations can be made, the decay curve eliminates the necessity of source strength measurement, or calculation, prior to source use. When source strength is known, decay curves are readily prepared by using half-life values and plotting the resultant curve on semi-logarithmic paper.

p. Densitometer. The densitometer is an instrument used to measure photographic film density. Radiographic film density is defined as the degree of blackening of the film. Visual and electronic densitometers are commercially available. Accuracy is desirable in a densitometer but consistency is more important. A good densitometer, under similar conditions of use, will give similar readings each time.

In addition to standard radiographic film imaging systems, fluoroscopic and television imaging systems are also used.

Fluoroscopic imaging systems substitute a fluorescent screen for the film used in conventional (film) radiography. The X-ray image is produced directly on the fluorescent screen, and is viewed indirectly through an optical system to prevent direct eye exposure to hazardous radiation. It is a relatively low-cost, high-speed process and is easily adapted to production line requirements. It is widely used in applications where rapid scanning of articles for gross internal flaws or abnormal conditions is desired. By use of fluoroscopy, a large number of articles can be screened prior to radiographic test. Those with gross defects are immediately rejected, with resultant cost savings. Fluoroscopy cannot be used with test items that are thick or of dense material since the intensity of the radiation passing through the test item would be too low to brighten the screen sufficiently for viewing. In using fluoroscopy, an image amplifier is employed to enhance the brightness of the image. This image amplifier also serves to protect the operator from radiation. It consists of an image tube and an optical system. The image tube converts the X-ray image on the fluorescent screen to electrons, and it accelerates and electrostatically focuses the electrons to reproduce the image on the smaller fluorescent screen. The optical system magnifies the image.

For television imaging, advanced electronic techniques are available which allow viewing radiographic images as television pictures. A special vidicon television pickup tube is used in the place of the film in conventional (film) radiography; associated circuitry and controls allow the X-ray image to be displayed directly on a television monitor screen. The tube differs from normal vidicon tubes in that it is X-ray sensitive rather than photo-sensitive. It is widely used to permit instant image reproduction, combined with observer protection from exposure. The system is designed for radiographic inspection of small items such as electronic components and assemblies, and system components. It is highly suitable for in-motion X-ray inspection. Permanent records may be obtained by photographing the monitor screen of the readout system.

Recently digital electronic radiography has been introduced which is growing in importance. Various methods are used to generate electronic images, which are digitized and processed by computers. Enhanced images are then presented to the inspector, or the computer may analyze the image automatically.

Advantages for both of the above systems include:

a. There is no delay in obtaining the image.
b. They can be used for in-motion imaging of test objects.
c. Television-type systems are applicable to remote monitoring, thus enabling the observer to be out of range of hazardous radiation.
d. Cost of film processing and identification of areas of test objects being radiographed are eliminated by fluoroscopic and electronic imaging systems.
e. Electronic X-ray imaging is applicable to continuous X-ray inspection to observe process operations and details.

Fluoroscopic and television imaging systems do have certain disadvantages:

a. Require additional expensive equipment.
b. Usually less sensitive than film radiography.
c. Radiation shielding might be a problem for certain applications.
d. A complete exposure and imaging system is required for one inspector; i.e., inspection cannot be "multiplexed" for productivity as with film.
e. Systems tend to be more specialized, being less flexible than film radiography.
f. Permanent records usually suffer loss of detail since they are secondary recording media (video tape, photographs, etc.) and they are not as "transportable" as x-ray film in that they often require special equipment for viewing.

5.3.2 GAMMA RAY EQUIPMENT

Radiation from radioactive material producing gamma rays cannot be shut off. Gamma ray equipment is therefore designed to provide radiation-safe storage and remote handling of a radioisotope source. The United States Nuclear Regulatory Commission (USNRC) and various state agencies prescribe safety standards for the storage and handling of radioisotopes under their control. Similar safety procedures are required for the storage and use of radium which is not under USNRC control.

The effective focal spot in X-radiography is the X-ray generating portion of the target as viewed from the specimen. In gamma-radiography, since all of the radioactive material is producing gamma rays, the focal spot includes all the surface area of the material as viewed from the specimen. For this reason it is desirable that the dimensions of a gamma ray source be as small as possible. Most isotope sources used in radiography are right cylinders whose diameter and length are approximately equal. This source shape permits the use of any surface as the focal spot, since all surfaces, as viewed from the specimen, are approximately equal in area. To assure maximum sharpness of the film image when using isotope sources that are not right cylinders, it is necessary to place the smallest surface area of the source parallel to the plane of the specimen.

Some specific radioactive sources are:

a. Radium. Radium is a natural radioactive substance having a half-life of approximately 1600 years. In practical applications, radium, because of its slow disintegration, is considered to have a constant rate of gamma ray emission. Radium itself does not produce useful gamma rays, but through decomposition produces radon and other daughter products, that cause the emission of useful gamma rays. By placing radium in a gas-tight capsule, preventing the escape of radon, a state of equilibrium is reached whereby the amount of radon lost through disintegration is equal to the amount produced by decomposition of the radium. For practical purposes, this state of balance causes a constant rate of gamma ray emission from a radium source. Pure radium is not used in radiography and most sources consist of radium sulfate packaged in either spherical or cylindrical capsules. Because of its low specific activity, radium is little used in industrial radiography.

b. Cobalt 60. Cobalt 60 is an artificial isotope created by neutron bombardment of cobalt, having a half-life of 5.3 years. Cobalt 60 primary gamma ray emission consists of 1.33- and 1.17-MeV rays similar in energy content to the output of a 2-MeV X-ray machine. The radioisotope is supplied in the form of a capsuled pellet and may be obtained in different sizes. It is used for radiography of steel, copper, brass, and other medium weight metals of thicknesses ranging from 1 to 8 inches. Because of its penetrating radiation, its use requires thick shielding, with resultant weight and handling difficulty.

c. Iridium 192. Iridium 192, another artificial isotope produced by neutron bombardment, has a half-life of approximately 75 days. It has high specific activity and emits gamma rays of 0.31, 0.47, and 0.60 MeV, comparable in penetrating power to those of a 600-KVP X-ray machine. Industrially, it is used for radiography of steel and similar metals of thicknesses between 0.25 and 3.0 inches. Its relatively low energy radiation and its high specific activity combine to make it an easily shielded, strong radiation source of small physical size (focal spot). The radioisotope is obtainable in the form of a capsuled pellet.

d. Thulium 170. Thulium 170, obtained by neutron bombardment of thulium, has a half-life of approximately 130 days. The disintegration of the isotope produces 84-KeV and 52-KeV gamma rays, soft rays similar to the radiation of X-ray equipment operating in the 50- to 100-KVP range. It is the best isotope known for radiography of thin metals since it is capable of producing good radiographs of steel specimens less than one-half inch thick. One of the major advantages of the use of thulium 170 is its soft wave radiation, which permits its containment in small equipment units of extreme portability since only a small amount of shielding is required. Because the pure metal is difficult to obtain, the isotope is usually supplied in capsules containing the oxide TM_2O_3 in powder form.

e. Cesium 137. Cesium 137, a by-product of the fission process, has a half-life of 30 years. It emits gamma rays of 0.66 MeV, equivalent in energy to the radiation of a one-MeV X-ray machine. It is used in the radiography of steel of thicknesses between one and two-and-one-half inches. It is superior to other isotopes of similar capability only in its slow rate of decay. Cesium 137 is usually handled in the form of the chloride CsCl, a soluble powder requiring special safety precautions. The USNRC recommends double encapsulation in containers constructed of silver-brazed stainless steel.

f. Other Radioisotopes. Many other radioisotopes that are radiographically useful are not considered here because in practical applications one or another of the four discussed is superior. Table 5.3(3) is a summary of the characteristics of the four most-used isotopes.

Because of the ever-present radiation hazard, isotope sources must be handled with extreme care, and stored and locked in adequately shielded containers when not in use. Equipment to accomplish safe handling and storage of isotope sources, together with a source, is called a camera. Figure 5.3(7) shows a typical camera consisting of:

a. Shield Case Assembly. A shield case assembly is a heavy gage steel case containing a block of lead or Uranium 238 (storage pig) which shields the source when not in use. Microswitches within the case energize the stored and open lights which indicate source positions. One end of the case has a connector for the control cable-to-crank extension and the other a connector for the extended source position cable.

Table 5.3(3). Isotope characteristics.

ISOTOPE	COBALT-60	IRIDIUM-192	THULIUM-170	CESIUM-137
HALF-LIFE	5.3 YR	75 DAYS	130 DAYS	30 YR
CHEMICAL FORM	Co	Ir	Tm_2O_3	CsC1
GAMMAS MeV	1.33, 1.17	0.31, 0.47, 0.60	0.084, 0.052	0.66
RADIATION LEVEL RHF/CURIE	14.4	5.9	0.032*	4.2
PRACTICAL SOURCES				
CURIES	20	50	50	75
RHM	27	27	0.1	30
APPROX DIAMETER	3 mm	3 mm	3 mm	10 mm

*VARIES WIDELY BECAUSE OF HIGH SELF-ABSORPTION

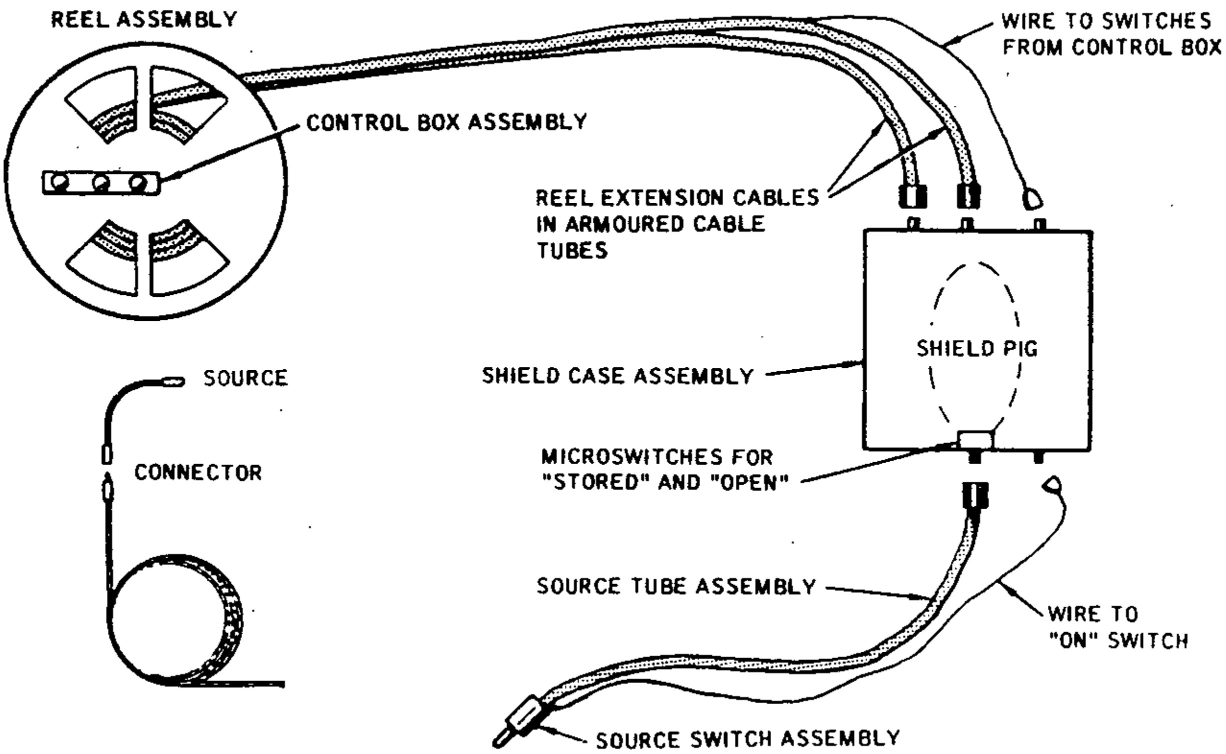

Figure 5.3(7). Diagram of typical isotope camera.

b. Reel Assembly. The reel assembly is comprised of a storage reel for the flexible armored steel cables, a crank to extend and draw back the source, and a light panel housing three lights that indicate positions of the source: "STORED" (safely shielded within the pig), "OPEN" (partially extended), and "ON" (fully extended).

c. Source Switch Assembly. Located at the extreme end of the extended source position cable, the source switch assembly houses the source capsule when it is in the fully extended position. The assembly contains a switch which functions to energize the "ON" indicating light when the source is in the fully extended position.

d. Source Capsule Assembly. The Source capsule assembly is a short length of cable with the source, in a stainless steel container, attached to one end and a connector for attachment to the control cable on the other. Figure 5.3(8) shows operation of a typical camera. Cameras that use a direct reading of the length of cable extended to indicate source position, and cameras that replace the manual crank with pneumatic or electrical drive units, are only modifications of the basic design. There are, however, other types of cameras (Figure 5.3(9)) that do not require removal of the source from the storage pig. These cameras permit exposure by removing or rotating a part of the source shielding. The required physical movement to expose the source is initiated from remote positions, either manually with long poles, or by electric drive units.

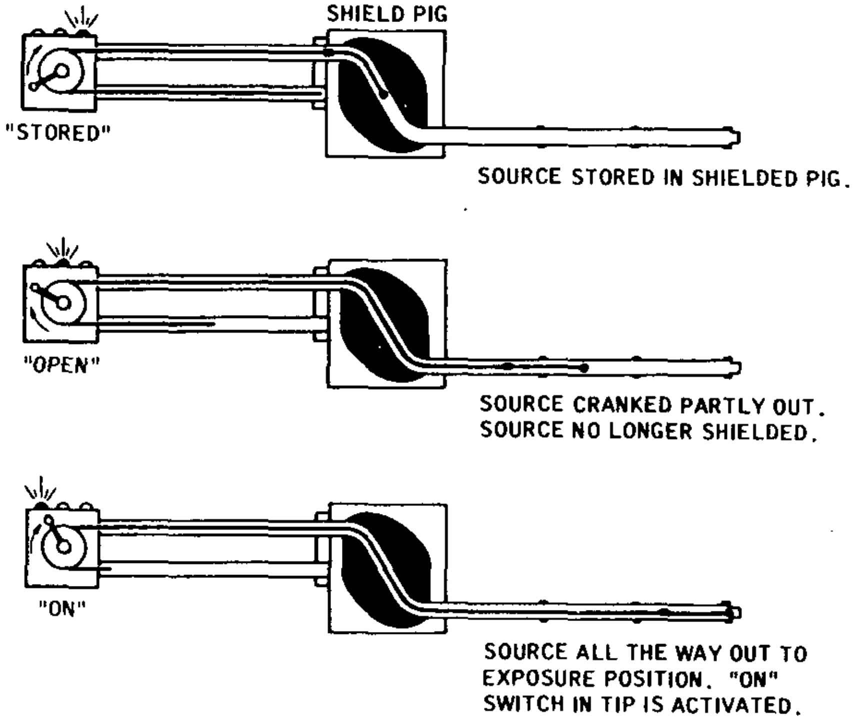

Figure 5.3(8). Operation of typical isotope camera.

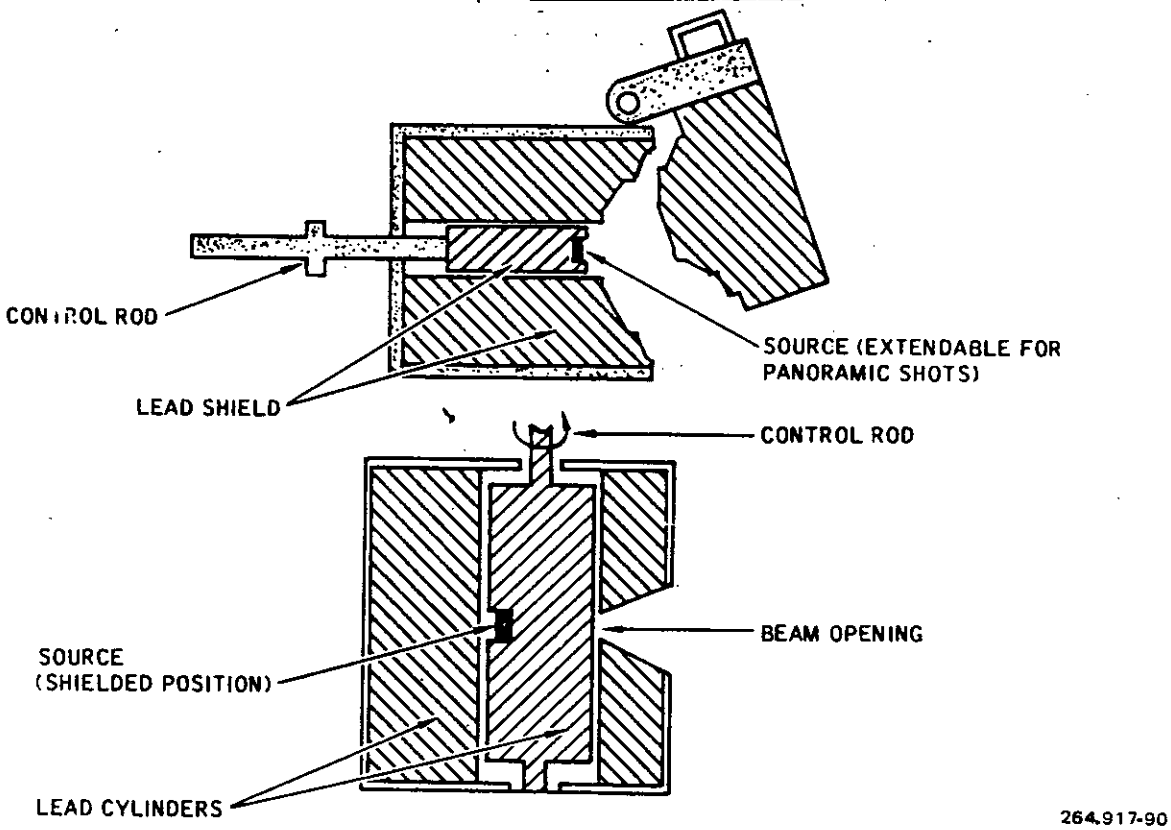

Figure 5.3(9). Isotope cameras.

5.4 PROCEDURES AND TECHNIQUES

5.4.1 BASIC PROCEDURES AND TECHNIQUES

To produce an acceptable radiograph, there are several specific determinations that must be established.

Somewhat in order, they are:

a. The specimen: the exact point and/or area of the specimen to be examined, the specimen variable being sought, the expected or preferred orientation(s), the number of desired shots and/or views, the material composing the specimen, the total thicknesses, the percent density variance expected, etc.

b. Geometric limitations: distance available between a source and the specimen, relative placement of film, etc.

c. Type of film (or recording device).

d. Desired densities and/or standards.

Once these first four items are established, a choice of equipment, if choices are available, must be made. (See section 5.3 for information on basic differences in equipment.) With selection of the equipment, initial settings must then be determined (these initial settings are expected to be changed when test results indicate a need for a change).

e. The exact geometries (distance from beam source to specimen, distance to film, etc.).

f. Initial voltage settings and initial amperage settings for X-rays.

g. Isotope selections for γ-rays.

h. Exposure times.

Throughout this process, safety must always be considered. Also, most of the above decisions will be affected by factors relating to the quality, or perfection, of the radiograph required or desired versus the allowable time or cost. There will sometimes be special problems, often relating to the accessibility or mobility of the specimen or the equipment.

Some of the last items that need to be considered are:

i. Identifications and markers to appear on each radiograph, for each view, etc.

j. Special filters, shields, screens, etc.

Not all specimens and specimen variables can be effectively examined by radiography. Since radiographs are shadowgraphs, specimens that have complicated geometries might consist of superimposed images that will preclude proper examination of the area of interest. This is especially true if internal scattering is present. In some cases, the geometry of the specimens prevents proper orientations between the beam rays, the expected defects, and/or the film.

The information depicted in a radiograph is obtained by virtue of density differences brought about by differential absorption of the radiation. These density differences, unless gross in nature, must be oriented parallel to the direction in which the radiation is traveling. Discontinuities of small volume, such as laminar flaws, will often be undetected because they do not present a sufficient density differential to the radiation. The very nature of a delamination precludes their ready detection, and radiographic inspection is seldom used to locate this type of flaw. A specimen can be too thick to penetrate. As material thickness is increased, the time required to obtain sufficient information on the film also increases. For a given energy (penetrating power) of X- or gamma radiation, there exists an economic maximum thickness beyond which radiography is not feasible. If the cost is warranted, radiographic equipment of higher energy potential could be obtained. Such costs increase markedly because of the barriers required to protect personnel from the harmful effects of the radiation as well as the basic cost of larger equipment.

Thus, it is vital for a radiographer to know and understand the limits of radiography. The determination of the feasibility of any particular assignment and its success will depend upon knowledge of the specimen; the type, nature, and extent of the expected defects or variables; and the choices in orientations or views available to the radiographer.

The geometric relationships are important for four reasons: 1) the area of exposure is normally a function of the distance from the source to the specimen, 2) the intensity of the beam and the exposure time required is a function of the distance from the source to the film, 3) the magnification factor between the image on the film and the specimen is the ratio of the distance between the film and source (d_f) to the distance between the specimen and source (d_s), and 4) the sharpness of the image will be a function of the difference between the above two distances (d_s-d_f) times the effective diameter of the source.

Figures 5.4(1) and (2) illustrate some of these concepts.

Optimum geometrical sharpness of the image is obtained when the radiation source is small, the distance from the source to the test item is relatively large, and the distance from the test item to the film is relatively small. The magnification factor approaches one under these optimum conditions, and normally radiographs are seldom taken with magnifications much different than one unless an extremely small focal spot was purposely designed into the X-ray apparatus.

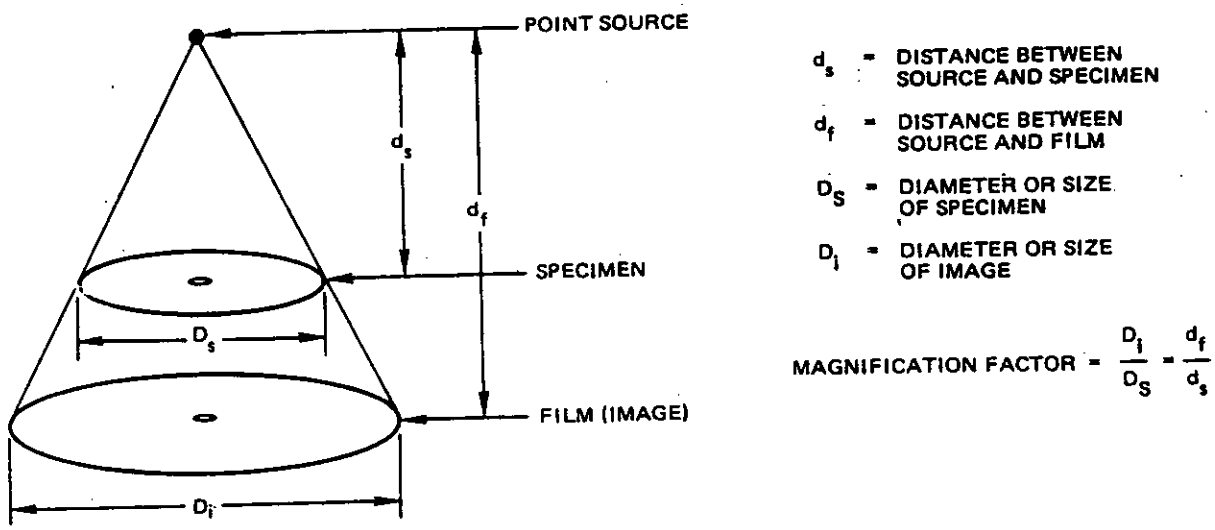

Figure 5.4(1). Magnification factor.

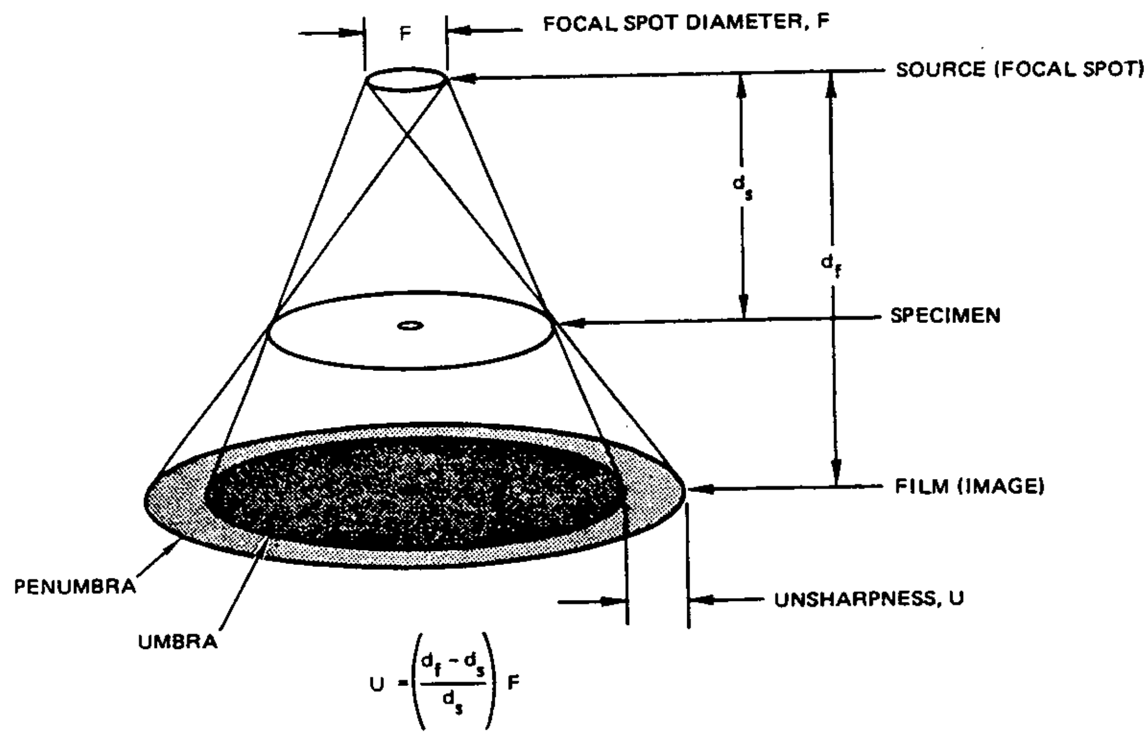

Figure 5.4(2). Geometric sharpness factor.

When X-ray films are read by eye, an unsharpness, U, as defined in Figure 5.4 (2), of 0.02 inches or less is often found to be acceptable. Assuming that the film is located directly behind the specimen, this degree of unsharpness will require a minimum source-to-specimen distance for any particular apparatus and thickness of material tested. This limit should be known by the radiographer for his equipment.

Figure 5.4(3) and(4) illustrates other geometric variables.

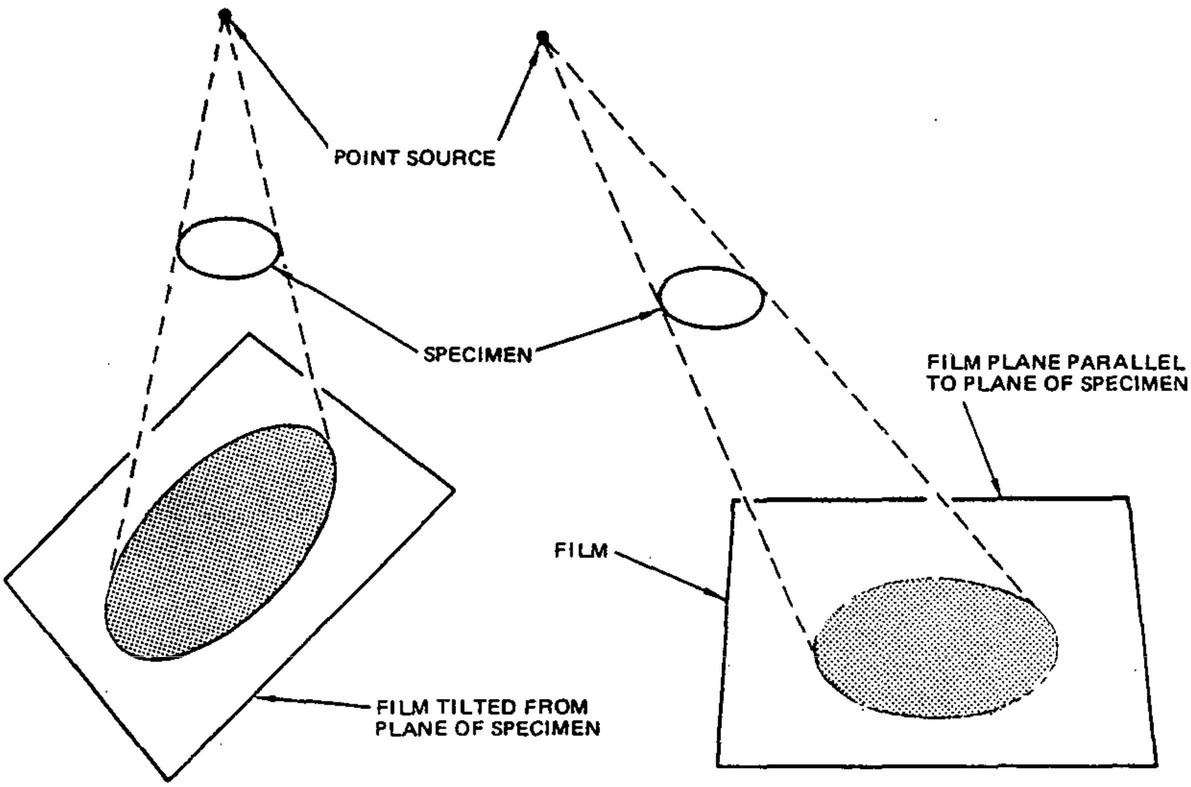

Figure 5.4(3). Angular image distortions.

If the plane of the test item and the plane of the film are not parallel, image distortion results. The same is true if the radiation beam is not directly perpendicular to the film plane. Whenever film distortion is unavoidable (as a result of physical limitations of a test), it should be remembered that all parts of the image, defects as well as geometry, are distorted; otherwise, an incorrect interpretation could result.

Very small source-to-specimen distances may be required when extremely low voltages (15 KVP or less) are being used when not in a vacuum. Air will greatly attenuate these beams, and must therefore be considered in these low-voltage setups.

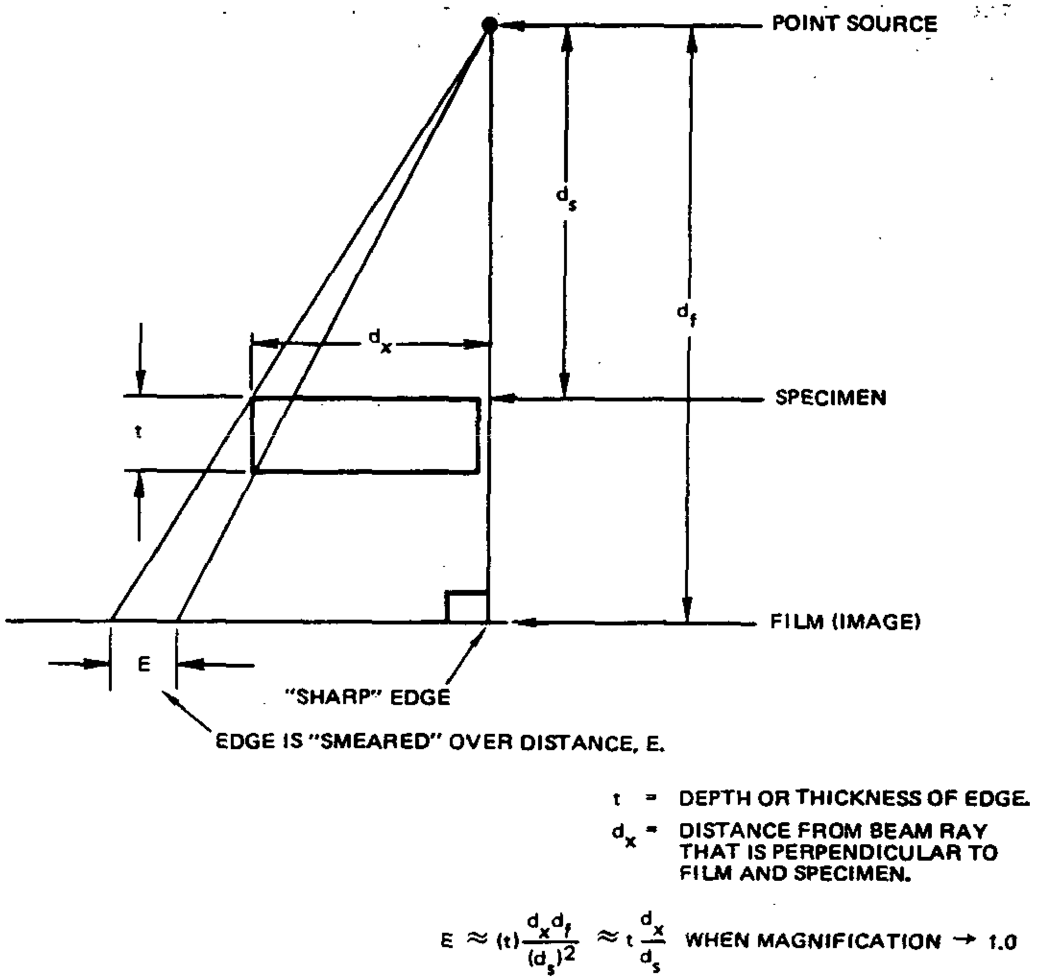

Figure 5.4(4). Edge or depth distortion factor.

Thus, the distance between source and specimen might need to be small to increase magnification (if desired), to increase beam intensity, and to shorten exposure times. This source-to-specimen distance might, however, need to be large to improve sharpness, to cover a larger area, or to improve angle or depth distortions. The proper choices often require compromises in these variables.

In choosing the voltage, current, and time settings, several considerations are important. The higher the voltage, the greater the penetration. Higher voltages allow thicker specimens to be examined and/or exposure times to be shortened. However, differentiations in thickness generally become less. If very small changes in thickness must be observed, then the lower kilovolt peak settings are often necessary.

The density of the film is dependent upon the beam intensity multiplied by the time of exposure. Generally speaking, the more dense the film, the greater will be the sensitivity of the information recorded. However, the ability to see this information will depend upon the brightness of the light that is used to read the film. Therefore, there is always a maximum, or optimum, density dependent upon the type of film reader available to the viewer. Normally a density of 2 to 4 is specified. Each film has an exposure characteristic curve that can be used to indicate the "amount of information" and establish the range of latitude that can be recorded. Normally the lower the density of the film, the greater the latitude.

Thus, if very small changes in variables must be detected, low voltages with extra long exposure times (for high film densities) must be expected. If large latitudes are required (exposing several different thicknesses at the same time), then high voltages and short exposure times will be needed. Again, compromises are often necessary.

All basic procedures and techniques cannot be covered in one handbook. Basic procedures used in X-raying various specimen geometries, choosing films, reducing scatter, using charts, etc., do exist. The most important guide, however, even when procedures are being used, is to observe the results. Only by making changes based on the results can optimum conditions be established.

5.4.2 NEWEST PROCEDURES AND TECHNIQUES

Advancements are being made in radiography, to include better films, more sensitive detectors, smaller focal spot sizes, and more efficient X-ray generators. Several "liquids" are now used, such as 1,4-Diiodobutane ($I(CH_2)_4I$), which can wick into surface cracks and delaminations, and because of their high X-ray densities, can be easily observed by X-rays. Using this method, many flaws can be observed that otherwise would not appear on a radiograph.

Because of computers, tomography is a useful modern method. Tomography uses multiple X-ray sources and receivers (or a single source and receiver that can move to multiple positions and orientations). The X-ray signals received are correlated by a computer routine to reconstruct a three-dimensional image of the specimen, and allows establishment of views that could not be done by a simple two-dimensional exposure.

A new X-ray method exists which allows X-ray analysis to be made on the same side as the X-ray source. Use is made of Compton scattering. A high power, narrow beam of X-rays, penetrating on a line through a material with detectors focused at specific points on this line, will "image" the part by detecting the amount of Compton scattering occurring at each point. The amount of scattering will be a function of the amount of mass present at each point. This method should find rapid employment in all areas where complicated geometries exist or where there is limited access.

5.5 STANDARDS

Penetrameters are often considered a standard to be used in radiography. In section 5.3, penetrameters were said to measure "radiographic quality" and to provide "a check on the radiographic technique." Therefore, penetrameters are very important, and do determine to a high degree the potential effectiveness of a particular radiograph. They are not, however, always sufficient. They do not always represent actual defects or all the variables being sought. For these reasons, there are special cases where specimens with known defects or flaws, both in the acceptable and unacceptable range, are used as true standards. One of the most critical points in radiographic work is the interpretation of the radiograph. Because radiographs are shadowgraphs, with three-dimensional data compressed onto two dimensions, often with specific geometric distortions and with many possible non-specimen related indications, interpretation by experienced and knowledgeable viewers is often critical. The use of true standards is usually a great help in guiding the interpretation as well as confirming the adequacy of the basic X-ray procedure.

Usually a series of radiographs that exhibit the types and sizes of flaws and/or acceptable variables are assembled. These radiographs are collectively called "radiographic acceptance standards." The radiographic viewer then has the task of comparing and deciding if the radiographs being inspected meet or exceed these radiographic standards. Several representative sets of standards are published by ASTM for certain aluminum, magnesium, copper, tin, and steel alloys.

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5.6 APPLICATIONS

Radiography is extensively used in the inspection of castings, welds, and forgings. Radiography is used in the inspection of finished parts as well as raw stock to verify completeness of assembly and the absence of cracks or other material flaws. Radiography is used in the medical profession and in research. Flash radiographic units are used for in-motion studies. Normally, radiographic exposure times are measured in minutes, but when exposures must be made of a moving subject, such as a bullet or projectile in flight, the exposure time must be extremely short to prevent blurring of the image. Flash radiography provides thse short exposure times; short enough to find application even in ballistic studies.

The main limitations in radiographic applications are: 1) access to both sides of the part to be inspected is required, 2) the part must not be too thick to penetrate (a function of the beam energy available, etc.), 3) the variable must provide an observable contrast (normally a two percent contrast is a reasonable minimum), and 4) all safety requirements must be met. Therefore, where extremely thick parts are involved, where designs prevent access to both sides, where variables are very small, or where safety can not be assured, radiography may not be a reasonable choice. As development in ultrasonics occurs, the medical area will be supplementing X-rays with ultrasonics for safety reasons.

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5.7 SPECIFIC GUIDELINES

In general, guidelines for radiography are well established and only a few additional comments are necessary in this section. This is partially due to the number of years radiography has existed as an inspection method with no major changes in principles, but also, because radiography does entail some dangers, those associated with X-ray work are by necessity well trained. Therefore, the following guidelines are somewhat superficial and are more of a review than a presentation of new material.

There is one warning. Because radiography is a well established method, it is often abused. It is often used even when it does not provide information on the quality of a product. Radiography is not an answer to every problem. It should not be automatically applied just because it is available.

5.7.1 GUIDELINES FOR DESIGNERS

Probably the most difficult concept for a designer to understand is some of the limitations of radiography. Radiographs can produce extremely sharp, finely detailed, views. This ability is called "definition" or sharpness of view. But the sharpness of view is of no value unless there is contrast, and contrast requires a significant change in the total density of adjoining paths of the radiating beam. If a change in a variable from one point to another on a specimen results in much less than a 2 percent change in the total beam intensity, then it will be difficult for radiography to detect this difference. A designer needs to appreciate this limitation when he is considering specifying a radiographic method. The importance of lining up the expected defect in the direction of the beam path is entirely due to this need to establish contrast. Once this principle is understood, the other limitations (access to both sides, finite thickness limits, safety, etc.) are usually well understood and acknowledged.

The difficulty of the interpretation of the radiograph is another area that designers often overlook. Only experience seems adequate to impress upon individuals that shadowgraphs are limited in the degree of information they present, and experience in interpretation is a necessity for acceptable confidence and reliability.

5.7.2 GUIDELINES FOR PRODUCTION ENGINEERS

The main drive for Production Engineers is efficiency, and, for radiographic work, efficiency means short exposure times, fast turnaround times, and the least delay on the production line. Safety requirements often involve exposure during night shifts when fewer personnel are around and the least delay to the line may be experienced. The fast exposure times required in this drive for efficiency minimizes the contrast of the radiograph. Therefore, under production conditions, the use of penetrameters are a must to ensure that contrast is not being lost.

5.7.3 GUIDELINES FOR QUALITY ASSURANCE PERSONNEL

Because radiography is a standard routine, Q.A. often relies upon routine methods for all radiographic work. The need for real standards (specimens with real flaws) and not just exposure standards (penetrameters) or sets of radiographs as radiographic acceptance standards must constantly be kept in mind. For some inspections the verification with real flaws is vital, both for exposure control as well as for proper interpretations of the radiographs.

(1) Procedures must be established and enforced to insure only experienced, qualified people perform the radiographic inspection function.

(2) For complex mechanisms and assemblies, QA personnel must determine that the desired feature of interest is actually capable of being radiographically observed and is not confused with some other feature.

(3) Where radiographic requirements and standards have been established for x-ray film, a change to fluoroscopy or other filmless methods should only be made with extreme caution. Many of the characteristics implicit in the film method (high detail, permanent records, ability to backtrack and review, transportability of data) are not always satisfactorily provided with a non-film method.

(4) Accept/reject criteria should be verified and clearly defined and presented to the x-ray inspector. Only the designer is in a position to evaluate the significance of a particular defect or condition in a product.

5.7.4 GUIDELINES FOR NDT ENGINEERS

The NDT Engineer has great influence in the quality versus time conflict that might exist in radiographic work. Many times the use of dual packs, the combining of films having different speeds into one exposure shot, will allow different thicknesses to be examined by the one setup. The use of single-side emulsion film must be considered by the engineer if extra fine, magnified details are sought. The final quality of all radiographic film methods depends upon the development of the film. If out-of-date film, or improper development solutions, or other inadequate development methods are used, the results will be as unacceptable as if improper exposures were used. The cause of a particular difficulty is not always obvious. Therefore, the radiographic engineer must keep knowledgeable of several interrelating activities if he is to be truly successful.

5.7.5 GUIDELINES FOR NDT TECHNICIANS

One of the most important attributes for a radiographic technician to develop is the habit of safety. When one works in a regularly maintained X-ray vault, safety interlocks usually exist to ensure some degree of safety. However, because there usually are times when work must be done in other locations and times when interlocks fail, it is imperative that the NDT technician adopts habits that will ensure his safety under all conditions.

An X-ray technician should never enter an exposure area with the equipment turned on even though interlocks are provided. The use of gamma ray sources is even more dangerous to the technician since safety interlocks are less likely to be present. The technician is entirely responsible for his own safety under these circumstances.

A technician must be observant of details. All variances from normal conditions should be noted and brought to the attention of the NDT Engineer. The placement of penetrameters and markers in each exposure must be carefully accomplished, with double checks on the proper placement of film, filters, screens, and masking materials when required.

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5.8 SAFETY

This section covers basic radiographic safety procedures, protection devices, and detection equipment. It is not an interpretation of government regulations nor can it be considered a complete safety guide. The radiographer is obligated to know all current regulations and to keep personally aware of all changes in these regulations. Most of the effects of radiation on the human body are known and predictable. Radiation safety practices are based on these effects and the characteristics of radiation. Since radiation cannot be detected by any of the human senses, and its damaging effects do not become immediately apparent, personal protection is dependent upon detection devices and adequate shielding. The United States Nuclear Regulatory Commission (USNRC) (formerly U.S. Atomic Energy Commission) enforces safety regulations covering the handling and use of radioisotopes. The United States Department of Transportation, the Civil Aeronautics Board, and the United States Coast Guard enforce safety regulations covering the transportation of radioactive material. The various states have similar regulations covering use, handling, and transportation of radioactive material and machine sources of radiation. All of these regulations are designed to limit radiation exposure to safe levels, and to afford protection for the general public. This government emphasis on safety practices indicates the mandatory nature of sure and certain safety practices in all radiation areas. The radiographer who is a licensee of the USNRC or who is employed by a licensee must have knowledge of, and comply with, all pertinent regulations. Radiography can be safe, but only as safe as those working with it make it safe.

5.8.1 UNITS OF RADIATION MEASUREMENTS AND MAXIMUM DOSAGES

For radiation safety purposes, the cumulative effect upon the human body of radiation exposure is of primary concern. Since the damaging effects of radiation to living cells are dependent upon both the type and the energy of the radiation to which they are exposed, it is impractical only to measure radiation quantitatively. For this reason, exposure is first measured in physical terms; then, a factor allowing for the relative biological effectiveness of different types and energies of radiation is applied.

The units used to measure radiation exposure are defined as follows:

a. Roentgen. The roentgen (r) is the unit measure of X- or gamma radiation in air. It is defined as the quantity of radiation that will produce one electrostatic unit (esu) of charge in one cubic centimeter of air at standard pressure and temperature. One roentgen of radiation represents the absorption by ionization of approximately 83 ergs of radiation energy per gram of air. In practical application, the milliroentgen (mr), one thousandth of a roentgen, is often used. The roentgen is a physical measurement of X- and gamma radiation quantity.

b. Rad. The rad (radiation absorbed dose) is the unit of measurement of radiation. It represents an absorption of 100 ergs of energy per gram of material, at the place of incidence. The roentgen applies only to X- and gamma rays; the rad applies to absolute dose of any type of radiation in any medium.

c. Rbe. The value assigned to various types of radiation, determined by the radiation's effect on the human body, is called relative biological effectiveness (rbe). Rbe values have been calculated by the National Committee on Radiation Protection as shown in Table 5.8(1).

Table 5.8(1). RBE values.

RADIATION	RBE
X-RAY	1
GAMMA RAY	1
BETA PARTICLES	1
THERMAL NEUTRONS	5
FAST NEUTRONS	10
ALPHA PARTICLES	20

d. Rem. The roentgen equivalent man (rem) is the unit used to define the biological effect of radiation on man. It represents the absorbed dose in rads multiplied by the relative biological effectiveness of the radiation absorbed.

Radiation safety levels are established in terms of rem dose. The calculating of rem dose of X- and gamma radiation is simplified by two facts: (1) the roentgen dose is equivalent to the rad dose, and (2) the rbe of both X- and gamma radiation is one. A measurement of dose thus is rad equivalent and then equivalent to a measurement of rem dose.

It is impossible to safeguard radiographic personnel from all exposure to radiation. Permissible dose is defined by the International Commission on Radiation Units (ICRU) as, ". . . the dose of ionizing radiation that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime." Maximum permissible dose (mpd) is the numerical value of the highest permissible dose, under prescribed conditions of exposure, stated in units of time. Currently accepted mpd, established through experience, is contained in USNRC regulations on Standards for Protection Against Radiation. Maximum radiation dose, in any period of one calendar quarter, to an individual in a restricted area, is normally limited government regulatory bodies, exposures up to 3 rem per calendar quarter may be permitted. Applicable radiation safety publications are issued by the National Bureau of Standards, the International and National Committee on Radiation Protection, the USNRC, and state authorities. The radiographer should be cognizant of the information in the "NRC Licensing Guide for Industrial Radiography," which is available from the U.S. Government Printing Office. For under 18 and the general public, .5 rem is the limit.

It should be emphasized again that regardless of limits that are set for allowable radiation exposures, the general policy is to avoid all unnecessary exposure to ionizing radiation.

This policy is referred to as the "as low as reasonably achievable" (ALARA) principle by the Nuclear Regulatory Commission (10CFR20.1C). The commission expects that its licensees will make every reasonable effort to maintain exposures to radiation as far below the limits as is reasonably achievable. Specific recommendations for implementing this policy are contained in NRC Regulatory Guides 8.8 (primarily for nuclear power stations), 8.1 (and an associated detailed report, NUREG-0267, for medical institutions), and 8.10. Some of the measures listed as indicators of a commitment by management to an ALARA policy include promulgation of the policy in statements and instructions to personnel; review of exposures and operating procedures to examine compliance with ALARA; and training programs including periodic reviews or testing of the understanding of workers on how radiation protection relates to their jobs.

5.8.2 PRINCIPLES OF PROTECTION AGAINST RADIATION

Three main principles govern safety practices for controlling body exposure to radiation: 1) time, 2) distance, and 3) shielding. Safe radiographic techniques and radiographic installations are designed by applying these three principles:

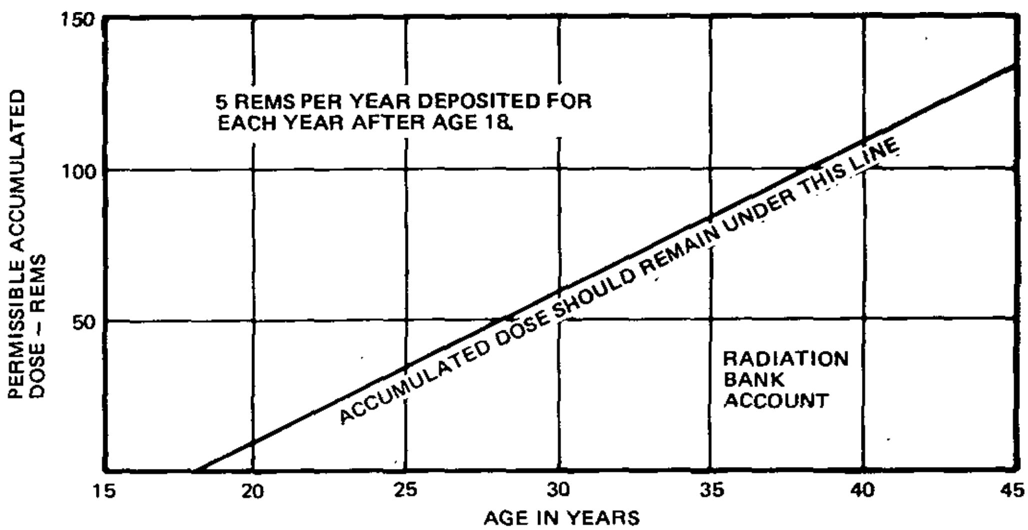

Figure 5.8(1). Banking concept.

a. Allowable Working Time. The amount of radiation absorbed by the human body is directly proportional to the time the body is exposed. A person receiving 2 mr in one minute at a given point in a radiation field would receive 10 mr in five minutes. Allowable working time is calculated by measuring radiation intensity and substituting in the following equation:

$$\text{Allowable working time in hr/wk} = \frac{\text{permissible exposure in mr/wk}}{\text{exposure rate in mr/hr}} \quad (1)$$

b. Working Distance. The greater the distance from a radiation source, the lower the exposure received. The inverse square law is used to calculate radiation intensities at various distances from a source. The inverse square law is expressed as:

$$\frac{I_1}{I} = \frac{D^2}{(D_1)^2} \quad (2)$$

where I_1 and I are intensities at D_1 and D respectively.

Intensity and dose rate calculations based on the inverse square law should never be accepted as exact. Radiation intensity at any point is the sum of the primary radiation and the secondary (scatter) radiation at that point. Therefore, the actual radiation will normally be greater than that calculated by this equation. Safety should always be established by actual measurements of the radiation level and not just by theoretical calculations.

c. Shielding. Lead, steel, iron, and concrete are materials commonly used as shielding to reduce radiation exposure to personnel. Since all of the energy of X- or gamma radiation cannot be stopped by shielding, it is practical to measure shielding efficiency in terms of half-value layers. The half-value layer is that amount of shielding which will stop half of the radiation energy. See Table 5.2(2). Similarly, shielding efficiency is often measured in tenth-value layers. A tenth-value layer is that amount of shielding which will stop nine-tenths of the radiation of a given intensity. Half- and tenth-value layers are, in all cases, determined by experiment and actual measurement. The radiographer should rely on actual measurement to determine the effectiveness of any shielding.

Wherever practicable, a working area should consist of a room completely lined with lead, steel, iron or concrete of sufficient thickness for protection. Concrete is the most commonly used material. If the construction of such a room is not feasible, then the equipment should be housed in a suitably shielded cabinet, large enough to also house the specimens under test. X-ray machine controls should be located outside the exposure area. To reduce the possibility of excessive radiation in occupied spaces, the exposure area should be as isolated as conditions permit. If neither a room nor a cabinet is available, any combination of shielding that safely encloses the radiation equipment, specimen, and the film is acceptable. It is not always practical to bring the specimen to the shielded exposure area. When radiography must be accomplished under this circumstance, the three safety factors (time, distance, and shielding) must be taken into account. Safe distances, in relation to exposure, must be determined, and adequately marked guard rails or ropes placed to enclose the radiation area. Sufficient shielding must be placed to protect the radiographer and others who must remain in the vicinity. When radiography is practiced outside a designated shielded exposure area the simplest, most effective safety consideration is distance. All personnel must be kept at a safe distance from the radiation source.

Theoretically, the lead housing around an X-ray tube effectively shields, to safe levels, all primary radiation except the useful beam. Practically, this is not always the case, and the only way to assure the safeness of an X-ray tube is to measure leakage (unwanted) radiation around it. To limit the unwanted radiation, the area of primary radiation should be fixed by a cone or diaphragm at the tube head.

Certain gamma radiations can be very penetrating, and the required protective shielding can be excessively thick and heavy. Gamma radiation cannot be shut off, and protection must be provided at all times.

Shielding is the primary protection from gamma rays. The penetrating capability of gamma radiation makes it impractical to rely only on shielding for protection during gamma radiography; a combination of distance and shielding is usually employed. The radiation danger zone is roped off and clearly marked with conspicuous signs, and only those persons making the radiograph are permitted in the zone. The extent of the danger zone is based on calculations of safe distance as determined by the source strength. In calculating the area of the danger zone, the possible effects of scatter radiation are considered and the calculations are confirmed by intensity measurements.

The continuous gamma radiation from radioisotopes necessitates strict accountability of radioactive sources. When not in use they are stored in conspicuously labelled, lead vaults and/or depleted uranium 238. After every use, intensity measurements are taken to ensure that the source is safely housed, and the storage pig is not permitting leakage radiation.

5.8.3 USNRC RULES AND REGULATIONS

Handling, storage, and use of radioisotopes are regulated by the USNRC. The regulations are published in the Code of Federal Regulations, Title 10, Chapter I, parts 20, 21, 30, 31 and 34. Part 34 of the Code is also published in the NRC Licensing Guide. The following regulations are subject to change and are presented for familiarization purposes only.

Limitations on individual dosages are specified in Table 5.8(2).

Doses greater than specified in the table may be permitted provided: 1) during any calendar quarter the dose to the whole body does not exceed 3 rems; 2) the dose to the whole body, when added to the accumulated occupational dose to the whole body, does not exceed 5 (N-18) rems where "N" equals the individual's

Table 5.8(2). Exposure limits in restricted areas.

	REMS PER CALENDAR QUARTER
WHOLE BODY, HEAD AND TRUNK; ACTIVE BLOOD-FORMING ORGANS; LENS OF EYES; OR GONADS	1-1/4
HANDS AND FOREARMS: FEET AND ANKLES	18-3/4
SKIN OF WHOLE BODY	7-1/2

age in years at his last birthday; and 3) the individual's accumulated occupational dose has been recorded on Form NRC-4 or equivalent and the concerned individual has signed the form. Note This is being replaced by an annual limit of 5 rems.

Form NRC-5, Current Occupational External Radiation Exposure, must be completed quarterly and is the source of the information recorded on Form NRC-4.

Minors are not allowed to work in restricted areas. Regulations to protect minors specify that no individual under 18 years of age is permitted to receive dosages exceeding 10 percent of the limits specified in Table 5.8(2).

Under approved circumstances, a limited amount of radiation is permitted in unrestricted areas. Exposure limits in unrestricted areas are listed in Table 5.8(3). These dosage limits are based on an individual being continually present in the area and thus the exposure limits represent maximum radiation levels permitted.

Personnel monitoring equipment must be used by:

a. Individuals entering restricted areas who receive, or may receive, dosage in any calendar quarter in excess of 25 percent of the applicable value specified in Table 5.8(2).

b. Individuals under 18 years of age entering restricted areas who receive, or may receive, dosage in any calendar quarter in excess of 5 percent of the applicable value specified in Table 5.8(2).

c. Individuals who enter high radiation areas.

Table 5.8(3). Exposure limits in unrestricted areas.

TIME	MILLIREMS
1 HOUR	2
7 CONSECUTIVE DAYS	100
1 CALENDAR YEAR	500

During radiographic operations, radiographers and their assistants shall wear radiation monitoring devices such as film badges or thermoluminescence dosimeters (TLD) and either pocket dosimeters or pocket chambers. Pocket dosimeters and chambers shall be capable of measuring doses from zero to 200 milliroentgens. They shall be read daily and the indicated dose shall be recorded. If a pocket chamber or dosimeter is discharged beyond its range, the film badge of the individual shall be processed immediately.

The radiation "Warning" symbol is shown in Figure 5.8(1). Signs bearing this symbol must be placed in conspicuous places in all exposure areas, and on all containers in which radioactive materials are transported, stored, or used. On each sign the word "Caution," or the word "Danger," must appear. Other wording required is determined by specific sign use. Area signs bear the phrases, "Radiation Area," "High Radiation Area," or "Airborne Radioactivity Area," as appropriate. Containers of radioactive materials and areas housing such containers must be marked with signs or labels bearing the radiation symbol and the words "Radioactive Material(s)." Special tags bearing the radiation symbol and the phrase, "Danger-Radioactive Material-Do Not Handle. Notify Civil Authorities If Found," must be attached to sealed sources not fastened to, or contained in, an exposure device.

Specific regulations provide standards for isotope cameras and other isotope exposure devices. Protective standards designed to protect personnel from sealed sources when they are in the fully shielded position are as follows:

a. Radiographic exposure devices measuring less than four inches from the sealed source storage position to any exterior surface of the device shall have no radiation level in excess of 50 milliroentgens per hour at six inches from any exterior surface of the device.

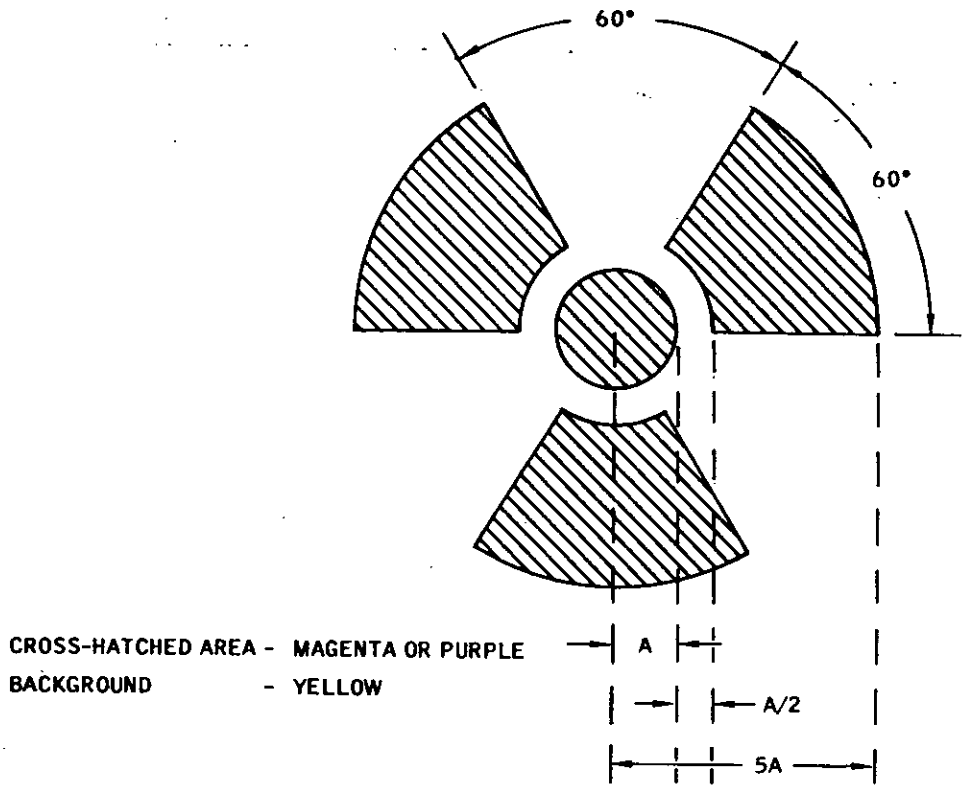

Figure 5.8(2). Radiation symbol.

b. Radiographic exposure devices measuring a minimum of four inches from the sealed source storage position to any exterior surface of the device, and all storage containers for sealed sources or for radiographic exposure devices, shall have no radiation level in excess of 200 milliroentgens per hour at one meter from any exterior surface.

For radiographic operations, it is required that calibrated and operable radiation survey instruments (meters) be available. The meters used shall have a range such that two milliroentgens per hour through one roentgen per hour can be measured. It is not necessary that any one meter be capable of measuring the entire required range.

Specific regulations for required isotope radiation surveys are as follows:

a. No isotope radiographic operation shall be conducted unless calibrated and operable radiation survey instrumentation is available and used at each site where radiographic exposures are made.

b. Physical radiation measurements (a radiation survey) shall be made after each isotope radiographic exposure operation to determine that the sealed source has been returned to its shielded condition.

c. A physical radiation survey shall be made to determine that each sealed source is in its shielded condition prior to securing the radiographic exposure device and storage container.

5.8.4 RADIATION DETECTION AND MEASUREMENT INSTRUMENTS

Based on the characteristic effects of radiant energy on matter, various techniques are employed in detection and measurement devices. Chemical and photographic detection methods are used, as well as methods which measure the excitation effect of radiation on certain materials. In radiography, however, the instruments most commonly used for radiation detection and measurement rely on the ionization produced in a gas by radiation. Since the hazard of radiation is calculated in terms of total dose and dose rate, the instruments used for detection and measurement logically fall into two categories: instruments that measure total dose and exposure, such as pocket dosimeters, pocket chambers, and film badges; and instruments that measure dose rate(radiation intensity), such as ionization chambers and Geiger counters. These last two instruments are known as survey meters.

The pocket dosimeter (Figure 5.8(2)) is a small device approximately the size of a fountain pen. Its operation is based on two principles: 1) like electrical charges repel each other; and 2) radiation causes ionization in a gas. The essential parts of the dosimeter are the metal cylinder, the metal-coated quartz fiber electrode consisting of a fixed section and a movable section, the transparent scale, and the lens. The electrode and the cylinder form an electroscope. When a potential (from an external source of voltage) is applied between the electrode and the cylinder, the electrode gains a positive charge and the cylinder a negative charge. Simultaneously, the movable portion of the electrode moves away from the fixed portion since they are mutually repellent, each carrying a positive charge. The transparent scale and the lens are so placed that, when the scale is viewed through the lens, the movable portion of the electrode appears as the indicator on the scale. When the dosimeter is properly charged, the indicator will be at zero on the scale and the dosimeter is ready for use.

When a dosimeter is placed in an area of radiation, ionization takes place in the cylinder chamber. Negative ions are attracted to the electrode and positive ions to the cylinder. As the positive charge on the electrode becomes neutralized, the repellent force between the fixed and movable portions decreases. The movable portion moves toward the fixed portion in an amount proportional to the ionization action. Since the quantity of ionization is determined by the quantity of radiation, the displacement of the movable portion of the electrode is a direct measure of the radiation. Pocket dosimeters are designed with a sensitivity that permits them to be scaled in dose/exposure from 0 to 200 milliroentgens.

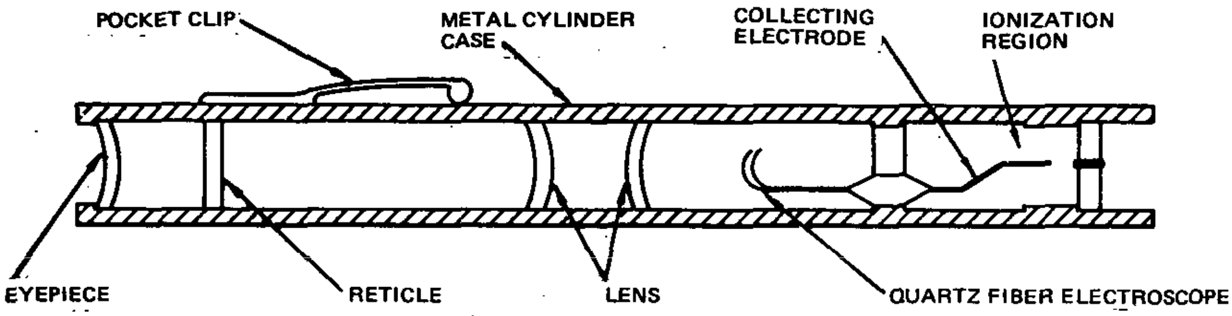

Figure 5.8(3). Pocket dosimeter cross-section (typical).

The film badge (Figure 5.8(3)) consists of a small film holder equipped with thin lead or cadmium filters, in which is inserted special X-ray film. The badge is designed to be worn by an individual when in radiation areas, and is not to be otherwise exposed. After a period of time, usually two weeks, the film is removed and developed by standard techniques. The density of the processed film is proportional to the radiation received. By use of a densitometer the density of the film is compared to that of a set of control films. Through this comparison, an estimate of the amount of radiation received by the individual who wore the badge is made. Film badges and dosimeters each record total radiation received and serve as a check on each other.

Because of the number of instruments that would be required, and the excessive amount of time necessary for their use, dosimeters and pocket chambers cannot be readily used for radiation area surveys. Such surveys require an instrument capable of obtaining and presenting an instantaneous measurement of radiation intensity. Two such instruments are in common use: the ionization chamber instrument and the Geiger counter.

Ionization chamber instruments basically consist of an ionization chamber containing two electrodes: a power supply, usually a battery, which is connected across the electrodes; and an ammeter connected in series with the power supply. When the instrument is exposed to radiation, ionization takes place in the chamber. Individual ions are attracted to the electrode of opposite potential, and upon reaching the electrode become neutral by removing a charge from the battery. The flow of current from the battery required to neutralize the ions is measured by the meter, which is calibrated in terms of milliroentgens or roentgens. The meter may be calibrated in physical quantities because the flow of current is proportional to the ionization caused by the radiation. In this manner, radiation intensity (dosage rate) is measured. Ionization chamber instruments attain an accuracy of ± 15 percent except in low radiation intensity areas. In areas of low intensity radiation, sufficient ionization current is not generated to indicate accurately on the meter. Radiation intensity measurements in areas of low radiation intensity are usually made with Geiger counters.

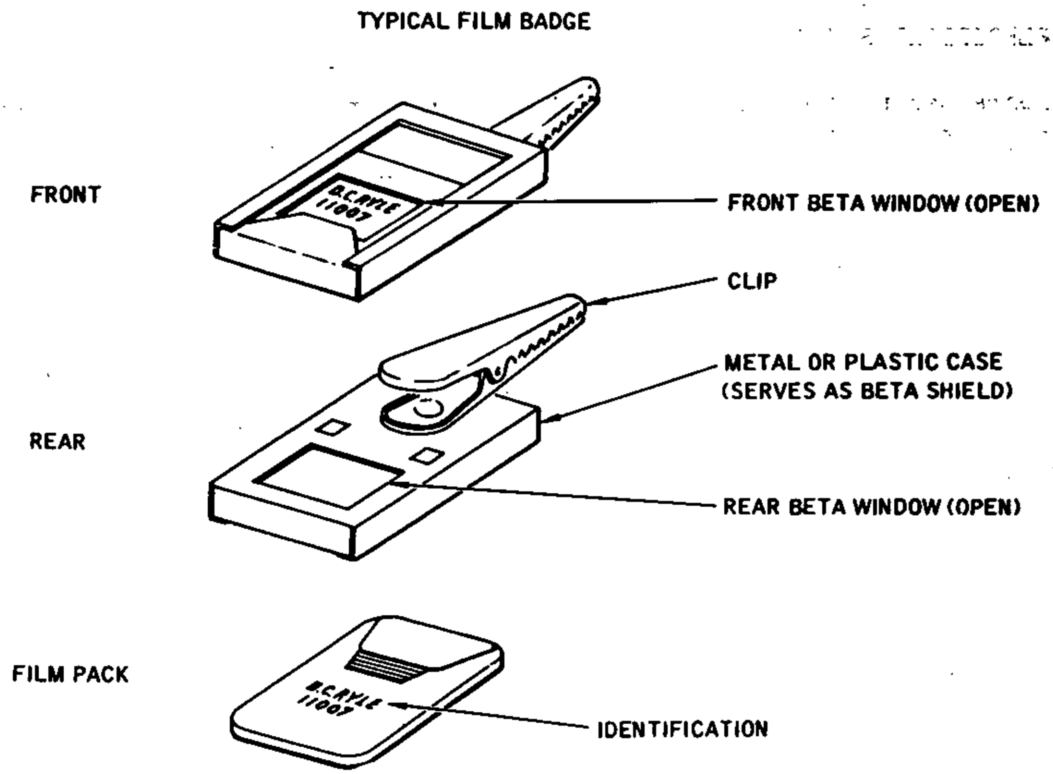

Figure 5.8(4). Film badge (typical).

Geiger counters utilize a Geiger-Muller tube as an ionization chamber in a high sensitivity radiation detecting device. The voltage difference between the tube anode and cathode, and the gas within the tube create an environment wherein any ionizing event is multiplied into many such events. The secondary ionizations are caused by the action of the electrons produced in the first ionization event. This phenomenon of a single ionization producing many in a fraction of a millisecond is known as gas multiplication. The resultant amplified pulse of electrical energy is used to cause an audible indication, deflect a meter, or light a lamp. Geiger counters are accurate to ± 15 percent for the quality of radiation to which they are calibrated. They are extremely useful as detection instruments particularly for gross contamination surveys, but are not intended to be accurate measurers of dose rate. In areas of high radiation intensity, Geiger counters have a tendency to block out, and the meter will indicate a false zero reading. For this reason, in areas of suspected high radiation intensity, chamber instruments should be used.

Area alarm systems consist of one or more sensing elements, usually ionization chambers, whose output is fed to a central alarm meter. The meter is preset so that an audible alarm is sounded, or a visual indication is given (lighted lamp), when permissible radiation levels are exceeded. Area alarm systems are often used in gamma radiography.

5.8.5 ELECTRICAL SAFETY

The radiographer must comply with safe electrical procedures when working with X-ray equipment. Modern X-ray machines use high voltage circuits. Permanently installed X-ray facilities are designed so that personnel trained in safe practices will encounter few electrical hazards; however, portable X-ray equipment requires certain electrical precautions.

Whenever X-ray equipment is being operated or serviced, the following precautions, applicable to either permanent or portable installations, should be observed:

a. Do not turn power on until the setup for exposure is completed.

b. Ensure that grounding instructions are complied with.

c. Regularly check power cables for signs of wear. Replace when necessary.

d. Avoid handling power cables when power is ON.

e. If power cables must be handled with power ON, use safety equipment such as rubber gloves, rubber mats, and insulated high-voltage sticks.

f. Ensure that condensers are completely discharged before checking any electrical circuit.

If common-sense precautions are observed, there are few electrical hazards in the use of X-ray equipment.

(KBWP# ID-1340P/DISC 0045A. FOR AMMRC USE ONLY)

5.9 GLOSSARY

absorbed dose (dose) - the amount of energy imparted by ionizing radiation per unit mass of irradiated matter. Symbol: D. Special unit: rad. One rad is equal to 0.01 joules per kilogram. SI (international System) unit: gray. One gray is equal to one joule per kilogram.

absorbed dose rate - the absorbed dose per unit time. Special unit: rads per second. SI unit: grays per second.

absorption - the process whereby the incident particles or photons of radiation are reduced in number or energy as they pass through matter.

absorption edge - see critical absorption wavelength

accelerator - a device used to impart kinetic energy to charged atomic particles. The beam of particles may be made to impinge on a heavy-metal target to produce x-rays or high-energy photon radiation. Examples of accelerators are the linear accelerator, betatron, Van de Graaff accelerator, and the x-ray machine.

activation - the process by which substances are made radioactive by irradiation (bombardment by particles or gamma rays).

activity - the rate at which spontaneous nuclear transitions occur in an amount of radioactive material at a given time. Symbol: A. Special unit: curie. SI unit: becquerel.

acute radiation syndrome - the immediate effects of short-term, whole-body overexposure of a person to ionizing radiation. These effects include nausea and vomiting, malaise, increased temperature, and blood changes.

added filter - any filter used to achieve filtration in excess of the inherent filtration.

additive, absorptive - see contrast agent.

aerial image - the representation (in relief) of the distribution of the intensity of the radiation in the plane of the radiograph (plane of the film).

afterglow - the persistence of light emission from an intensifying screen or fluorescent screen after an exposure. It is a form of phosphorescent radiation.

air-cooled tube - an x-ray tube for which the principal method of cooling is dissipation of heat into surrounding air.

air scatter - ionizing radiation that, because of a scattering interaction with air, arrives at a point by way of an indirect route instead of arriving directly from the source.

alkali - the alkaline constituent (e.g., sodium carbonate) which is normally added to the developer to bring the solution to, and maintain it at, the desired level of chemical activity.

alpha particle - a positively charged particle emitted by certain radionuclides. It consists of two protons and two neutrons, and is identical to the nucleus of a helium atom.

alpha ray - a beam of alpha particles that has a small cross-sectional area.

aluminum equivalent - the thickness of aluminum (with specified purity) affording the same attenuation, under specified conditions as the material in question.

anode - the positive electrode, usually including the target, in an x-ray tube.

anode current - the current passing from the cathode to the anode in an x-ray tube.

anode stem - the metallic rod on which the target is mounted, and which is sealed to the envelope of the x-ray tube.

anti-scatter grid - an array of x-ray opaque and transparent sections of materials placed between the specimen and the film to minimize the effect of scattered radiation on the radiographic image, e.g., a Potter-Bucky diaphragm.

area monitoring - the continued measurement of ionizing radiation exposure or dose levels in an area for the purpose of radiation protection.

area of interest - the specific portion of the specimen image on the radiograph that is to be evaluated.

artifact - a spurious indication on a radiograph caused by faults in the manufacture, handling, storing, exposing, or processing of a film.

atomic number - the number of protons in a given atomic nucleus. Symbol: Z.

atomic weight (atomic mass) - the mass of an atom. The basis of the physical scale of atomic weights is the carbon atom, and the isotope carbon-12 has arbitrarily been assigned an atomic weight of exactly 12 atomic mass units. Hence the atomic mass unit is 1/12 the weight of carbon-12, or roughly the mass of the proton or neutron. The atomic weight of an element, therefore, is approximately equal to the total number of protons and neutrons in its nucleus. One atomic mass unit = 1.66×10^{-24} gram.

attenuation - reduction in the intensity of a beam of ionizing radiation due to passage through matter.

attenuation coefficient - the average fraction of photons or uncharged ionizing particles that interact per unit pathlength in an absorbing material.

Auger electron - an orbital electron emitted by an atom, instead of a photon of characteristic radiation, when a vacancy in an inner electron shell is filled.

autoradiograph - the image of an object obtained on a photographic emulsion by means of radiation emitted by the object itself.

autoradiography - the process by which the image of an object is obtained on a photographic emulsion by means of radiation emitted by the object itself.

autotransformer - a transformer in which the output voltage can be easily varied.

average life (mean life) - the arithmetic mean value of the lives of the atoms of a radioactive nuclide. It is the reciprocal of the decay constant. Symbol:

background count - the number of counts recorded by a counting system over a period of time due to background radiation and electronic noise in the counting system.

background counting rate - the number of background counts per unit time.

background radiation - the radiation in man's natural environment, consisting of that which comes from cosmic rays and the naturally radioactive elements of the earth.

back-scattered radiation - radiation that was scattered at angles greater than 90° with respect to its direction of incidence.

barium clay - a clay containing barium that is used to eliminate or reduce the amount of scattered or secondary radiation reaching a radiographic film.

barium concrete - concrete containing a high proportion of barium compounds, used for radiation protection purposes.

barium plaster - plaster containing a high proportion of barium compounds, used for radiation protection purposes.

barn - a unit used to express nuclear cross section ($1 \text{ barn} = 10^{-24} \text{ cm}^2$).

beam - a directed flow of energy into space or matter, in which the directions of propagation of individual particles or photons are nearly parallel.

beam angle - the angle between the central axis of the radiation beam and the plane of the (radiographic) film.

beam divergence - the solid *angle of the beam of radiation as it emerges from* the x-ray tube or gamma-ray exposure device.

beam quality - an expression used to describe the penetrating power (energy spectrum) of a beam of radiation. The quality of an x-ray beam is usually expressed in terms of half-value layer of some reference material, such as aluminum or copper.

becquerel - the SI (international system) unit of activity. One becquerel equals one nuclear transition per second. Abbreviation: Bq. (1 Ci = 3.7×10^{10} Bq.).

beta decay - the nuclear transition process characterized by the emission of a beta particle. The parent atom involved is called a beta emitter.

beta particle - an elementary particle emitted from a nucleus during nuclear transition. It has an electrical charge of 1.602×10^{-19} coulomb and a mass equal to 1/1836 that of a proton. A negatively charged beta particle is physically identical to the electron.

beta ray - a beam of beta particles that has a small cross-sectional area.

betatron - a circular-orbit accelerator in which the acceleration of the particles is produced by an electric field created by the variation in a magnetic field also used as a guide field. It can accelerate electrons to energies on the order of 10^6 to 10^8 electron volts, which can impinge on a heavy metal target to produce high-energy x-rays.

blocking - surrounding specimens or covering them partially with radiation-absorbing material.

blocking medium - material of appropriate radiation opacity for applying to an object, either around the edges or as a filling for holes, to reduce the effect of scattered radiation and to shield portions of the film which would otherwise be over-exposed (e.g., radiographic putty).

blur- see unsharpness.

body burden - the amount of radioactive material present in the body of a human or an animal.

boundary wavelength (quantum limit) - the shortest wavelength present in a continuous x-ray spectrum, It is inversely proportional to the peak voltage applied to the x-ray tube.

branching - the occurrence of competing radioactive decay processes (branches) in the disintegration scheme of a particular nuclide.

branching fraction - that fraction of the total number of atoms involved which follows a particular branch of the disintegration scheme. It is usually expressed as a percentage.

branching ratio - the ratio of two specified branching fractions. The term is also commonly used as a synonym of branching fraction.

bremsstrahlung - electromagnetic radiation emitted by charged particles when they are slowed down by electric fields in their passage through matter. literally "braking radiation" in German.

brightness amplifier - see image intensifier.

broad beam - an uncollimated beam containing scattered radiation as well as the primary beam.

broad-beam absorption - absorption measured under conditions in which scattered radiation is not excluded from the measuring apparatus.

build-up - an increase in a specified radiation quantity due to the contribution from scattered and secondary radiation.

build-up factor - in the passage of radiation through a medium, the ratio of the total value of a specified radiation quantity at any point to the contribution that value from radiation reaching the point without having undergone a collision.

Bunsen-Roscoe reciprocity law - see reciprocity law.

byproduct material radioactive - any radioactive material (except source or fissionable material) obtained in the process of producing or using source or fissionable material. Includes fission products and many other radionuclides produced in nuclear reactors.

calcium tungstate - a fluorescent chemical compound which emits primarily blue-violet light when activated by either x or gamma radiation or charged particles..

calibration - see instrument calibration or source calibration.

cannon tube shield - a tube shield in the form of a long cylinder, generally supported in cantilever fashion. The x-ray beam emerges through an aperture in the lead-lined wall of the cylinder, at right angles to its axis.

capacity - the maximum activity in curies (becquerels) specified for a given radionuclide that may be contained in an exposure device.

cascade tube - a high-voltage x-ray tube of cylindrical form divided into sections, the potential difference across each of which is a fraction of the voltage applied to the whole tube. The electron stream is accelerated to its maximum energy in stages.

cassette - a light-tight container for holding a radiographic film, paper or plate with or without screens during exposure, the front face of which is relatively transparent to x and gamma rays.

cathode - the negatively-biased electrode of an x-ray tube.

cathode ray - a stream of electrons emitted by a heated structure (or by a cold structure under the influence of an electric field of high intensity) and accelerated in a somewhat confined beam by means of an electric field or a changing magnetic field.

certified density - see step-wedge calibration film.

cesium-137 - a radioactive nuclide of the element cesium having a half-life of 30 years, and a photon energy of 662 keV (which is 0.662 MeV).

characteristic curve - for a particular type of film, a curve showing the relation between the common logarithm of exposure (frequently expressed in arbitrary units) and the photographic density, under specified conditions of exposure and processing.

characteristic radiation - x-radiation consisting of discrete wavelengths which are characteristic of the emitting material.

chemical fog (aerial fog) - see fog.

cine-fluorography - cine-radiography of images produced on a fluorescent screen.

cine-radiography - the production of a series of radiographs which can be viewed rapidly in sequence, thus creating an illusion of continuity.

clearing time (opaqueness) - the time required for the first stage of fixing during which the whiteness of the film disappears.

clockwork timer - a timer controlled by a clockwork mechanism.

cobalt-60 - a radionuclide of the element cobalt, emitting gamma rays with energies of 1.33 and 1.17 MeV, with a half-life of 5.3 years.

coincidence loss - loss of counts due to the occurrence of ionizing events at intervals less than the resolving time of the counting system.

collimator - a device used to limit the size, shape, and direction of the primary radiation beam.

combination screens - a pair of intensifying screens in which the front screen (to be placed on the tube side of the film) is usually thinner than the back screen.

composite filter - a filter of two or more materials chosen so that the longer wavelengths of a beam are strongly absorbed, and within this range anomalous transmission is avoided. The materials are usually arranged so that the second material filters secondary radiation produced in the first material and so on. A particular example is the "Thoraeus filter" which consists of 0.44 mm of tin, 0.25 mm of copper and 1 mm of aluminum in this order in the beam of radiation.

Compton absorption (Compton effect) - the reduction of the energy of an incident photon by its interaction with an electron. Part of the photon energy is transferred to the electron (Compton electron or recoil electron) and part is redirected as a photon of reduced energy.

Compton scattering - a process in which an incident photon transfers a portion of its energy to an electron in matter and a lower energy photon is scattered at an angle to the original photon path.

computed tomography - a method by which a radiograph of a predetermined interior plane of a thick material is obtained through the use of a computer. The images resulting from a series of exposures at different angles are stored and reconstructed into a single image by the computer.

condenser ionization chamber - an ionization chamber which, having been charged to a certain potential, can be irradiated and subsequently attached to an electrometer to measure the residual charge, whereby the exposure is determined.

constant-potential circuit - a circuit which is so arranged to apply and maintain a substantially constant potential across an x-ray tube.

constant voltage (constant potential) - a unidirectional voltage of essentially constant magnitude.

container, gamma-ray source - a device for housing radionuclides and giving a required degree of protection against radiation. (This may take the form of an exposure device or a storage container).

contamination - the presence of unwanted radioactive matter, or the "soiling" of objects or materials with "radioactive dirt".

continuous spectrum - an array of the relative number of particles or photons that have a specified wavelength, frequency, or energy in a beam of radiation; for the case when the wavelengths, frequencies, or energies cover an unbroken range of values.

continuous wedge - a wedge, the thickness of which varies continuously.

contrast - the relative brightness of two adjacent areas in a radiograph, photographic reproduction, or fluorescent-screen image.

contrast agent - any suitable substance, solid, liquid, or gas, applied to a material being radiographed, to enhance its contrast in total or in part.

contrast, film - the property of a film to record differences in density in relation to radiation intensity. It depends on the slope (gradient) of the characteristic curve at a given density.

contrast, radiographic - differences in density from one area to another on a radiograph.

contrast ratio - the relative amount of light emitted or reflected as between an indication and its background.

contrast, subject - see subject contrast.

controlled area - any area to which access is controlled for radiation protection purposes.

control panel - a console or unit that contains the controls necessary to operate a radiation source and any ancillary equipment used for radiography.

Coolidge tube - an x-ray tube in which the source of the bombarding electrons is a heated filament in the cathode.

corpuscular radiation - see particulate radiation.

count - a pulse that is recorded by a counter and which has been initiated in a detector by an ionizing event.

counter - a device that reacts to signals produced by individual ionizing events, thus enabling them to be summed over a specified period of time.

counting rate - the average rate at which counts are recorded.

counting-rate meter - an instrument that indicates counting rate.

critical absorption wavelength (absorption edge) - the wavelength, characteristic of a given electron energy-level in an atom of a specified element, at which as absorption discontinuity occurs.

cross section - a measure of the probability for an atomic or nuclear interaction. It is usually expressed in barns (1 barn = 10^{-24} cm^2). It can be considered as the effective target area presented by an atom, subatomic particle, or photon for a particular process, e.g., scattering, absorption, or total.

cumulative dose, biological - the total dose resulting from repeated exposure to radiation of the same part or of the whole body.

curie - (Ci) the special unit of activity. One curie equals 3.7×10^{10} spontaneous nuclear transitions per second exactly, or by popular usage, the quantity of any radioactive material having an activity of one curie.

cyclotron - a particle accelerator in which the charged particles are accelerated in an orbit that is approximately a spiral between the ends of a huge magnet, gaining energy with each rotation. The cyclotron is normally used for nuclear research but the particles can be made to collide with a target to produce x-rays.

deadmen switch - a switch so constructed that a circuit-closing contact can only be maintained by continuous pressure by the operator.

dead time - the minimum amount of time following the detection of an event by a counting system before another event can be detected. The minimum time may be set by the detector itself, or by the associated electronics.

decay - the decrease in the activity of a radioactive source, the rate of which is controlled by its half-life.

decay constant - the probability that a given nucleus will undergo a spontaneous nuclear transition from a particular energy state in a unit of time. Symbol:

decay curve - the activity of a radioactive source, measured in curies (becquerels), plotted against time.

decontamination - the removal of radioactive contaminants from surfaces, as by cleaning and washing with chemicals.

decontamination factor - the ratio of the amount of radioactive contaminant initially present to the amount remaining after a suitable processing step has been completed. A factor referring to the reduction of the gross measurable radioactivity.

defect detection sensitivity - see sensitivity, defect.

definition - a general and qualitative term that refers to the degree of distinctness of image details in a radiograph, photographic reproduction, or viewing-screen image.

densitometer - an instrument used for optical density measurements either by reflection or by transmission of light.

density (film density; optical density; photographic density) - the quantitative measure of film blackening:

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

where:

D = density,
I_o = light intensity incident on the film, and
I = light intensity transmitted.

density comparison strip - alternative term for step-wedge comparison film.

density gradient - the change in density of a radiographic film (at a particular film density) per unit change in the logarithm of the exposure received by the film.

detector - a device that determines the presence of ionizing radiation.

developer, photographic - a chemical solution that reduces exposed silver halide crystals to metallic silver, thereby producing a visible image.

developing agent - the constituent of a developer that reduces sufficiently exposed silver halide grains to metallic silver at a greater rate than unexposed or insufficiently exposed grains.

development - the conversion of a latent image into a visible image by treatment of the film emulsion with a suitable chemical solution (developer).

dichroic fog - see chemical fog

differential mottling - minor irregularities in the distribution of density over the whole of the radiograph.

diffraction - the scattering of incident radiation from the regularly spaced atoms in crystals or complex molecules such that interference between the scattered waves results in a pattern of maxima and minima in the intensity of the scattered radiation.

diffraction mottle - a superimposed mottle or pattern on an image due to diffraction of certain wavelengths in the incident beam, caused by the size and orientation of the crystals of the material through which they have passed.

direct film - see non-screen film.

discharge tube - a tube usually exhausted to a low gas pressure and commonly provided with electrodes for the passage of electricity.

discontinuity - a term generally referring to any kind of flaw, defect, or lack of continuity in a material.

disintegration, nuclear - a spontaneous nuclear transition characterized by the emission of energy and/or mass from the nucleus.

disintegration scheme - the modes of decay of a radioactive nuclide, generally expressed in the form of a diagram which normally includes details of the corpuscular emission and of such subsequent radiations as gamma rays or characteristic x-rays.

distortion - the amount of geometrical departure of an image from the true reproduction of the object.

dose - a general term denoting the quality of energy absorbed from radiation.

dose, absorbed - see absorbed dose.

dose-effect relation - the relationship between the dose absorbed and the effect produced.

dose equivalent - the product of D, Q, and N at the point of interest in tissue where D is the absorbed dose, Q is the quality factor, and N is the product of all other modifying factors. Symbol: H. Special unit: rem. SI unit: sievert.

$$H = DQN$$

dose equivalent rate - the dose equivalent per unit time. Special unit: rems per second. SI unit: sieverts per second.

dose rate - the radiation dose absorbed per unit time and measured, for instance, in rads (grays) per hour.

dose rate meter - an instrument for measuring dose rate.

dosimeter - a device that measures radiation dose.

double-focus tube - an x-ray tube having a cathode provided with two filaments, only one of which is used at a time, and which generally give two different sizes of focal spot.

d/t ratio - the ratio of the source-to-specimen distance (d) and the specimen thickness (t).

elastic scattering - scattering in which the total kinetic energy of the incident radiation and the scatterer remains unchanged.

electromagnetic radiation - radiation consisting of electric and magnetic waves that travel at the speed of light. Examples: light, radio waves, gamma rays, x-rays.

electron - an elementary particle with a negative electrical charge of 1.602×10^{-19} coulomb and a mass equal to 9.1×10^{-28} gram.

electron capture - a mode of radioactive decay in which a bound electron is captured by the nucleus of the same atom, producing a vacancy in an inner electron shell. Subsequent filling of the vacancy results in the emission of characteristic x-rays of Auger electrons.

electron focus - the surface of the intersection of the electron beam and the anode of the x-ray tube.

electron gun - a device in which electrons (usually liberated from a hot filament) are focused and accelerated, and from which they are emitted as a narrow beam.

electron pair - an electron and a positron arising from pair production.

electron radiography - the process whereby a photographic image of an object is produced by electron radiation that has penetrated through the object.

electron volt - a unit of energy equal to the kinetic energy acquired by an electron when it is accelerated through a potential difference of one volt in vacuum. ($1 \text{ eV} \approx 1.602 \times 10^{-19}$ joule approximately).

elementary particle - originally a term applied to any particle that could not be further subdivided; now usually applied only to protons, electrons, neutrons, and their antiparticles, but not to alpha particles.

emulsion - a photosensitive layer of a gelatin and silver halide crystal mixture coated onto a film base.

encapsulation - the process of sealing a radioactive material in a capsule to prevent its dispersion during use as a radiation source. This term is also used to describe the type, thickness, and number of layers of material used to construct the capsule.

end-window detector - a detector designed to be irradiated from one end. This end may have a very thin window to permit the detection of alpha rays or beta rays.

equalizing filter - a filter used to equalize the intensity of a primary radiation beam over its effective area.

equi-opaque substance - a material having radiation absorption similar to that of the specimen, applied along its edges or in its cavities in order to obtain homogeneous absorption and thereby avoid local overexposure of film.

equivalent penetrameter sensitivity (equivalent IQI sensitivity) - that thickness of penetrameter, (image quality indicator), expressed as a percentage of section thickness radiographed, in which a 2T hole would be visible under the same radiographic conditions.

exposure (radiation quantity) - the absolute value of the total charge of the ions of one sign produced in a a unit mass of air when all the electrons liberated by photons are completely stopped by the air. Symbol: X. The special unit of exposure is the roentgen.

exposure, radiographic - the subjection of a recording medium to radiation for the purpose of producing an image. Radiographic exposure is commonly expressed in terms of milliampere-seconds (for x-rays) or millicurie-hours (for sealed sources) for a known source-to-film distance.

exposure chart - a chart indicating the radiographic exposures appropriate for different thicknesses of a specified material, given a specified radiation energy and other fixed conditions.

exposure device - a shield in the form of a package designed to contain and allow the controlled use of one or more sealed sources for the purpose of making radiographic exposures.

exposure factor - the product of current and time divided by the distance squared for x-rays, and the product of curies and time divided by the distance squared for gamma rays.

exposure head - a device that locates the sealed source at the desired focal position. It may be a separable unit or an integral part of a source guide tube.

exposure latitude. - the range of thickness of a specified material that correponds to the range of useful film densities.

exposure meter - an instrument for measuring exposure (radiation quantity).

exposure rate (radiation quantity) - the exposure per unit time. Special unit: roentgens per second.

exposure rate meter - an instrument for measuring exposure rate (radiation quantity).

exposure table - a table giving the radiographic exposures suitable for the different thicknesses of a specified material.

fail-safe design - one in which all failures of indicator or safety components that can reasonably be anticipated cause the equipment to fail in a mode such that personnel are safe from exposure to radiation. For example:(a) if a light indicating "x-rays on" fails, the production of x-rays shall be prevented, and (b) if a shutter status indicator fails, the shutter shall close.

field emission (auto-electronic emission; cold cathode emission) - the emission of electrons in vacuo from the surface of an unheated cathode due to an intense electric field.

filament - the source of electrons in a hot-cathode tube. It is usually a heated wire.

filament transformer - a transformer supplying power to heat the filament of a hot cathode. The primary and secondary windings must be sufficiently insulated to withstand the peak potential difference between the cathode and earth.

film badge. - a package of photographic film which may be worn like a badge to measure exposure of an individual to ionizing radiation. The absorbed dose or dose equivalent can be calculated from the degree of film darkening caused by the irradiation.

film base - a flexible, transparent, or translucent material that is coated with a photosensitive emulsion.

film clearing time - see clearing time.

film contrast - see contrast, film.

film holder - a light-tight carrier for films and screens (see cassette).

film illuminator - a device incorporating a suitable source of illumination for viewing radiographs or other transparencies.

film processing - see processing, film.

film, radiographic - a photographic film that is usually coated on both sides with an emulsion designed for use with x-rays and gamma rays.

film ring - a film badge worn as a ring to measure the exposure of the fingers to ionizing radiation.

film speed - a measure of the exposure required to produce a given density on a photographic emulsion under any given set of conditions. Fast films require less exposure than do slow films to produce the same density.

film unsharpness - see unsharpness.

film viewer - see film illuminator.

filter - material placed in the beam of radiation for the purpose of absorbing selectively that radiation which is within a certain range of wavelengths or energies.

filtration - the use of a filter to alter the characteristics of a radiation beam.

filtration, inherent - the filtration of an x-ray beam by any parts of the tube or tube shield, including insulating and cooling fluids, through which it must pass.

fixer (for film) - a chemical solution that dissolves unexposed silver halide crystals from developed film emulsions.

fixing - the chemical removal of unexposed silver halides from an emulsion after development.

flash radiography - a technique of producing radiographs, with an extremely short exposure time, useful for examining transient effects.

flash tube - an x-ray tube designed for use in flash radiography.

flaw sensitivity - see sensitivity, defect.

fluence, particle - the number of particles incident on a sphere of unit cross-sectional area. Symbol: ϕ .

fluence rate, particle - the fluence per unit time. Symbol: ρ .

Note: The term particle flux density is also used as the name for this quantity. As the word density has several connotations, the term particle fluence rate is preferable.

fluorescence - luminescence of a substance as the result of the absorption of electromagnetic or particulate radiation. Fluorscence is characterized by the fact that it occurs only so long as the stimulus responsible for it is maintained.

fluorescent screen - see intensifying screen.

fluorography - the use of photography to record fluoroscopic images on film.

fluorometallic screen - see intensifying screen.

fluoroscopy - the visual observation of an image of an object produced on a fluorescent screen by radiation that has penetrated through the object.

flux, particle - the number of particles emitted, transferred, or received in a unit time interval.

focal-film distance (ffd or FFD or SFD) - see focus-to-film distance.

focal spot (focus) - the area of the target on which the electron stream impinges and from which x-rays are emitted.

focal spot size (focus size) - the apparent dimensions, as viewed along the x-ray beam axis, of that portion of the target from which x-rays are emitted.

focusing - concentration or convergence of energy into a narrow beam.

focus-to-film distance - the distance from the focal spot of an x-ray tube to a film set up for radiographic exposure. Abbreviation: ffd.

fog - a general term used to denote any increase in the optical density of a processed film caused by anything other than the direct action of image-forming radiation. It can be of any of the forms defined below

ageing fog - fog arising from long-term storage of film prior to use.

chemical fog - fog arising from unwanted chemical reactions during processing of a film.

dichroic fog - fog arising from the deposition of a very thin layer of finely divided silver on an emulsion, which when examined in white light, appears in two colors, red by transmission and green by reflection.

exposure fog - fog arising from any unwanted exposure of a film to ionizing radiation or light, at any time between manufacture and final fixing.

inherent fog - see ageing fog.

oxidation fog - fog caused by exposure of a film to air during development.

photographic fog - fog arising solely from the properties of an emulsion and the processing conditions, i.e., the total effect of inherent fog and chemical fog.

fog density - see fog.

fog threshold - the minimum uniform density inherent in a processed emulsion without prior exposure.

forward scatter - that part of the scattered radiation which has a scattering angle of less than 90°.

frequency - the number of repetitions of a periodic process in a unit of time, such as the number of complete oscillations of an electromagnetic wave per second.

frilling - the loosening of an emulsion from its base, commencing at the edges. It is usually caused by prolonged immersion in a liquid at too high a temperature or of unsuitable chemical composition.

full-wave rectification - rectification that allows current to flow through an x-ray tube, in the same direction, during each half-cycle of an alternating supply.

gamma, film - see gradient.

gamma infinity - the maximum gamma that can be achieved by prolonged development of a photographic film. Symbol: .

gamma radiation (gamma rays) - electromagnetic radiation emitted by a radioactive nuclide as the result of a nuclear transition.

gamma radiography - the process whereby a photographic image of an object is produced by gamma radiation that has penetrated through the object.

gamma radiography system - all components necessary to make radiographic exposures with gamma radiation, including the exposure device, source assembly, control, and other components associated with positioning the source such as source guide tubes, exposure head, and collimators, if used.

gamma-ray source - a quantity of a radionuclide that emits gamma radiation suitable for radiography.

gamma-ray source container - see container, gamma-ray source.

gas tube - an x-ray tube that depends on the presence of a small quantity of residual gas for the supply of electrons to be accelerated.

Geiger counter (Geiger-Muller counter) - a radiation-detection instrument that consists of a Geiger-Muller tube, associated electronics for counting output pulses of the tube, and an indicator of the rate at which pulses are counted.

Geiger-Muller tube - a gas-filled radiation detector that uses a high electric field to cause gas multiplication that greatly increases the charge resulting from an ionizing event. The output pulse is of the order of volts.

geometric unsharpness - see unsharpness.

gradient - the slope of a characteristic curve at a specified density. Symbol: G_d. NOTE: The term "gamma" is used for the slope of the approximately straight portion of the curve.

graininess - visible irregular variations in the density of a radiograph that are caused by non-uniform distribution of silver grains in the photographic emulsion.

grain size - the average size of the silver halide particles in a photographic emulsion.

gray - the SI (international system) unit for absorbed dose. Symbol Gy. One gray is equal to one joule per kilogram. To convert from the special unit, 1 rad = 0.01 Gy.

Grenz tube - an x-ray tube having a window of low absorption permitting the transmission of x-rays produced at low voltages (e.g., below 12 kV).

grid - an assembly of strips of metal, opaque to x-rays, assembled edgewise and interleaved with material of low absorption, to be placed between the object and the screen or film, in order to reduce the effects of scattered radiation from the object.

grid ratio - the ratio of the depth of the opaque strips of a grid, measured in the direction of the primary beam, to the spacing between them.

grid tube - an x-ray tube in which a grid, operated with negative bias, is mounted between the cathode and anode.

H and D curve - see characteristic curve.

half-life, biological - the time required for a biological system, such as a man or animal, to eliminate, by natural processes, half the amount of a substance which has entered it.

half-life, radioactive - the time taken for the activity of an amount of radioactive nuclide to fall to half its initial value. Symbol $T_{1/2}$.

half-value layer (HVL) - the thickness of a specified substance which, when introduced into the path of a given beam of radiation, reduces the value of a specified radiation quantity upon transmission through the substance by one-half. It is sometimes expressed in terms of mass per unit area.

half-value period - see half-life.

half-wave rectification - rectification that allows current to flow in the same direction through an x-ray tube only during alternate half-cycles of an alternating supply.

hardener - a substance (e.g., chrome alum or formalin) used to harden the gelatine in the photographic emulsion, commonly added to the fixing bath.

hard radiation - a term used to describe qualitatively the more penetrating types of radiation.

health physics - a term in common use for that branch of radiological science dealing with the protection of persons from harmful effects of ionizing radiation.

heterogeneous radiation - radiation consisting of particles or photons that have a broad spectrum of energies.

high radiation area - any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirems.

high-voltage change-over switch - a device whereby the high-voltage supply may be connected to any one of several x-ray tubes.

hooded anode - a type of anode, in medium or high voltage x-ray tubes, in which the target is recessed in a metal hood that intercepts electrons. The hood may also incorporate a filter to absorb unwanted radiation.

hot-cathode tube - an x-ray tube in which the cathode is electrically heated to provide electrons.

hot cell - a heavily shielded enclosure in which radioactive materials can be handled remotely through the use of manipulators and viewed through shielded windows so that there is no danger to personnel.

image amplifier - a device that enhances a radiographic image for the purpose of decreasing interpretation time or increasing image detail.

image contrast - see contrast.

image definition - see definition.

image intensifier - a device used in fluoroscopy to produce an image brighter than that which would be produced by the unaided action of the x-ray beam on a fuorescent screen.

image quality indicator (IQI) (penetrameter) - a device used to determine, from the appearance of its image in a radiograph, the overall quality of that radiograph.

image quality level - see radiographic quality level.

impulse timer - a synchronous timer that is preset in terms of the number of pulses of current required during an exposure, instead of the duration of the exposure.

induced radioactivity - radioactivity resulting from irradiation of matter

industrial radiology - that branch of radiology covering industrial applications of ionizing radiation.

inelastic scattering - scattering in which the total kinetic energy of the incident radiation and the scatterer is changed.

inherent filtration - see filtration, inherent.

inherent fog - see fog.

inherent unsharpness - see unsharpness.

in-motion radiography - a method in which either the object being radiographed or the source of radiation is in motion during the exposure.

insert tube - an x-ray tube intended to be placed within a tube shield.

instrument calibration - a comparison of the response of the given instrument with the response of a standard instrument when both are exposed to the same radiation source under the same conditions; or the determination of the response of the given instrument when exposed to the output of a standard source under well-defined conditions.

intensifying factor (intensification factor) - for a type of intensifying screen, the ratio of the duration of exposure with the screen to that without the screen, all other conditions (including the film density) remaining the same.

intensifying screen - a layer of material that, when placed in contact with a photographic film, improves the efficiency of the photographic action of ionizing radiation on the film emulsion. The increased rate of absorption of radiation energy by the emulsion enables reduction of exposure time.

fluorscent screen (salt screen) - a screen consisting of a substance (such as calcium tungstate) that fluoresces when exposed to ionizing radiation.

fluorometallic screen - a screen consisting of a metal foil (usually lead) coated with a material that floresces when exposed to ionizing radiation. It combines the properties of the fluorescent and metal screen.

metal screen (lead screen) - a screen consisting of a foil of dense metal (usually lead) that emits secondary electrons when exposed to x or gamma radiation. It also reduces the undesirable effects of scattered radiation.

intensity, radiation - the amount of energy passing per unit time per unit area at a point in a beam of radiation, the area being perpendicular to the direction of propagation.

interaction - any process in which all or part of the energy of incident radiation is transferred to the electrons or nuclei of the atoms that constitute matter, or in which only the direction of the incident particle is altered.

interlock - see radiation safety interlock.

internal conversion - the transfer of nuclear deexcitation energy directly to a bound electron in the same atom, which causes the electron to be ejected from the atom. Subsequent filling of the vacancy thus created results in the emission of characteristic x-rays or Auger electrons.

inverse square law - the relationship between radiation intensity and distance from a point source, namely that the intensity changes inversely with the square of the distance. If the distance from a point source is doubled, the intensity is reduced to one-fourth the original value, and conversely.

inverse voltage - a voltage that may appear across an x-ray tube or rectifier during one half-cycle of an alternating current and that reverses the polarity of the electrodes relative to the previous half-cycle.

ion - an atom or group of atoms that carries a positive or negative electric charge as the result of having lost or gained one or more electrons.

ionization - the process of removing electrons from, or adding electrons to, atoms or groups of atoms, thereby creating ions.

ionization chamber - a gas-filled encosure in which ion pairs created by incident radiation are collected on electrodes that produce an electric field within the enclosure. The number of collected charges is an indication of the radiation intensity.

ionizing radiation - any radiation that has sufficient energy to create ions in matter, either through direct or indirect processes of interaction. Examples are alpha, beta, gamma, x, and neutron radiation.

ion pair - a positive ion and a negative ion or electron having charges of the same magnitude, and formed simultaneously from a neutral atom or molecule with energy supplied by radiation or any other suitable source.

ion source (ion gun) - a device by which gaseous ions are produced, focused, and accelerated, and are emitted as a narrow beam.

IQI sensitivity - the sensitivity (quality level) of a radiographic process, as determined by the use of an image quality indicator (IQI). Properly called radiographic sensitivity.

iridium-192 - a radioactive nuclide of the element iridium that has a half-life of 74 days. It emits gamma radiation with photon energies of 468, 316, 308, and 296 keV.

irradiation - exposure to radiation.

isomeric transition - the transition of an isomer to a lower energy state. It is accompanied by the emission of gamma radiation that may be internally converted.

isomers - nuclei that have the same mass number and atomic number, but have different energy states and relatively long lives.

isotopes - atoms that have the same atomic number (same chemical characteristics) but have different mass numbers. An equivalent statement is that the nuclei have the same number of protons but different numbers of neutrons. Thus, $^{12}C_6$, $^{13}C_6$, $^{14}C_6$ are isotopes of the element carbon, the subscripts denoting their common atomic numbers, the superscripts denoting the different mass numbers.

K-electron capture (K-capture) - electron capture by a nucleus of an electron from the "K" or innermost shell of electrons surrounding it.

key switch - a device that requires a key for making and breaking electrical connections.

kilovolt - a unit of electromotive force or potential, equal to 1000 volts.

kilovolt peak - the largest instantaneous value of electromotive force or potential attained by a pulsating source of electric potential, expressed in kilovolts.

laminography - a process that enables the production of a radiograph of a thin section of the interior of a thick specimen. It is achieved by synchronous rotation of both the film and the specimen during exposure, so that only the desired section remains in focus. A form of tomography.

latent image - an invisible image that was produced in a photographic medium by exposure to radiation and that is capable of being converted into a visible image by processing.

latitude - see exposure latitude.

law of reciprocity, photographic - see reciprocity law.

LD_{50} - see median lethal dose.

lead equivalent - the thickness of lead affording the same attenuation of radiation, under specified conditions, as the material in question.

lead glass - glass containing a high proportion of lead compounds, used as a transparent shielding material.

lead rubber - rubber containing a high proportion of lead compounds. It is used as a flexible shielding material.

lead-rubber gloves (protective gloves) - gloves incorporating lead rubber as a shielding material.

lead screen - intensifying screen.

leakage - the undesired release of radioactive material from a sealed source.

leakage radiation - radiation other than the useful beam emitted from an x-ray tube assembly or a source housing.

leak test - a method capable of detecting the leakage of radioactive material from a sealed source.

licensed material - source material, special nuclear material, or byproduct material received, possessed, used, or transferred under a general or special license issued by the Nuclear Regulatory Commission or an Agreement State.

Lindemann glass - glass of low x-ray absorption containing lithium, boron, and beryllium.

linear accelerator (linac) - an accelerator in which charged particles are accelerated along a straight line by a radio-frequency field inside a waveguide. Accelerated electrons may be made to impinge on a heavy-metal target to produce high-energy photon radiation.

linear energy transfer (LET) - the energy lost by a charged particle per unit distance of material traversed. It can be expressed as electron volts per meter, or some convenient multiple or submultiple, such as keV per millimeter.

line focus - an elongated, rectangular electron focus so angled that the focal spot size, as viewed along the x-ray beam axis, is smaller and approximately square, thereby permitting increased total area loading of the target for a given focal spot size.

line focus principle - the process of making the angle between the anode face and the axis of the electron beam such that the focal spot size is small in relation to the size of the electron focus.

line-focus tube - an x-ray tube in which the electron focus is approximately a rectangle and the focal spot size is approximately a square.

localizing cone (collimating cone) - a cone that limits the divergence of a beam of radiation.

luminescence - a phenomenon in which the absorption of radiation by a substance gives rise to the emission of light characteristic of the substance.

mAs - see milliampere-seconds.

masking - the application of radiation-absorbing material which limits the area of irradiation to that region of the specimen undergoing radiographic examination.

mass attenuation coefficient - the fraction of uncharged ionizing particles that experience interactions in traversing a unit distance in a material of density ρ. Symbol: μ/ρ.

mass number - the total number of neutrons and protons in a nucleus. It is the whole number nearest to the exact atomic weight. Symbol: A.

maximum permissible dose - see maximum permissible dose equivalent.

maximum permissible dose equivalent (MPD) - the maximum dose equivalent that the body of a person or specific parts thereof shall be permitted to receive in a stated period of time.

mean life - the average time during which an atom or other system exists in a particular form.

median lethal dose (LD_{50}) - the whole-body dose, resulting from a single short exposure (minutes or hours), that will cause the death, within a specified period of time, of 50 percent of the individuals irradiated. The dose sufficient to cause death to 50 percent of the individuals within 30 days is indicated as LD_{50}^{30} and is on the order of 300 rads.

metal screen - see intensifying screen.

MeV - one million electron volts.

micro - a prefix that divides a basic unit by one million.

microradiography - a technique used to examine very small objects or thin sections of material through the use of low-voltage x-rays and an ultra-fine grain film emulsion to produce a radiograph that is examined with the aid of optical enlargement.

milli - a prefix that divides a basic unit by one thousand.

milliamperage - a measure of the current flowing between the cathode and the anode in an x-ray tube. The intensity of the output radiation is directly proportional to this current.

milliampere - a unit of electric current equal to one thousandth of an ampere.

milliampere-seconds - a term used to quantify radiographic exposures made with x-rays. It is the product of tube current in milliamperes and exposure time in seconds. Abbreviation: mAs.

millicurie-hour - a term used to quantify radiographic exposures made with a gamma-ray source. It is the product of the activity of the source in millicuries and the exposure time in hours.

milliroentgen (mR) - one-thousandth of a roentgen.

miniature-film radiography (mass miniature radiography) - fluorography using miniature photographic film.

monitoring, radiation (for radiation protection) - the continuing collection and assessment of pertinent information to determine the adequacy of radiation protection practices and to alert to potentially significant changes in conditions.

movement unsharpness - see unsharpness.

neighborhood effect - the name given to various effects arising from the diffusion of developer which has become locally exhausted or loaded with oxidation products by its action on a heavily exposed region of an emulsion. Typical examples are developer streaks and abnormal density variations near the edges of regions of high density.

net density - total film density less fog and support (film base) density.

neutron radiography - the process whereby a photographic image of an object is produced by neutron radiation that has penetrated through the object.

non-screen film - x-ray film designed for use with or without metal screens, but not intended for use with salt screens. It may be of relatively high speed and coarse grain (ordinary non-screen film) or of lower speed and finer grain (fine-grain non-screen film).

nuclear reaction - the transformation of an atomic nucleus that results from interaction with a charged particle, neutron, or photon.

nuclear transition - a change in the energy state or level of an atomic nucleus which may, or may not, result in the emission of radiation.

nucleus - the positively-charged core of atom. It is only about 1/10,000 the diameter of the atom, but contains nearly all the mass. Except for ordinary hydrogen, all nuclei contain both protons and neutrons.

nuclide - a species of atom characterized by its mass number, atomic number, and nuclear energy state, and that has a measurable mean life.

object-to-film distance - the distance from the tube or source side of the irradiated specimen to the film surface, i.e., inclusive of specimen thickness. Abbreviation: ofd.

occupancy factor - the factor by which the workload should be multiplied to correct for the degree or type of occupancy of the area in question. Symbol: T.

occupational dose - the dose, or dose equivalent, resulting from exposure of an individual to radiation in the course of gainful employment.

oil-cooled tube - an x-ray tube in which the heat produced is dissipated, directly or indirectly, by means of oil.

oil-immersed tube - an x-ray tube designed for operation in oil.

optical density - see density.

orbital electron (shell electron) - an electron in the extra-nuclear structure of an atom.

over-development - development which is greater than that required to produce the optimum results in a particular radiograph. It may arise from development for too long a time, or at too high a temperature, and may give rise to excessive graininess, fog, and lack of contrast.

overload interlock x-ray unit - an x-ray machine in which the presetting of voltage, current, and time are interlinked in such a way that if their product (i.e., the energy to be applied) exceeds the permissible loading of the x-ray tube, the latter cannot be energized.

oxidation fog - see fog.

pair production - the transformation of a high-energy photon into an electron-positron pair in the field of an atomic nucleus or some other particle. It occurs only if the energy of the incident photon is above 1.02 MeV.

panoramic exposure - simultaneous exposures made possible by the use of a source that emits radiation over a wide range of directions.

particulate radiation - radiation consisting of charged or uncharged atomic particles.

particle - a minute constituent of matter with a measurable mass, such as an electron, neutron, proton, or meson.

peak voltage - the maximum value achieved by a varying voltage.

penetrameter - an image quality indicator composed of material identical, or radiographically similar, to the specimen being radiographed, and whose thickness is a percentage of the specimen thickness. It may also contain steps, holes, slots, or wires.

penetrameter sensitivity - see sensitivity, radiographic.

penumbra - an area of partial shadow, bordering the area of total shadow (umbra), cast on a film by a specimen exposed to a radiation source. The area of a partial shadow is caused primarily by the finite size of the source (each part of the source casts its own shadow) and appears on the radiograph as geometric unsharpness.

personnel monitor - a device designed to be worn or carried by an individual for the purpose of measuring the dose received (e.g., film or TLD badges, pocket chambers, film or TLD rings).

personnel monitoring - the determination, by means of a personnel monitor, of the dose received by an individual.

photoelectric absorption - the complete absorption of a photon by an atom with the ejection of an orbital electron (photoelectron). Also called photo-electric effect.

photographic emulsion - see emulsion.

photographic fog - see fog.

photographic intensification - chemical treatment of a processed emulsion, when under-exposed or under-developed, to increase the overall contrast, or density, or both.

photographic reduction - treatment of a processed emulsion, usually with an oxidizing agent, to lessen the density. There may be a change of contrast, depending on the process used.

photographic transmission density - see density.

photon - a discrete quanity (quantum) of electromagnetic energy. Photons have no electrical charge and no mass, but have momentum. They exhibit the properties of both particles and waves. Includes x and gamma radiation.

photo-sensitivity - a property of a photographic emulsion by virtue of which electromagnetic or particulate radiation may produce chemical or physical changes in the emulsion.

pinhole - a through hole of small diameter in a sheet of material opaque to radiation.

plate penetrameter (strip penetrameter) - a plate of material similar to the specimen under examination, having a thickness of 1 or 2 percent of the specimen thickness, and having holes of different diameters.

positron - an elementary particle with a mass equal to that of the electron, and a positive charge equal to the negative charge of the electron. It is said to be the antiparticle of the electron.

Potter-Bucky diaphragm - a device incorporating an anti-scatter grid which is kept in motion during the time of a radiographic exposure so as to avoid grid images on the radiograph.

Potter-Bucky grid - see Potter-Bucky diaphragm.

preservative, developer - a constituent (e.g., sodium sulphite) that minimizes the exhaustion of a developer caused by aerial oxidation, and that also serves to remove oxidation products which might otherwise retard development or produce stain.

pressure mark - an effect produced by pressure on a film which after developing results in areas of either increased or decreased density. The crescent-shaped pressure mark due to severe local bending of a film is often called a crimp mark.

primary radiation - radiation coming directly from the source.

processing, film - a series of operations, such as developing, fixing, and washing, associated with the conversion of a latent image into a stable visible image.

processing unit - a series of tanks forming a single unit for holding chemical solutions used during processing.

projector - see exposure device.

protective material - shielding material used for the purpose of radiation protection.

proton - an elementary particle with a single positive electrical charge and a mass approximately 1836 times that of the electron.

pulsating voltage - a voltage that undergoes periodic variations in magnitude, generally at a frequency related to that of the supply. The term is usually confined to unidirectional voltage.

quality - see beam quality.

quality factor - the linear-energy-transfer-dependent factor by which absorbed doses are to be multiplied to obtain, for radiation protection purposes, a quantity (i.e., dose equivalent) that expresses on a common scale for all ionizing radiations the irradiation incurred by exposed persons. The quality factor weights the absorbed dose for the biological effectiveness of the particular type of radiation producing the absorbed dose. Symbol: Q.

quality level - see radiographic quality level.

quantum - a discrete amount of radiation energy. The quantum energy is $E = h\nu$, where ν is the frequency of the radiation and h is Planck's constant.

rad - the special unit of absorbed dose. 1 rad is 10^{-2} joule per kilogram.

radiation - energy transmitted through space or a medium in the form of particles (electrons, neutrons, protons, etc.) or electromagnetic waves.

radiation area - any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of 5 millirems, or in any 5 consecutive days a dose in excess of 100 millirems.

radiation burn - a burn caused by overexposure to radiant energy.

radiation damage - the undesired alteration of the properties of a material arising from exposure to radiation.

radiation detector - see detector.

radiation hazard - a situation or condition that represents potential danger to health as the result of exposure to ionizing radiation.

radiation indicator - a device used for the purpose of indicating audibly or visually, the presence of ionizing radiation.

radiation maze - an indirect route of access to a room that contains a radiation source. It is designed to allow easy access when the source is turned off or is fully shielded, and to reduce radiation intensity outside the room to acceptable levels when the source is turned on or exposed. Reduction of radiation intensity is achieved through multiple scattering from walls and application of the inverse-square law.

radiation meter - an instrument consisting of one or more radiation detectors, associated electronics, and an indicator of the magnitude of the measured radiation quantity.

radiation monitor - a radiation meter that is designed and used to keep track of radiation levels in a specific area, and to record those levels, or to provide an audible or visual signal when a predetermined level is exceeded.

radiation protection - a branch of the physical, biological, and chemical sciences applying to the prevention of the risks presented by exposure of persons to ionizing radiations.

Radiation Protection Guide - recommended upper bounds of occupational dose resulting from exposure to ionizing radiation under ordinary circumstances. This guidance is approved by the President as recommendations to Federal agencies for their implementation. It is developed cooperatively by concerned Federal agencies.

radiation protection survey - evaluation of the radiation hazards in and around an area where a radiation source is used or stored. It customarily includes an examination of the arrangement and use of the source and related equipment, and measurements of exposure rates under expected operating conditions.

radiation quality - see beam quality.

radiation safety interlock - a device for precluding access to an area of radiation hazard either by preventing entry or by automatically removing the hazard.

radiation safety officer - an individual responsible for applied radiation protection.

radiation sickness - see acute radiation syndrome.

radiation source - a machine or a material emitting, or capable of emitting, ionizing radiation.

radiation survey - see radiation protection survey.

radiation trap - see radiation maze.

radioactive - exhibiting radioactivity.

radioactive contamination - the presence of unwanted radioactive material, particularly in circumstances which may be hazardous to health or which may interfere with the normal use of measuring equipment.

radioactive decay - see decay.

radioactive half-life - see half-life, radioactive.

radioactive material - any material that exhibits the property of radioactivity.

radioactive series - a sequence of radionuclides formed by successive nuclear transitions until a stable (non-radioactive) nuclide, the end product is reached.

radioactive source - a radiation source consisting of radioactive material.

radioactive waste - equipment and materials (from nuclear operations) that are radioactive and for which there is no further use.

radioactivity - the property possessed by some nuclides of emitting particulate or electromagnetic radiation as the result of spontaneous nuclear transition.

radiobiology - the study of the scientific principles, mechanisms, and effects of the interaction of ionizing radiation with living matter.

radiograph - a photographic image of an object that was produced by radiation that penetrated through the object.

radiographer - an individual who performs or personally supervises radiographic operations and who is responsible for assuring compliance with the requirements of pertinent regulations and conditions of licenses.

radiographer's assistant - any individual who, under the personal supervision of a radiographer, uses radiation sources, related handling tools, or survey instruments in radiography.

radiographic code - a code for specifying minimum standards related to radiographic practices.

radiographic contrast - see contrast, radiographic.

radiographic equivalence factor - that factor by which the thickness of a specific material must be multiplied in order to determine what thickness of a "standard" material (often steel) will have the same absorption.

radiographic exposure - exposure, radiographic.

radiographic exposure device - see exposure device.

radiographic film - see film, radiographic.

radiographic inspection - the use of radiography to detect discontinuities in material, and to present their images on a recording medium.

radiographic interpretation - the determination of the cause and significance of subsurface discontinuities indicated on the radiograph. The evaluation as to the acceptability or rejectability of the material is based upon the judicious application of the radiographic specifications and standards governing the material.

radiographic paper - white paper coated on one side with emulsion, suitable for some purposes as an alternative to x-ray film.

radiographic projection method - a method whereby image magnification is achieved by projection.

radiographic quality level - an expression of the quality (sensitivity) of a radiograph in terms of an image quality indicator (penetrameter). When a standard hole-type penetrameter is used, quality level is stated as a-bT, where a is the penetrameter thickness, expressed as a percentage of the maximum thickness of the specimen, and b is the diameter of the smallest discernible penetrameter hole, expressed as a multiple of penetrameter thickness, T. For example, the 3 2T quality level means that the penetrameter thickness equals 3 percent of the maximum specimen thickness, and the smallest discernible penetrameter hole has a diameter equal to twice the penetrameter thickness.

radiographic range - see exposure latitude.

radiographic screen - see intensifying screen.

radiographic sensitivity - see sensitivity, radiographic.

radiographic stereometry - the process of finding the position and dimensions of details within a specimen by measurements made on radiographs taken from different directions.

radiographic technique - the selection of those radiographic factors such as kilovoltage, milliamperage, type of film and screens, distances, and calculated exposure time to produce the desired radiographic sensitivity.

radiography - the process whereby a photographic image of an object is produced by ionizing radiation that has penetrated through the object.

radioisotope - a radioactive isotope of an element.

radiology - the science and application of x-rays, gamma rays, and other penetrating ionizing radiations.

radionuclide - a radioactive nuclide.

radium - a radioactive element with the atomic number 88 and mass number 226. In nature, radium is found with uranium, which decays to radium by a series of alpha and beta emissions. Radium is used as a radiation source, emitting photons with a broad range of energies. It has a half-life of 1600 years.

range - of an ionizing particle. The maximum thickness of a given medium that can be penetrated by such a particle. It may be either the total path length (integrated range) of the rectilinear distance between the ends of the path (practical range).

range of correct exposure - the range of correct exposure is the difference between the two extremes of correct exposure. These are set on the one hand by the minimum acceptable gradient and on the other hand by the maximum readable density.

ratemeter - an instrument for measuring and indicating counting rate, exposure rate, or dose rate.

ray - a beam of energy of small cross section; a stream of particles traveling in the same line.

RBE - see relative biological effectiveness.

real-time radiography - a type of radiography in which an image is not produced photographically, but is instead produced on a fluorescent screen viewed by a video camera. The image may be intensified or enhanced before display on a television monitor. This enables radiographic interpretation concurrent with irradiation of a specimen, and lends itself to remote rapid inspection of items on an assembly line. A videorecorder may be used to record the image.

reciprocity failure - departure from the reciprocity law by any given emulsion under specified conditions (e.g., when salt screens are used).

reciprocity law (Bunsen-Roscoe law) - states that the extent of a photochemical reaction is dependent only on the product of the radiation intensity (I) and the duration of the exposure (t), and is independent of absolute values of either quantity. This implies that the resultant density of a film depends only on the product of the radiation intensity reaching the film and the exposure time.

recording medium - a photographic film or other material that converts radiation energy into a permanent visible image.

rectification - any method by which a unidirectional voltage can be obtained from an alternating supply.

rectifier - a device that converts alternating current into direct current by allowing current to flow in only one direction.

reduction factor - the exposure rate without a shield divided by the exposure rate with a shield interposed between a radiation source and the point at which radiation is measured.

reflection density - the common logarithm of the ratio of the brightness of a non-absorbing perfect diffuser to that of the sample, both being illuminated at an angle of 45° to the surface, the direction of measurement being normal to the surface.

relative abundance - the propostion of a given nuclide in a particular sample of an element, usually expressed as a percentage.

relative biological effectiveness (RBE) - a factor used to compare the biological effectiveness of absorbed radiation doses due to different types of ionizing radiation. It is the experimentally determined ratio of an absorbed dose of a radiation under consideration to the absorbed dose of a reference radiation required to produce the same degree of a stipulated biological effect in a particular experimental organism or tissue. The RBE is not equivalent to the quality factor and should not be used in radiation protection.

relative speed - the speed of a radiographic film relative to a reference film that is arbitrarily assigned a value of 100. A film that requires only half the exposure to achieve the same density as the reference film will have a relative speed of 200.

rem - the special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, and any other necessary factors. (rem is an acronym for roentgen equivalent man).

replenisher - a modified form of the original developer which, when added to partially exhausted developer, restores its efficiency.

resolution - the smallest distance between adjacent distinguishable images on a radiograph or viewing screen. It may be expressed as the number of lines (or line pairs) per millimeter which can be seen as discrete images.

resolving time - the minimum amount of time that must separate two events in a counting system so they will be recorded as two separate pulses. The limiting time may be set by the detector itself, or by the associated electronics.

restrainer - the constituent (e.g., potassium bromide) that reduces the activity of the developing agent but enhances its preferential action by reducing the rate of development of unexposed grains to a greater extent than it does that of exposed grains. It thus tends to reduce chemical fog.

restricted area - any area to which access is controlled for the purposes of radiation protection.

reticulation - a net-like structure appearing in the emulsion of a photographic film as a result of damage due to differences in temperatures between processing baths, or rinsing water.

reversal - the production of a positive instead of a negative image in an emulsion or vice versa.

Rhm - see roentgens per hour at one meter.

ripple - the periodic variation in the potential difference betwen the cathode and anode of an x-ray tube, resulting from rectification of an alternating current. As the ripple is decreased by the use of filtering circuits, a constant potential is more nearly approached.

R-meter - an ionization-type instrument designed to measure radiation exposure.

rod-anode tube - a special type of x-ray tube in which the target is situated at the outer end of a long tubular anode. It usually produces panoramic radiation.

roentgen - the special unit of exposure. One roetgen equals 2.58×10^{-4} coulumb per kilogram of air.

roentgens per hour at one meter - a specification of the output of a source of x or gamma radiation in terms of the exposure rate, in roentgens per hour, measured in air at a distance of one meter from the source. Abbreviation: Rhm.

rotating-anode tube - an x-ray tube in which the anode can rotate. The axis of rotation is offset from the axis of the electron beam, so that the focus lies on a circle on the rotating surface.

safelight - a special lamp used in darkrooms to provide working visibility without significantly affecting the photosensitive emulsion of the radiographic film.

salt screen - see intensifying screen.

scatter - see scattered radiation.

scattered radiation - radiation that, as the result of interaction with matter, has had its direction changed and, for some interactions, its energy decreased.

scattering - a change of direction, and possibly reduction of energy, of an incident particle or photon as the result of interaction with an atom, nucleus, or other particle.

scattering angle - the angle between the directions of propagation of the incident and scattered radiation.

scatter unsharpness - see unsharpness.

Schwartzchild exponent - a mathematical index that may be applied to one of the variables in order to correct for the failure of the reciprocity law over a limited range.

scintillation - a localized flash of light caused by a particle or photon of ionizing radiation incident on a fluorescent material.

scintillation counter - an instrument that detects and counts the number of scintillations occurring over a specified period of time.

scintillator - a substance that emits a localized flash of light when excited by an incident particle or photon of ionizing radiation.

screen - alternative term for intensifying screen.

screen, intensifying - see intensifying screen.

screen, radiographic - see intensifying screen.

screen-type film - a radiographic film produced specially to be used with fluorescent screens. This type of film has high sensitivity to the fluorescent light emitted by such screens under the effect of ionizing radiaitions. (Improperly called screen film).

screen unsharpness - see unsharpness.

sealed source - a radioactive source that is bonded or encapsulated to prevent dispersion of the radioactive material under the conditions of use for which it was designed.

secondary radiation - radiation other than primary radiation emerging from irradiated matter.

self absorption - reduction of the emission rate of a radioactive source due to absorption of radiation in the radioactive material itself, or in any non-radioactive material with which it may be mixed.

self-rectifying tube - any hot-cathode x-ray tube that permits current to flow only from the cathode to the anode, when the anode is kept cool.

sensitivity - a general term used as an indication of the ability to detect small differences.

sensitivity, defect - the minimum dimension of a discontinuity, considered to be a defect, that can be detected in a radiograph under specified conditions.

sensitivity, equivalent penetrameter - see equivalent penetrameter ssensitivity.

sensitivity, IQI - see IQI sensitivity.

sensitivity, radiographic - the ratio of the smallest difference in thickness that is detectable on the radiograph to the thickness of the specimen. It may be expressed as a percentage, and is an indication of ability to detect a small discontinuity. In practice, it is determined by the use of an image quality indicator (penetrameter).

sensitivity, spectral - the variation in radiographic exposure, as a function of x-ray energy, required to produce a given film density.

sensitometric curve - see characteristic curve.

senitometry - characterization of the properties of emulsions by measurement of the changes in photographic density produced under different conditions of exposure and processing.

sequestering agent - a constituent (e.g., sodium hexametaphosphate) which is sometimes added to a developer to prevent the formation of scum from hard water.

sharpness - see definition.

shield - a layer or mass of material used to reduce the intesity of ionizing radiation, primarily for the purpose of radiation protection.

shielding barrier - see shield.

shock-proof - a term applied to those components of the high-voltage circuit of x-ray equipment which are entirely surrounded by grounded metal enclosures, e.g., shock-proof tube, shock-proof cable.

shock-proof tube - an x-ray tube surrounded by a grounded conducting enclosure.

shutter - a device that incorporates a movable shield used to block the useful beam emitted from an x-ray tube assembly or source housing.

sievert - the SI (international system) unit for dose equivalent. Symbol: Sv. One sievert is equal to one joule per kilogram. To convert from the traditional unit, 1 rem = 0.01 Sv.

silver halide - a compound of silver with one of the halogen elements, e.g., silver bromide.

soft radiation - a qualitative term used to describe the relatively less penetrating types of ionizing radiation.

soft x-rays - a qualitative term used to describe the relatively less penetrating types of x-rays, i.e., those with lower photon energies (longer wavelengths).

solarization - the diminution in (photographic) density produced by exposure additional to that required to give maximum density. This may result in reversal.

source - radiation source.

source assembly - a component of a gamma radiography exposure device to which the sealed source is affixed or in which the sealed source is contained. The source assembly includes the sealed source.

source calibration - the determination of the output of a radiation source by comparison with the output of a standard source, or by the response of a standard instrument to the output of the source.

source capsule - the immediate container that, along with the contained radioactive material, constitutes a sealed source of ionizing radiation.

source changer - a shielded enclosure that is designed specifically for use in the replacement of the sealed source contained in an exposure device.

source container - see container, gamma-ray source.

source guide tube (conduit) - a flexible or rigid tube for guiding the sealed source from the exposure device to the exposure head.

source housing - an enclosure for a sealed source which provides attenuation of the radiation emitted by the source. The enclosure may have an aperture through which the useful beam is emitted or through which the source is extracted.

source material - any material, except special nuclear material, which contains 0.05% or more of uranium, thorium, or any combination of the two.

source-shift radiography - a method involving two offset exposures, each for half the normal time. Used for determining the depth of a discontinuity.

source size, effective - the apparent dimensions, as viewed along the beam axis, of that portion of the source from which ionizing radiations are emitted. For the purpose of calculating geometric unsharpness, the effective dimensions must always be used.

source-to-film distance - the distance between the radiation source and the plane of the film in position for a radiographic exposure (Abbreviation: sfd).

special nuclear material - plutonium, uranium-233, uranium containing more than the natural abundance of uranium-235, or any material artificially enriched by any of these substances, not including source material.

specific activity - the activity per unit mass of a radioactive material (expressed in curies per gram or becquerels per gram).

spectrum - an orderly array of the components of a beam of radiation according, for example, to their wavelengths, frequencies, or energies.

speed, film - for a praticular film, the reciprocal of the exposure required to achieve a certain density.

stabilizer - a device that automatically compensates for variation of main voltage and/or frequency in an electric circuit. An example is the stabilization of filament heating current, and therefore the anode current, in an x-ray tube.

stable isotope - a non-radioactive nuclide of a particular element.

stationary grid - a grid in which the opaque strips are so thin and so close together that it can remain stationary during exposure without causing images of the strips that would interfere with interpretation of the radiograph (e.g., Lysholm grid).

step wedge - a block of material in the form of a series of steps in thickness, used for the preparation of exposure charts.

step-wedge calibration film - a step-wedge comparison film, the densities of which are traceable to a nationally recognized standardizing body. It is used for reference when determining the density or densities of a radiograph.

step-wedge comparison film - a strip of processed film carrying a stepwise array of increasing photographic density.

step-wedge penetrameter (step penetrameter) - a penetrameter of similar material to the specimen under examination, having steps ranging usually from 1 to 5 percent of the specimen thickness. Each step may contain one or more drilled holes for the assessment of definition.

stereofluoroscopy - a fluoroscopic technique that enables screen images to be viewed three-dimensionally.

stereograticule - a scale which enables direct measurements in the direction of viewing to be made during stereoscopic examination.

stereoradiography - the production of a pair of radiographs suitable for stereoscopic viewing.

stereoscopic - a type of viewing that employs an optical instrument (stereoscope) to combine the images of two radiographs taken from slightly different angles, thus achieving a three-dimensional effect.

stereocopy - the three-dimensional visual effect resulting from binocular vision.

stop bath - a mildly acid bath used to arrest development and to neutralize alkaline developer in an emulsion before transfer to the fixing bath.

stray radiaion - radiation other than the useful beam. It includes leakage, secondary, and scattered radition.

stripping emulsion - a photographic emulsion, for use in autoradiography, which can be removed from its base and placed in contact with a specimen containing radioactive material.

subject contrast - the ratio (or the logarithm of the ratio) of the radiation intensities transmitted by selected portions of the specimen.

subjective contrast - a qualitative estimate of the contrast in a radiograph or fluorescent screen reproduction.

subject range - the range of thickness or radiation opacity of material in a specimen.

surface irregularity - an image on a radiograph that corresponds to an irregularity visible on the surface of a specimen.

surge suppressor - a device that automatically reduces abnormally high voltage or current transients to acceptable levels.

survey - see radiation protection survey.

survey meter - a hand-carried instrument that provides a prompt indication of exposure rate or other radiation quantity of interest for radiation protection purposes.

synchronous timer - a timer that is operated by a synchronous motor.

target - the area on the anode of an x-ray tube on which the electron stream impinges and from which the primary beam of x-rays is emitted.

technique chart - see exposure chart.

tenth-value layer (TVL) - the thickness of the layer of a specified substance which, when introduced into the path of a given narrow beam of radiation, reduces the intensity of this radiation to one-tenth the original value.

thermal focus - that part of the anode of an x-ray tube submitted to direct heating by the electron beam.

thermionic emission - the emission of electrons from the surface of a heated material by virtue of their thermal energy.

thermoluminescence - the property, possessed by certain crystals, of emitting light when heated after having been exposed to ionizing radiation.

thermoluminescence dosimeter (TLD) - a dosimeter, commonly used as a personnel monitor, that uses thermoluminescent material. The total amount of light emitted upon heating of the material is proportional to the amount of radiation energy absorbed.

threshold dose - the minimum absorbed dose or dose equivalent that will produce a specified effect.

timer - a time-measuring device designed to automatically make or break electrical connections at the end of a preset time interval.

tomograph - a radiograph of a specified plane of deep structures.

tomography - the radiography of a predetermined interior plane of a thick material. In one method the x-ray tube and the film are moved simultaneously in opposite directions about a pivotal point in the plane of the layer.

transmission target - a relatively thin target so arranged that the x-ray beam emerges from the surface remote from that on which the electron stream is incident.

tube current - the current, measured in milliamperes, flowing between the cathode and anode during the operation of an x-ray tube.

tube diaphragm - an adjustable device, normally attached to a tube housing, that limits the cross section of the emergent x-ray beam.

tube filter - a filter that can be attached to the x-ray tube housing.

tube housing - an enclosure that contains an x-ray tube and has a port through which the useful beam is emitted. The tube housing may also contain transformers and other appropriate components.

tube rating - the maximum electrical power (in watts) that can be safely applied to an x-ray tube for a specified period.

tube shield - the housing of an x-ray tube which normally provides protection against electric shock and affords a degree of protection against radiation.

tube-shift radiography - a technique requiring two exposures at slightly different angles for determining the depth of an imperfection, but using the same focus-to-film or source-to-film distance.

tube shutter - a device attached to a tube housing, generally of lead and usually remotely operated, used to permit or to prevent the emergence of the x-ray beam.

tube stand - a support, often in the form of one or more vertical pillars with adjustable attachments, for holding an x-ray tube in position for use.

tube window - the relatively thin section of the x-ray tube through which the useful beam emerges. (Materials have different absorption properties, and thus some "windows" are designed by their material, e.g., "beryllium window").

tungsten alloy (heavy alloy) - a shielding material containing tungsten, copper, and nickel, and having a density about 50 percent greater than that of lead.

two-film technique - a procedure wherein two films of different relative speeds are used simultaneously to radiograph both the thick and the thin sections of a specimen.

type A packaging - the name given, in the regulations concerning the transport of radioactive materials, to packaging capable of preventing any loss or dispersion of the radioactive contents and of maintaining its function of shielding against radiations in normal transport conditions.

type B packaging - the name given, in the regulations concerning the transport of radioactive materials, to packaging capable of resisting not only normal transport conditions like type A packaging but also a serious accident.

umbra - a region behind an object in a beam of radiation such that a straight line drawn from any point in this region to any point in the source passes through the object. The umbra is sometimes referred to as the region of total shadow.

undercut (scatter)- radiation that has reached the film cassette or screen by passage through a thin portion, or along an edge, of a specimen and is then scattered into the shadow of an adjacent thicker portion. This causes excessive film density along the edges of the thicker portions.

under-development - development which is less than that required to produce the optimum results in a particular radiograph. It may arise from development for too short a time, or at too low a temperature, or from the use of exhausted developer.

unidirectional voltage - a voltage of which the polarity, but not necessarily the magnitude, is constant.

unrestricted area - any area to which access is not controlled for purposes of radiation protection.

unsharpness (blur) - a general and qualitative term that refers to a lack of distinctness of image details in a radiograph, photographic reproduction, or viewing-screen image.

film unsharpness - image spread (diffusion) caused by scatter of electrons or light through the emulsion grans (also called inherent unsharpness).

geometric unsharpness - unsharpness of the image that is determined by the size of the radiation source-to-specimen distance, and the specimen-to-film distance. Geometric unsharpness is minimized when the source is small, the source-to-specimen distance is large, and the specimen-to-film distance is small.

inherent unsharpness - see film unsharpness.

movement unsharpness - unsharpness arising from the relative movement of the source of radiation, irradiated object, or film or screen, during film exposure.

scatter unsharpness - unsharpness due to radiation scattered by an irradiated object or intensifying screen.

screen unsharpness - image blurring caused by the use of an intensifying screen or a fluorescent viewing screen. It may result from the scatter of light by the crystals of the fluorescent layer, or poor contact between screen and film, or both.

use factor - the fraction of the workload during which the useful beam is pointed in the direction under consideration when designing shielding. Symbol: U.

useful beam - all radiation that emerges from a source housing or an x-ray tube assembly through a port, diaphragm, or cone.

useful density range - the range of density over which the gradient is adequate for the recognition of image details. The upper density limit is determined mainly by the brightness available in the film illuminator, and the lower density limit by the sensitivity required.

Van de Graaff accelerator - an accelerator that is based on the principle of transfer of charge from a carrier (a moving belt) to the inside of a hollow conductor. The high potential (several million volts) thus generated is used to accelerate ions or electrons, which can be impacted on a heavy-metal target to produce x-rays.

viewing mask - a device for limiting the field of examination of the radiograph.

voltage regular - a device that automatically compensates for variations in line-power voltage, thus maintaining a nearly constant voltage on the circuits of an x-ray machine.

water-cooled tube - an x-ray tube for which the principal method of cooling is dissipation of heat, directly or indirectly, by means of water.

wavelength - the distance, in the direction of propagation of a wave, between two successive crests (or troughs).

wedge - see step wedge.

wedge filter - a filter so constructed that its thickness varies continuously or in steps from one edge to the other. Wedge filters may be used to increase the uniformity of radiation in certain types of exposures.

wetting agent - a substance used in film processing to reduce surface tension. When used in a pre-development bath it promotes the subsequent uniform diffusion of developer into the emulsion. It may also be used in a final bath to assist rapid and uniform drainage of the film and so reduce the occurrence of marks caused by uneven drying (drying marks).

wire penetrameter - an image quality indicator incorporating a series of wires that are graded in diameter and usually of similar material to the specimen under examination.

workload - a measure in suitable units of the amount of use of radiation sources. It is usually expressed in milliampere-minutes per week for x-ray sources and roentgens per week at one meter from the source for gamma-ray sources and high-energy sources (such as linear accelerators, betatrons, etc.).

xero-radiography - a process using the photo-conductive property of amorphous selenium to reproduce a radiological image, instead of photographic film.

x-radiation - see x-rays.

x-radiography - the process of producing radiographs using x-rays.

x-rays - penetrating electromagnetic radiation produced artificially when a beam of charged particles (usually electrons) is made to impact upon a metallic target. X-rays are emitted when the incident particles (1) are slowed down by interactions with nuclei in the target material, and (2) excite electrons in the target material which subsequently release energy.

x-ray film - a film base that is coated (usually on both sides) with an emulsion designed for use with x-rays.

x-ray paper - white paper coated on one side with emulsion for use with or without an intensifying screen. It is suitable for some purposes as an alternative to x-ray film.

x-ray spectrometer - an instrument used to determine the wavelengths of x-rays and the relative intensities of different wavelengths in an x-ray beam.

x-ray spectroscopy - the study of x-ray spectra and their interpretation.

x-ray tube - a vacuum tube intended for the production of x-rays by bombarding the anode with a beam of electrons accelerated under a difference of potential between anode and cathode.

x-ray tube assembly - a tube housing with the tube installed. It may include high voltage and filament transformers and other appropriate elements when they are contained within the tube housing.

zircon sand - a highly absorptive material used as a blocking or masking medium for drilled holes, slots, and highly irregular geometric parts to reduce or eliminate scattered radiation.

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