Nondestructive Examination (NDE) Technology and Codes
Student Manual

Volume 1

Chapter 5.0

Introduction to Radiographic Examination

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5.0 INTRODUCTION TO RADIO-GRAPHIC EXAMINATION

Learning Objectives:

To enable the student to:

1. Achieve an understanding of radiographic testing (RT) basics, including X-ray and gamma radiography.

2. Understand the variables in the process of radiography.

3. Understand how sensitivity is achieved, controlled, and optimized in radiography.

4. Achieve an understanding of radiographic interpretation.

5. Recognize the advantages and limitations of this method.

5.1 History

During the 1890's several eminent physicists turned their attention to experiments with gas discharge tubes. These tubes consisted of an elongated glass vessel into which electrodes had been hermetically sealed and the air removed (or reduced to very low pressures). A voltage could then be applied to the electrodes and results observed.

At normal atmospheric pressure inside the tube, a very high voltage is needed to make the current jump between the electrodes, because the air acts as an insulator. Furthermore the electrons move between the electrodes in a burst of harsh sparks. If the air pressure in the tube is reduced, the harsh sparks change into a soft continuous glow. The electrons can now flow between the electrodes. This is the same principle used in modern day neon strip lighting.

In 1895, during one of these experiments, a German professor Wilhelm Conrad Roentgen made a discovery that was to be one of the most important in the development of modern science.

In his darkened laboratory he noticed that when the discharge tube was turned on, cardboard coated with a fluorescent salt began to glow. Further experiments established that some invisible ray or beam of energy was being produced by the discharge tube. This ray could penetrate the glass vessel and cause the salts to fluoresce. He found that he could place his hand in the beam and the rays would pass through the skin and flesh leaving an image of the bones. A few days later he recorded this effect on a photographic plate thus producing the first radiograph. These previously unknown rays were called X-rays.

Roentgen showed that X-rays are a form of electromagnetic energy and are part of the same spectrum as light (Figure 5-1). They travel at the same velocity of light and obey most of its laws though their wavelength is very much shorter. It is this shorter wavelength that allows X-rays to penetrate materials. Upon reading Roentgen's findings Henri Becquerel, working with the Curies in France, realized that some of the

energy emitted during the disintegration process of certain natural elements such as radium (refined from pitch-blend) was indeed identical to Roentgen's X-rays although Becquerel had given them the name of gamma after the third letter in the Greek alphabet.

5.2 Personnel Qualification and Certification

Of all the NDE methods except VT, RT has been a requirement in the ASME Code the longest. The development and application of the most effective technique for a given application, requires that the RT examiners are highly qualified. The interpretation of the radiographs, considered to be highly subjective, requires skills and experience in order that discontinuities are observed, then properly dispositioned. The quality of the radiographic technique must also be assessed by the interpreter. RT personnel, whether they are taking the radiographs or interpreting them, must be qualified and certified.

The 2007 Edition with 2008 Addenda of the ASME Code Section V requires that NDE personnel be qualified in accordance with either:

SNT-TC-1A (2006 Edition Addenda), or
ANSI/ASNT CP-189 (2006 Edition)
ACCP

Qualifications in accordance with a prior edition of either SNT-TC-1A or CP-189 are considered valid until recertification. Recertification must be in accordance with SNT-TC-1A (2006 Edition) or CP-189 (2006 Edition).

Section XI requires that personnel performing NDE be qualified and certified using a written practice prepared in accordance with ANSI/ANST CP-189 as amended by Section XI. IWA 2314 states that the possession of an ASNT Level III Certificate, which is required by CP-189, is not required by Section XI. Section XI also states that certifications to SNT-TC-1A or earlier editions of CP-189 will remain valid until recertification at which time CP-189 (1995 Edition) must be met.

A Level II Radiographic examiner, who is a high school graduate, must complete one of the following for Section V and only the CP-189 requirements for Section XI.

SNT-TC-1A stipulates the following for RT examination personnel:

	Training	Experience
Level I	40 hours	210 hrs*/400hrs**
Level II	40 hours	630 hrs*/1200hrs**

*The time in RT
**The total time in NDE

NOTES:

1. To certify to Level II directly with no time at Level I, the training and experience for Level I and II shall be combined.
2. Training hours may be reduced with additional engineering or science study beyond high school. Refer to Chapter 2.
3. There are no additional training

requirements for Level III. Refer to Chapter 2 of this manual for Level III requirements.

The CP-189 requirements as required by Section XI are:

	Training	Experience
Level I	40 hours	200*/600**
Level II	40 hours	600*/1200**

*Hours in RT
** Total Hours in NDE

NOTES:

1. Experience is based on the actual hours worked in the specific method.
2. A person may be qualified directly to NDT Level II with no time as certified Level I providing the required training and experience consists of the sum of the hours required for NDT Levels I and II.
3. The required minimum experience must be documented by method and by hour with supervisor or NDT Level III approval.
   While fulfilling total NDT experience requirement, experience may be gained in more than one (1) method. Minimum experience hours must be met for each Method.

5.3 Principles

Radiography relies on the fact that X and gamma rays possess the capability of penetrating materials. The penetrating power of the X-ray beam can be increased or decreased to examine different materials by changing the applied voltage. The amount of X-rays reaching the object can also be controlled. While passing through an object, some of the radiation is also absorbed and scattered. The amount of absorption that occurs depends on the thickness and densityof the material; therefore, the intensity of the radiation emerging from the material varies accordingly. The emergent radiation causes an invisible change to the emulsion of the film. By subsequent development, the affected silver halides are converted to black metallic silver. After development, the unaffected silver halides are removed by “fixing” and thus an image of the object is produced. The film is then washed and dried and is ready for viewing.

Because of the penetration and absorption capabilities of X and gamma radiation, radiography is used to examine a variety of products such as welds, castings, forgings, and various fabricated parts. Radiography is one of the primary NDE methods in use today. It requires exposing film to X or gamma rays that have penetrated a specimen, then processing the exposed film, and subsequently interpreting the resultant radiograph. Other recording media may also be used.

The most important difference between light rays and X and gamma rays is their penetrating ability. Visible light is stopped by opaque substances. However, because X-rays have such a high frequency and short wavelength, they are able to penetrate opaque objects and expose radiographic film. The depth of penetration

depends upon the type of material density, its thickness, and the energy of the radiation.

X and gamma ray energy is dependent on frequency and wavelength. High energy X and gamma rays are characterized by a high frequency and short wavelength. It is important to note that X and gamma rays of the same frequency and wavelength have identical properties.

X and gamma rays also travel in straight lines. The radiation produces the image of a specimen - just as a shadow picture of an object can be produced with a strong light and a screen. X and gamma rays expose radiographic film because of their ability to ionize matter.

When the radiation penetrates the film, it ionizes the tiny silver grains in the film emulsion. The ionization of the film's emulsion forms a "latent (or invisible) image", which is developed during later processing of the film.

The specimen itself is an important consideration in making a radiograph. Enough radiation must penetrate the object to form an image. Too much radiation overexposes the film. "Absorption" is the ability of the specimen to block the passage of X-rays through the material. When the film is developed, the exposed portion on the film turns dark while the unexposed portion is clear or light.

The two sources of radiation used in radiography are gamma rays and X-rays. Gamma and X-rays are exactly the same kind of radiation, except that X-rays come from an X-ray tube and gamma rays come from a radioactive isotope.

5.3.1 Characteristics of Matter

All atoms are composed of three basic particles:

Proton - A proton has a positive charge and is relatively heavy (1 Atomic Mass Unit).

Neutron - A neutron is about the same size and weight as the proton but has no electrical charge.

Electron - An electron is a very light particle, about 1/1840 of the weight of a proton. It has a negative charge.

The number of protons present in an atom determines the element.

Over 100 different kinds of atoms exist and they are called elements. Oxygen, copper, and lead are some common elements. Elements or combinations of elements (molecules) form all the things we see in everyday living. For examples there are billions of atoms in the tip of a pencil, with over 99.99 percent of each atom being empty space.

5.3.1.1 Atomic Weight

The protons and neutrons are packed together in the center of the atom. This forms the nucleus and is referred to as the atomic weight of the atom. For example, the helium atom has two protons and two neutrons in the nucleus. The neutrons are neutral so this gives the nucleus a +2

electrical charge. To be stable, the atom must be electrically balanced; therefore, two electrons with negative charges orbit the nucleus.

Isotopes of basic elements are identified by their weight. The mass number or "A" number is a combination of protons and neutrons (heavy part of the atom). Each isotope is then assigned a weight equal to the total weight of protons and neutrons in the nucleus.

5.3.1.2 Atomic Number

Atomic numbers or "Z" numbers are the number of protons in the nucleus of the atom and determine the type of element. For example, an atom of beryllium with four protons would have a "Z" number of 4. No other element would have a "Z" number of 4.

An atom of hydrogen, the simplest of all atoms, has a nucleus containing one proton with one orbiting electron. This hydrogen atom has the only nucleus that does not contain neutrons.

An atom of oxygen has eight protons and eight neutrons in the nucleus with eight orbiting electrons.

5.3.1.3 Electron Configuration

The electrons orbit the nucleus in particular paths known as shells. The different orbits have different energy levels and are given a letter to identify each shell. The innermost shell is called the K shell. It can hold a maximum of two electrons. The next shell is called the L shell and, depending upon the element concerned, can hold a maximum of eight electrons. As the elements change in mass so do the number of shells, which continue through M, N, and so on until the final, O shell of the heaviest elements (Figure 5-2).

5.3.2 Radiation Theory

X and gamma rays are in the electromagnetic family of radiation. The electromagnetic spectrum is arranged in order by energy and frequency of the wave. The waves with the lowest energy and frequency are listed at the left end of the chart illustrated in Figure 5-1, while the waves with the highest energy are at the right. Higher energy and frequency produces shorter wavelengths and higher frequency.

5.3.2.1 Radiation Characteristics

Radiation is part of our daily lives, and it is constantly present in very small amounts. The main source of radiation is the sun. Fortunately the atmosphere surrounding the earth is an absorber. However, the higher elevations receive more radiation than lower regions since they are closer to the source - the sun. There are other sources of radiation that cause slight exposure to humans. For example, certain rocks, such as granite and some minerals, will give off low levels of radiation.

In order to understand how radiographs are made, it may be well to consider the major characteristics of radiation. The major sources of the radiation used to produce radiographs are X-ray machines and radioactive isotopes. There is no difference between X-rays and gamma rays

of the same energy except for their origin.

X and gamma rays have the following characteristics:

- They penetrate matter depending on the radiation energy, material density, and material thickness.
- They travel in straight lines.
- They travel at the velocity of light (186,262 miles per second, 344,472 km/sec).
- They cause fluorescence in some materials.
- They ionize matter and they expose film by ionization.
- They are scattered by a process of photoelectric effect, Compton scattering, and pair production.
- Their energy is inversely proportional to their wavelength.
- They are invisible and undetectable by human senses.
- They are not particulate.
- They have no electrical charge.
- They have no rest mass or weight.

Source selection involves several considerations. Generally, the material type and thickness determine the radiation energy range to be used. The radiation energy relates to the thickness of a given material that can be penetrated within a reasonable time. The radiation source also must produce the needed radiographic definition and contrast to produce an image with acceptable sensitivity. The energy of X-rays and gamma rays is expressed in:

- Thousand (Kilo) electron volts (KeV) and
- Million (Mega) electron volts (MeV).

An electron volt is the amount of energy equal to the energy gained by one electron when it is accelerated by one volt.

Example - If one electron were accelerated by a potential of a 100 thousand volts (100 kV) machine, the electron would have energy of 100 thousand electron volts (100 KeV)

When X-rays are produced, there is a wide range of energies (wavelengths). Not all electrons are accelerated to the maximum voltage set on the X-ray machine. However, every gamma producing isotope emits rays of one or more specific energies.

The greatest density difference or contrast in the radiograph, corresponding to a change of section thickness in an object, is obtained when the lowest practical energy is used. When a change in energy is made, two factors have an affect on the X-ray film. First, the quality of radiation is changed; harder, more penetrating X-rays are produced if energy is increased, or softer radiation is produced when it is reduced. Second, for fixed milliamperage (mA), an increase in kV produces an increase in intensity, or more radiation, and, conversely, a decrease in intensity, when the kV is reduced.

5.3.2.2 Interaction with Matter

X or gamma rays penetrate light materials better than they penetrate dense materials. The heavier, denser materials offer greater resistance to X or gamma ray penetration. X or gamma rays (or photons) are little packets of energy

moving at the speed of light. The photons' energy does not just disappear; it has to be transformed in a process known as "ionization". One of the basic laws of nature is that energy can neither be created nor destroyed, but it can be converted into different forms.

An "ion" is a charged atom, group of atoms, or atomic particle with either a positive or negative charge. Removing an electron from an atom creates a position ion with a "plus one" charge. Ions are produced when a photon (X or gamma ray) collides with an electron in the penetrated material. The photon ejects the electron from its orbit and transfers some of its energy to the electron. This process is called ionization and creates a positive or a negative ion depending on the net electrical charge of the ion.

Free electrons produced by ionization absorb some of the energy from the photon and move with different velocities in different directions.

Since X-rays are generated whenever free electrons collide with matter, it follows that low energy "secondary" or scattered radiation will be produced.

Absorption and scatter take place in three ways:

Photoelectric Effect - The photoelectric effect (Figure 5-3) occurs primarily with low energy photons (10 KeV to 500 KeV). In the photoelectric effect, the electron absorbs all of the photon's energy. The photon is weakened in this process as some of its energy is absorbed in removing an electron. The photoelectric effect involves complete absorption of the photon. Part of the energy is expended in ejecting the electron from its orbit, and the remainder imparts velocity to the electron. Remember that a photon is not a particle although it may act like one. When the photon's energy is used, there is nothing left.

Compton Effect - The Compton Effect is a logical extension of the photoelectric effect except that the photon energies are usually higher (300 KeV to 3.0 MeV) (Figure 5-4). In the Compton Effect all of the photon's energy cannot be absorbed in removing the electron, and there is energy left over. The excess energy takes the form of a new photon that has a longer wavelength. The new photon moves off in a new path.

Pair Production - In pair production at still higher energy levels, above 1.02 MeV, the photon is absorbed by the nucleus of an atom and changes from a photon to an electron-positron pair (Figure 5-5). These particles annihilate each other and their energy is converted to a pair of photons. The energy level of each half of the pair is equal to 0 .51 MeV.

High Speed Electrons - What happens to the high speed electrons produced in the Compton and photoelectric effect? The kinetic energy (energy of motion) of these high speed electrons is absorbed in two ways:

1. Additional ions are created simply by an electron colliding with another electron. The electron that is struck is knocked out of orbit, but has taken some of the energy of the first

electron. This process continues until there is very little energy in any one electron. This low energy is then given off as ultraviolet rays, light, or heat.

2. The Bremsstrahlung process (Figure 5-6) slows down the high speed electron due to the positive field of the atomic nucleus.

The energy that is absorbed by the nucleus is in excess to the atom's need, and this energy is immediately radiated as an X-ray of equal or lower energy. If the electron were completely stopped, the X-ray emitted will have an energy equal to the total kinetic energy of the electron. The Bremsstrahlung process can cause other (low energy) X-rays which in turn can cause additional Compton and photoelectric effects. This scattered (secondary) radiation is an important concern in radiograph.

Half Value Layer - Due to the absorption, there will be a relationship between the amount of radiation incident upon a material and the amount of radiation passing out of the material (transmitted). This relationship of incident to transmitted radiation will depend upon such factors as:

- The wavelength (penetrating power) of the radiation,
- Type of absorbing material (density, grain structure, etc.), and
- Thickness of the material.

The thickness of a material that reduces the intensity of transmitted radiation to half the incident radiation intensity is known as the "Half Value Layer" (HVL). Since one HVL reduces the intensity by a factor of ½, two HVLs will reduce the intensity by ½ x ½ or ¼, so the absorption is an exponential function (Figure 5-7).

Sometimes it is necessary to know how much shielding is required in order to reduce a particular level of radiation to an acceptable level. This may be achieved by calculating the number of HVLs required of a particular material (lead, concrete, brick etc.) and multiplying this number by the thickness of material that constitutes one HVL. The formula for calculating the number of HVLs is given as:

No. of HVL's = $(\text{Log } I_0/I_t) / \text{Log } 2$

Where;

I_0 =Intensity of incident radiation (R/hr)

I_t = Intensity of maximum permissible level (R/hr)

Table 5-1 lists the HVLs (and Tenth Value Layers) for several common materials.

Through an understanding of the HVL, safety shielding requirements of transmitted radiation through a wall can be calculated.

Tenth Value Layer - The tenth value layer is the thickness of a material that reduces the intensity of radiation by 90 percent.

Reduction Factor - The concept of a reduction factor is useful in computing the amount of shielding needed. The reduction factor is the intensity of gamma radiation reaching a point at some distance from a source with no shield, divided by the intensity reaching the same point

with some shield interposed. This reduction factor depends upon the radiation energy and the shielding material atomic number, thickness, and density.

$RF = I_0 / I_t$

Where;

RF = Reduction factor

I_o = Incident gamma intensity

I_t = Transmitted gamma intensity

5.3.2.3 Radiation Measurement

The basic unit used to express the quantity of exposure from X or gamma radiation is the “Roentgen”. The “Roentgen” expresses radiation exposure in air, based on the “ionizing” effect of radiation. The ionization process creates ion pairs, in which each ion pair consists of a negatively charged ion and a positively charged ion. The number of ion pairs can be measured by the amount of electric current they produce in radiation detection equipment. The electric current can, in turn, activate an analog meter or digital counter.

Technically defined, the Roentgen is the quantity of ionizing radiation that produces 2,083 million ion pairs (or one electrostatic unit of charge) in one cubic centimeter of air at standard temperature and pressure. This unit is also defined in the SI system as Coulombs/Kg. 1 R = 2.58×10^{-4} C/kg.

The “milliroentgen” is often used as a measurement of personnel exposure and is abbreviated “mR” (“m” for milli and “R” for Roentgen). One mR is 1/1000 of a Roentgen (0.001 Roentgen). (1mR=0.01 mSv/hr)

Curie - The basic unit of measurement of intensity for radioactive material is the “Curie”. When a radioactive material decays, it is said to have an “activity” or strength of one curie when 37 billion of its atoms disintegrate in one second. This is written 3.7×10^{10} disintegrations/second.

However, when comparing two different sources, just because one has a higher activity does not mean it is always producing more radiation.

Example: When a Cobalt 60 atom decays it emits one beta particle and two gamma rays. When a Thulium 170 atom decays, ¼ of the atoms emits a beta particle and one gamma ray, and ¾ of the atoms emit beta particles with no gamma rays.

The activity of a radioisotope is normally rated in “Curies at one foot from the source”, the whole term being shortened such that only Curie is used to describe the activity of a radioisotope.

Specific Activity - Specific activity of any radioactive source is activity in curies per gram.

Example: If 4 grams of Cobalt 60 has an activity of 100 curies, then the specific activity would be 25 Curies per gram.

Half-life - Definitions of three types of half-life:

“Radioactive half-life”-This is the time it takes for one-half of the radioactive atoms to decay or disintegrate.

"Biological half-life" - This is the time it takes one-half of the radioactive material to be passed from the body as waste.

"Effective half-life" - This is a combination of the above two. It is the time needed to lose one-half of the radioactive threat by a combination of biological elimination and radioactive decay.

5.3.3 Radioactive Isotopes

The two radioactive isotopes primarily used as sources of gamma rays in RT are:

- Cobalt 60 and
- Iridium 192.

Each radioactive isotope has a characteristic half-life, which is the time it takes for the source to decay or disintegrate to one half of its original activity (G Becquerel or Curies). The half-lives of some common radioisotopes are as follows:

Isotope	Half-live
Radium 226 (Ra-226)	1620 years
Cesium 137 (Cs-137)	30 years
Cobalt 60 (Co-60)	5.3 years
Thulium 170 (Tm-170)	130 days
Iridium 192 (Ir-192)	74 days

The penetration of gamma rays, which is comparable to X-rays of 500 to 2000 kV is particularly valuable where the thickness or density of the specimen is beyond the range of X-ray equipment generally available.

5.3.3.1 Characteristics of an Isotope

In an electrically neutral atom, the number of protons in the nucleus equals the number of electrons in orbit around it. An element owes its unique chemical characteristics to the number of protons or Atomic Number, as previously discussed.

If the number of protons in the nucleus is altered (and hence the number of electrons), the element will be changed chemically and become another element. However, if the number of neutrons in the nucleus is altered, no chemical change takes place, and the element retains the same chemical characteristics. The only change that takes place will be in the element's mass. Elements with the same number of protons but with a different number of neutrons are called isotopes.

A particular element can have several isotopes; some of these are stable and will continue to exist in a neutron rich or neutron deficient state.

Some elements, however, have isotopes that are unstable. In this case the isotope will not continue to exist in its neutron rich or neutron deficient state but will try to return to a more stable condition. These isotopes are called radioisotopes, or radioactive isotopes.

The process of a radioisotope returning to a stable condition is known as "disintegration". This does not mean the nucleus will be destroyed, only that a particle is either ejected or captured by the nucleus in order to stabilize it.

With the heavier atoms, the nucleus may reject an alpha particle consisting of two protons and two neutrons (identical to a helium nucleus) and so it becomes an alpha emitter. In many others a beta particle consisting of an electron or a positron may be ejected, and it becomes a beta emitter. While in others an orbital electron may be captured into the nucleus (so called "K" capture), resulting in the formation of an additional neutron.

In many instances these disintegrations are accompanied by the emission of intense energy from the nucleus in the form of gamma radiation. This is due to the binding forces (energy) in the nucleus being released as the nucleus reverts to a more established state.

Whereas the X-ray spectrum is continuous, gamma ray spectrum is a line. The main energy levels for Ir. 192 are shown in Figure 5-8.

5.3.3.2 Production of Radioactive Isotopes

Although many isotopes of various elements occur in nature, artificial isotopes are very common. Artificial isotopes are created by bombarding a stable element with neutrons. This is done in a nuclear reactor where the atomic fission process emits large numbers of free neutrons. As a result of being exposed to neutron radiation, elements absorb some of these neutrons, which increases the element's "A" number or mass.

When these additional, absorbed neutrons do not upset the proton-to-neutron ratio of the nucleus, the new isotope is said to be "stable". When these additional, absorbed neutrons upset the balance of the nucleus, the isotope is unstable (or radioactive) and the atoms disintegrate or decay into a more stable form. Radioactive atoms disintegrate or decay by the emission of radioactive particles and/or photons (gamma rays).

When Iridium 191 (A#) is placed in a reactor and bombarded with neutrons, some of the atoms of Ir. 191 absorb one neutron into their nucleus creating the radioisotope Ir. 192. Following irradiation, the isotope disintegrates in an attempt to return to Ir. 191. The disintegration is by beta emission and "K" capture. This results in the emission of 20 discrete energy levels of gamma radiation.

5.3.3.3 Radioactive Decay

The activity or strength of radioactive material is expressed by the unit "Curie." The SI unit is "Becquerel". When a radioactive material has an activity of one Curie, it decays or disintegrates at a rate of 3.7×10^{10} (37 billion) times per second (1 Becquerel = 1 disintegration per second).

The quantity of radioactive material decaying in a given time is directly proportional to the quantity present. It is therefore impossible to give the period that will be required for the complete decay of a radioactive-element, as theoretically this is an infinite time. In referring to radioactive decay, therefore, the period of time in which half the radioactivity is lost is taken as the unit of measure. The curve in Figure 5-9 shows the decrease in radioactivity of Iridium 192. This graph illustrates that the half life of Ir.

192 is 74 days. It should be remembered, only the intensity of the gamma energy diminishes with decay. Wavelength remains the same. The penetrating power will therefore not change. Only the time needed to produce an acceptable radiograph will increase as the isotope decays.

5.3.4 Generation of X-rays

The generation of X-rays requires the following:

- A source of electrons,
- A means of accelerating the electrons to a high velocity,
- A target for the impact of the electrons, and
- An evacuated atmosphere (vacuum).

X-rays are generated when high speed, free electrons release some of their energy during interaction with either the nucleus or orbital electrons of the target atom. As the velocity of the free electrons increase, the energy of the x-rays produced will increase.

A heated wire filament usually serves as the source of the electrons. A current is applied to this tungsten wire filament that begins to emit electrons when its temperature increases. A high positive charge on the anode causes these electrons to travel at high speeds. The electrons interact with a target (usually tungsten) embedded into the anode. All this is contained in a tube, consisting of a sealed glass envelope, which is evacuated to the highest attainable vacuum (Figure 5-10).

In general, X-rays produce radiographs of better quality and sensitivity than do gamma rays since an optimum energy can be selected for a given object.

5.3.4.1 Theory of Generation

Orbiting electrons become excited and “boil off” when the material is heated. This is especially true when contained in a vacuum. The number of free electrons liberated in this manner is dependent upon the material and the temperature of the radiating source. X-rays are produced when free electrons, traveling at high speed, collide with a target.

5.3.4.2 X-ray Spectrum

Continuous X-rays - This range of wavelengths also occurs when a constant potential type circuit is used. In a constant potential circuit the incoming alternating current is rectified and smoothed as much as possible.

X-rays are produced when the high speed electrons collide with the atoms of the target material. They may hit the nucleus head on, hit the orbiting electrons head on, or strike several orbiting electrons with glancing blows. If the high speed electrons hit the nucleus or the orbiting electrons head on, they give up all their energy as very short wavelength photons. If the high speed electrons strike the orbiting electrons with glancing blows, they impart some of their energy to each collision and emit medium and long wavelength photons.

The high energy X-rays are generally used

for the penetration of thicker or heavier materials (increase in kV gives decrease in wavelength) although for any given specimen, a radiograph made with high kV will have a lower contrast than one made at a lower kV. The quality of radiation is affected by changes in kV because of the disproportional effect on intensity.

Characteristic X-rays - If during X-ray production, the high speed electron hits an orbiting electron directly, it may give up all its energy. Part of that energy is given up in knocking an orbiting electron out of its shell. This will render the target atom electrically out of balance.

The vacancy is quickly filled, however, by an electron moving from an outer orbit. Since each shell represents a different energy level, the movement of an electron from one shell to another is always accompanied by a release of intense energy of a particular wavelength.

For example, if an orbiting electron is knocked out of the K shell, an electron will move from the L shell to fill the vacancy. This leaves the L shell deficient of an electron. Its place is filled by an electron moving from the M shell and so on, until the atom returns to electrical stability.

Movement from L to K produces energy of a different wavelength and intensity than a movement from M to L, but the wavelengths and intensities will always be the same for the atoms of each particular material. The energy levels of the K, L, and M shells for tungsten differ from those of copper and therefore produce a series of different wavelengths and intensity, which is characteristic of the target materials. These peaks are called characteristic radiation peaks. The energy release is not useful in the production of radiographs.

5.3.4.3 Milliampere-Time or Exposure

With a given energy of X-radiation, the three factors governing exposures are the mA, time, and the source-to-film distance (SFD). Since the product of intensity (mA) and time (sec or min) determines the amount of radiation striking the part, it is usually combined and expressed as mA-time or exposure.

5.3.4.4 Effective vs. Actual Focal Spot Size

In order to achieve good definition, it is preferable to have as small a focal spot as possible, but this imposes limitations on the rating of the tube. This difficulty is considerably overcome by using the “Benson” or “line-focus” principle. The actual focal area on the target may then be made fairly large while the projected area is much smaller. When the angle between the target face and the tube axis is about 70°, the effective area of the focal spot is then only about one third of its actual area (Figure 5-11).

5.3.5 Geometric Factors

It is the goal of the radiographer to obtain the best image quality and radiographic sensitivity as specified by the applicable codes and standards. Sensitivity is defined as the ability of the radiograph to display the smallest change in the objects cross section. Radiographic sensitivity is

influenced by two major factors:

- Radiographic definition and
- Radiographic contrast which is made up of film contrast and subject contrast.

5.3.5.1 Definition

Radiographic definition is the sharpness or the line of demarcation between areas of different densities on a radiograph. If the image is clear and sharp, the radiograph is said to have good definition.

Image unsharpness refers to the "fuzzy" edges or penumbra that diminish detail sharpness at the edges of the objects. Several factors cause the unsharpness of radiographic images. Most sources of image unsharpness can be controlled to some extent. It is always a challenge to the radiographer to minimize image unsharpness in a radiograph. An image that is unsharp has poor definition.

Source-to-Film Distance--SFD (Figure 5-12) is a primary factor in controlling the unsharpness of a radiograph. SFD, which is sometimes referred to as target-to-film distance (TFD), source to detector distance (SDD) or focal spot to film distance (FFD) with relationship to X-ray equipment, is usually specified in codes specifications. If the SFD, TFD, or FFD is not specified, the radiographer must determine the appropriate distance to meet the applicable quality level.

Object-to-Film Distance - Object-to-Film Distance is another primary factor in controlling the unsharpness of a radiograph. The closer the film is to the specimen, the greater reduction in the unsharpness. When this dimension is increased, it has the greatest effect on unsharpness compared to the other geometric factors (Figure 5-13). The film should always be placed in such a manner as to minimize the distance from the area of interest to the film. Additionally, where practical, the film should be at 90^o to the primary beam of radiation.

Source-to-Object Distance - Unsharpness can be reduced when the source-to-object distance (SOD) is increased. This should be as great as practical, without unduly increasing the exposure time.

Screens - When radiation reaches the film, only a very small portion is absorbed. An effective means of increasing the exposure effect is through the use of radiographic screens. These are also called intensifying screens. Lead foil on both sides of the film has an intensifying effect. Lead, upon being excited by radiation, emits electrons. Electrons expose the film just as the X or gamma radiation does. In fact, the electrons are more easily absorbed than the radiation. Also, fluorescent intensifying screens are occasionally used in radiography, but as a rule are not used with gamma rays. These screens consist of a smooth layer of powdered fluorescent chemicals coated on a piece of cardboard or plastic. Such screens may lower the exposure needed to produce satisfactory radiographs by a factor of more than 100.

Scatter - Another variable that affects definition is scatter. Internal scatter results from

the interaction of the photons (X and gamma rays) with the test object. As it scatters, the radiation loses some of its energy, therefore increasing its wavelength and it usually changes direction. A second type of scatter, side scatter, originates from radiation reflecting off walls and other objects nearby that are in the region of the primary radiation beam. The third type of scatter, backscatter, is caused by radiation reflecting off objects located behind the object and film. Backscatter can be identified by placing a lead letter "B" on the back side of the cassette. If a light image of the "B" appears on a dark background on the processed radiograph, this indicates that backscatter is present and excessive. A dark image of the "B" is acceptable on the radiograph.

Unsharpness - Some sources of unsharpness (such as inherent graininess and internal scattered radiation within a specimen) are impractical to control. However, routine techniques involve factors that must be considered to control unsharpness. Unsharpness is influenced by several geometric factors.

A major factor of geometric unsharpness relates to the size of the radiographic source or focal spot. When the source or focal spot is not a point but a small area, the image cast is not perfectly sharp. The unsharpness cannot be completely eliminated because a "point" source cannot be obtained (Figure 5-14).

It has been determined that 0.020-inch (0.5 mm) penumbra still appears sharp to the human eye. Therefore, any unsharpness over 0.020 inch (0.5 mm) will start to appear "fuzzy" or unsharp to the unaided human eye.

The amount of sharpness (Ug) is determined by the following equation:

$$Ug = Fd/D$$

Where:

D = Source-to-object distance,

F = Effective focal spot or source size (maximum projected dimension)

And;

d = Distance from the source side of the object to the film (the specimen thickness when the film is in contact with specimen).

In order to achieve optimum sharpness or definition, the following conditions should occur:

- The radiation source is small.
- The distance from the source to the specimen is as far as practical.
- The distance from the specimen to film is as close as possible.

Whenever possible, the rays from the radiation source should be directed perpendicularly to the plane of the specimen and film to prevent a distorted image, as illustrated in Figure 5-15.

5.3.5.2 Contrast

Radiographic contrast is a comparison between film densities on different areas of the radiograph. Radiographic contrast combines subject contrast and film contrast.

Those factors in the specimen and the radiation beam that affect contrast relate to subject contrast. Those factors in the film, screens and processing that affect contrast relate to film contrast.

Film Contrast - Film contrast, by definition, is a film's ability to show a change in density for a given change in exposure. The formation of an image on the film depends upon the amount of radiation received by different regions of the film. Film contrast is determined by the film density, the characteristics of the film emulsion, intensifying screens, and processing. A discontinuity represents a thickness reduction or a material density change within the specimen. It appears as a darker or lighter area in the processed film. If the discontinuity is an inclusion that is more dense than the specimen material, the image on the film is lighter at that region. More radiation is absorbed by the dense inclusion as compared to the material. A less dense discontinuity appears as a darker image on the film.

Subject Contrast - Subject contrast, by definition, is the ratio of the radiation intensities transmitted through two areas of the specimen.

A part with the uniform thickness would have a very low subject contrast. One with a wide range of thickness variations would in turn have high subject contrast.

For a given part, high energy radiation results in low contrast and low energy results in a high contrast image. While subject contrast is primarily related to the density variations on the radiographic film as a function of part thickness or density changes, it (subject contrast) is also affected by energy.

Scatter - Radiographic contrast can also be reduced by scatter radiation. Materials not only absorb radiation but scatter radiation in all directions. Thus, the film receives not only radiation from the primary radiation source, but also receives scattered radiation from the object being radiographed, the film holder, and the walls and floor of the room. Scattered radiation tends to make the whole image blurry on a radiograph. Scattering may be reduced by screens, masks, diaphragms, and filters.

The radiographic energy, or wavelength, has an affect on the contrast of the radiograph. For maximum contrast, the lowest practical energy level, or the longest wavelength radiation should be chosen. It is not normal to carry out radiographic X-ray exposures at the lowest practical kV setting because this requires longer exposure times. Many times, contrast is sacrificed in order to minimize exposure times.

5.3.6 Exposure Considerations

There are various ways to determine the correct radiographic exposure required for a given specimen:

- Trial and error,
- Reference to previous exposure data, and
- Use of an exposure chart.

The first two ways are considered unscientific, but in the hands of an experienced technician they may be necessary, especially when developing techniques for unusual parts. The third has the advantage that often "first time" acceptable results can be achieved simply by applying the information from the exposure chart.

An exposure chart for X-rays is in the form of a graph relating exposure time to material thickness. Therefore, it is necessary to "fix" as many conditions as possible. These conditions listed below, should be noted on the finished chart so that it is possible to follow the correct conditions for its use.

Fixed Conditions:

- X-ray equipment;
- The specimen material;
- The type of film used;
- The type of screens used, if applicable;
- The processing details (developer, time, temperatures etc.);
- The source (or target) to film distance;
- The type of filtration used, if applicable; and
- The film density to be achieved.

X-ray Exposure Charts - As shown in Figure 5-16, the exposure is plotted on a logarithmic scale to shorten the chart in the vertical direction. The vertical axis of the chart shows exposure in milliampere-minutes (mAm) or milliampere-seconds (mAs), and the material thickness is displayed on the horizontal axis. To use this chart, move across bottom to the thickness of the specimen. Follow the chart vertically to the selected kV. Then move horizontally to the correct exposure.

Example: 1 inch of steel at 180 kV would require about 4,000 mA. At a tube current of 10 mA, the exposure time would be 400 seconds or 6 minutes and 40 seconds.

Gamma radiography also uses charts to determine the exposure factor. The gamma ray exposure chart is simpler than the X-ray chart since the gamma source is a fixed energy.

Figure 5-17 illustrates a sample exposure chart for Ir-192. The exposure factor for a gamma ray source is defined in terms of the intensity of the source (curies), the time of exposure (minutes), and square of the source-to-film distance ($feet^2$).

Exposure Factor = $(Ci \times T)/ D^2$

5.3.6.1 Inverse Square Law

The intensity of radiation is inversely proportional to the square of the distance from the radiation source, conforming to the "Inverse Square Law", and may be stated as:

$I_1 / I_2 = D^2_2 / D^2_1$

Or $I_2 = (D^2_1 * I_1) / D^2_2$

Where;

I_1 and I_2 are the intensities at distances D_1 and D_2, respectively.

5.3.6.2 Reciprocity Law

Relationships between mA time and the inverse square law for time and distance calculations dictate that a known change of mA or distance will require a precise change of exposure time. This is referred to as the "Reciprocity Law" and is accurate for direct X-ray and lead screen exposures.

The intensifying effect of screens requires modified exposure times to ensure comparable radiographic density. Each particular type of screen will have an intensification factor and, using the factor, the new exposure times may be calculated by applying the formula:

Exposure time with screens = Exposure time without screens / Intensification Factor

The intensification factor using lead screens is about 3 for X-rays and about 2 for gamma rays.

5.3.6.3 Film Density

Film density, which is a function of the amount of radiation exposure and development, refers to the degree of film blackening. The amount of light transmitted through a radiograph measures film density, which can be quantified by comparing it to a film strip with various density steps or measured with an instrument called a densitometer.

Density values for an acceptable radiograph are specified by the codes. This is usually described as the amount of blackening of the image and typically is between 2.0 and 4.0 for a radiograph. A high density area of a radiograph will absorb more light than a low density area. Density (D) can be quantitatively defined as the logarithmic ratio of the light intensity incident on the film (I_o), to the light intensity transmitted by the film (I_t).

In equation form $D = \text{Log}\,(I_0 / I_t)$

Where;

D = Film density

I_o = Incident intensity

I_t = Transmitted intensity

Over the useful density range, the logarithmic ratio is proportional to the logarithm of exposure, and the numerical value of a series of densities may be added together to give the total density. It is essential to be able to measure densities accurately. For this purpose a special instrument called a "densitometer" is used.

The principle of this instrument is explained by the following example. If the intensity of the incident light on a selected area of the film, is 1,000 units, and if the intensity of the transmitted light from the same area is 100 units, then its density is:

$$D = \text{Log}\,(I_0 / I_t) = \text{Log}\,(1000 / 100) = 1$$

When the transmitted light intensity is 1/10th of the incident light then the D = 1. If it is 1/100th, then, D = 2. If it is 1/1000, then, D = 3.

5.3.6.4 Film Characteristic Curves

Although films (Figure 5-18) may be compared qualitatively by describing them as slow or fast, low contrast, etc., a quantitative examination is necessary if precise meanings are to be given to these terms. This is achieved by measuring the densities produced by a range of accurately known exposures and plotting one against the other. The resulting curve is known as a "characteristic curve", "sensitometric curve", or "H&D curve".

5.3.6.5 Exposure vs. Density

For any given exposure change, density will not change in a proportional or linear fashion. This is due to the non linearity of the characteristic curve of the film described in paragraph 5.3.6.4.

5.3.6.6 Gamma Ray Exposure

In general, gamma radiography is similar to X-radiography. The choice of the isotope will depend upon such factors as the dimensions, shape and material of the specimen. Each source is supplied with a decay curve for its first two half life periods, which will show its activity at any date during that time.

The intensity of radiation will be low with a source of little activity; therefore, exposure will be relatively long. The time can be reduced by using a faster film, but at the expense of contrast which will be low anyway, due to the low absorption of the short wavelength radiation. Faster film also has less definition.

Before an exposure can be calculated, certain factors must be known:

- The type and thickness of material to be examined,
- The activity of the isotope (by reference to its decay curve),
- The equivalent material to steel thickness,
- The desired source-to-film distance,
- The quality of the radiograph that is required, and
- The type and speed of the film.

5.4 Equipment

5.4.1 X-ray Machines

A typical X-ray control panel (Figure 5-19) will usually consist of the following controls:

- mA - expressed as milliamperes. Controls filament current and free electrons,
- kV - expressed as kilovolts and permits adjustment of voltage between cathode and anode,
- Timer - calibrated in minutes and controls the length of exposure,
- Power on-off switch - controls application of power to X-ray unit, and
- Indicator lamp - indicates when the equipment is energized and X-rays are being produced.

An X-ray tube (Figure 5-10) consists of an evacuated glass envelope into which are sealed

an anode and a cathode. The anode usually consists of a solid block of copper, with its forming an angle of about 70° to the tube axis. A thin disc of tungsten is inserted into the anode face to form the target. A filament is mounted in the end of the cathode facing the target. Any increase in current heats the filament increasing the number of electrons liberated.

By applying a high potential across the tube, it is possible to accelerate a beam of electrons from the cathode to the target. The actual area on which they impinge is termed the "focal spot". The size of this focal spot will depend on the shape of the filament and the form of the focusing cup in which it is mounted.

The flow of electrons from cathode to anode constitutes the "tube current" which in most industrial X-ray equipment is very small, being measured in milliamperes. Thus the tube current can be controlled by means of a simple resistance or choke in the filament circuit.

The speed at which the electrons travel from the cathode to the anode is controlled by the voltage applied across the tube. The voltage required to make the electrons travel at sufficient speed to produce X-rays useful for radiography is very high and is measured in kilovolts.

When the electrons are brought to an abrupt halt or slowed down by the target, a small amount of their kinetic energy, (2 to 3 percent) is released as X-rays. Most remaining kinetic energy is converted to heat. The efficiency of this process is increased by using an element of high atomic number, such as tungsten, for the target. This has the added advantage of having a high melting point and is therefore, not affected greatly by the heat generated.

The heat liberated by electron bombardment is dissipated by the copper anode into which the target material is mounted. This in turn may be cooled by the circulation of oil or water through its interior.

Limitations are imposed upon the electrical rating of the tube both by the efficiency of the heat dissipation and by the size of the focal point. There is therefore a maximum value of tube current for the continuous operation of any one X-ray unit. If very short exposure times are used, then a higher maximum tube current can be used, as there is time for the target to cool between exposures. The maximum available "time on" period to "time off" period for any X-ray set is known as the duty cycle.

5.4.2 Isotope Exposure Devices

Since there are many different types of radioisotope cameras and related equipment, it is beyond the scope of this chapter to describe them all. Figure 5-20 is an example of camera and accessories. Nevertheless, proper operating instructions and emergency procedures should be written by any company using a radioisotope and a fully qualified Radiation Safety Officer (RSO) should be responsible for safe operation. The name of the RSO should be displayed in a prominent place so that all personnel will know who to contact (and how) should any advice be required.

5.4.3 Radiographic Film

Various types of film are manufactured for industrial radiography. The film types offer differences in contrast, speed, and sensitivity. The slowest exposure films provide better detail and sensitivity because of their finer grain. The exposure speed of the finest grain film is approximately 16 times slower than the fastest film. Film selection is usually based upon the most economical film type that consistently provides the sensitivity required by the applicable code or standard.

5.4.3.1 Composition

Industrial radiographic films are composed of an emulsion, which is a suspension of silver halides in gelatin, coated on a transparent, blue-tinted, non-flammable, pliable base (polyester or acetate). It is coated on both sides of the base to provide maximum speed and contrast in the film, and to allow the film to be processed and dried in the shortest possible time (Figure 5-21). Exposure of the film to radiation results in the formation of what is called the latent image. The mechanism of exposure is beyond the scope of this text but suffice it to say that the electrons emitted by an absorption event modify the structure of individual silver halide crystals so that upon development they are preferentially reduced to (dark) metallic silver.

5.4.3.2 Lead Screens

Three types of radiographic screens enable more effective use of radiation: lead, fluorescent, and fluorometallic. Lead screens are the most common to be used in industrial radiography. Fluorescent and fluorometallic screens are not typically used for Code applications. The major advantage of the two latter screens is the significant reduction exposure time.

The lead screen consists of a thin lead sheet (usually 0.005 to 0.010 in. [0.125 to -.25 mm]) mounted on a cardboard or plastic base. The lead screens are placed in both front and back of the unexposed film with the lead surfaces in contact with the film. The lead screen in front of the film serves two important purposes:

- It absorbs low energy or scatter radiation.
- It increases the photographic action on the film emulsion.

The lead screen in back of the film, often thicker (0.010 in.[0.25 mm]), serves to absorb the backscatter radiation that is lower energy radiation and also increases the photographic action on the film emulsion.

Lead screens must be free of any irregularities that can produce indications on the radiograph and which are identified as artifacts (false indications). Screens that have been damaged and cannot be properly corrected should be discarded.

5.4.4 Film Processing

Once a radiographic exposure has been made, the film is processed so that the “latent”

image produced by the radiation is made visible. Three
processing solutions are essential to convert an exposed film into a useful developed radiograph: developer, fixer, and wash water.

Automatic processing units are available, if the throughput of film is sufficient to justify such expensive equipment. When properly maintained and operated, these units result consistently in radiographs of superior quality to those produced by manual processing.

5.4.4.1 Manual System

The most widely used processing unit is simply a large water tank, thermostatically heated, into which are placed smaller tanks containing the processing chemicals. The processing sequence is development, stop, fix, wash, wetting agent, and then dry (Figure 5-22).

5.4.4.2 Automatic System

Automatic processors can produce consistent quality radiographs in short periods of time (i.e., 7 to 14 minutes), as opposed to the usual 1 hour required for manual processing. The shorter processing times are due to elevated temperatures, and the solutions used in automatic processors are of a different concentration than those used for manual processing.

Most processors have a roller type of mechanism (Figure 5-23). The stop bath and wetting agent tanks are eliminated due to squeegee rollers at the exit of each tank. The squeegee rollers reduce the retention of solution on the film from tank to tank, and the rollers at the wash tank exist to remove most of the water, so that the film is in a damp-dry condition entering the drying compartment.

Replenishment of the solutions is done automatically and is usually controlled by the quantity of film being processed.

With all darkroom activity, cleanliness is of the utmost importance, especially with automatic processors. Regular maintenance following the manufacturers' recommendations should be closely followed.

5.5 Techniques

5.5.1 Single Wall Exposure / Single Wall Viewing

For cylinders of large internal diameter the single wall technique is employed (Figure 5-24).

This technique is suitable for 360°, rod anode, and gamma ray sources where the source is positioned at the center axis of the cylinder. Films wrapped around outer surfaces are simultaneously exposed. For flat parts, the source is on one side of the part and the film is on the opposite side.

5.5.2 Double Wall Exposure / Double Wall Viewing

Welds in pipe and tubes 3-1/2 inches and less in nominal size (diameter) may be radiographed

using the double wall technique where the radiation passes through both walls and both walls are evaluated (Figure 5-25). An image quality indication (IQI), based on the single wall thickness plus the weld reinforcement (if present), is placed on the source side of the upper wall, on top of a shim approximately equal to twice the weld reinforcement. As an alternate, the same IQI and shim may be placed on the top of a like section that is placed adjacent to the weld being radiographed. When impractical to do the above, the IQI may be placed on top of a block that is approximately equal to twice the wall thickness plus twice the weld reinforcement.

5.5.3 Double Wall Exposure/Single Wall

For welds in pipe and tubes greater than 3-1/2 inches in outside diameter, the weld closest to the film can be reviewed (Figure 5-26). An IQI, corresponding to the single wall thickness plus any single-wall weld reinforcement, is placed adjacent to the weld on the inner wall on top of a shim equal to the weld reinforcement. When that is not possible, the same IQI and shim may be placed on the bottom of the inner wall of a like section of a tube placed adjacent to the weld being radiographed. When a like section of the tube is unavailable, the IQI may be placed on a block adjacent to the weld being radiographed. The block thickness should be equivalent to twice the wall thickness plus any single wall weld reinforcement. The top of the block should not be lower than the bottom of the inner wall of the tube.

5.5.4 Multiple Film Techniques

Film techniques with two or more films of the same or different speeds in the same film holder are used for either single or composite film viewing, providing that the applicable radiographic quality level and film density requirements are achieved for the area of interest. Multiple film techniques are beneficial in that there are at least two images of the object making easy disposition of any artifacts. This also provides greater coverage, especially if the part has varying section thicknesses.

5.5.5 Coverage

Areas to be examined should be identified on the drawing by using symbols. If the number of parts to be examined and the amount of coverage of each part is not specified, all parts should be examined and receive 100 percent radiographic coverage. There must be sufficient overlap in the event the part is longer than the film.

5.5.6 Use of Blocks and Step Wedges

When shims are used with penetrameters in the RT of welds (Figure 5-27), or when the penetrameters are placed on separate blocks, the shims or blocks should be made of radiographically similar materials in a given materials group.

5.5.7 Penetrameter Placement

As a general rule, penetrameters are placed:

- No closer to the film than the top surface of the part,

- No closer to the X-ray beam axis than the extreme discontinuity expected,
- So as not to obscure the area of interest, and
- On shims so that the density through the penetrant and shim is similar to area of interest.

Figures 5-28 to 5-31 give an extract from ASME Section V, Article 2, which shows examples of penetrameter and shim placement.

5.5.8 Structural Welds

The standard technique for structural welds requires the beam of radiation to be directed to the middle of the section under examination and should be normal to the material surface. Special examinations for certain discontinuities would best be revealed by a different angle of the beam (e.g., lack of fusion). The exposure may be made with the beam directed along the fusion face.

5.6 Radiographic Quality

5.6.1 Image Quality Indicators

The image quality indicator (IQI), or penetrameter, is a device whose image on a radiograph is used to establish the radiographic quality level (sensitivity) of the technique used. It is not intended for use in judging the size or in establishing acceptance limits of discontinuities.

5.6.1.1 Hole Type IQIs

The hole type IQI is usually a shim of metal that is radiographically similar to the material being examined and whose thickness is usually a specified percentage (i.e. 1, 2, or 4 percent) of the specimen thickness. Three holes are drilled into the IQI with diameters equal to 1, 2, and 4 times the thickness of the IQI.

ASTM and ASME IQIs have an identification number that represents the thickness of the penetrameter in thousandths of an inch. Figure 5-32 shows an IQI that would be used on a part that is 0.25-inch thick, if the IQI thickness is based on 2 percent of the specimen thickness. The number "5" represents thousandths of an inch; therefore, the actual thickness of the IQI is 0.005 inch, which represents 2 percent of the 0.250-inch part being radiographed. Based on the hole diameter perceptible on the radiograph, the radiographic quality level and equivalent sensitivity can be determined.

5.6.1.2 Wire IQIs

The wire type image quality indicator consists of six wires of increasing diameters mounted in a plastic tab and placed on the specimen (see Figure 5-33). The ability to see a specified wire on the radiographic image is an indication that the required sensitivity has been met.

5.6.1.3 Penetrameter Requirements

Penetrameters are not normally required when:

- Examining assemblies for debris.

- Conducting radiography for discontinuity removal or grind out. The final acceptance radiography should include an IQI as required.
- Examining to show details of component parts or assemblies.
- While examining for corrosion, to show side wall contour in pipes and other components.

5.6.2 Density

For single film viewing, the density should be between 2.0 and 4.0 (inclusive) in the area of interest for gamma radiography and 1.8 to 4.0 for X-radiography. Where superimposed film viewing is used, the density of the superimposed films should be between 2.6 and 4.0 (inclusive) in the area of interest, and each individual film must not have a density below 1.3 in the area of interest. The Code also requires that the density in the area of interest fall within +30 percent to-15 percent of the density through the penetrameter. In the 2001 edition of the ASME Code, the +30 percent variations are waived if a shim is used with the penetrameter and the minimum density does not apply to the penetrameter as long as the proper sensitivity is obtained.

In any event, the densities of the area of interest cannot be acceptable unless they fall within 1.8 to 4.0 (X-ray) or 2.0 to 4.0 (gamma ray).

5.6.3 Improper Use of Penetrameters

An observant and qualified film interpreter will normally detect penetrameter alterations by virtue of the extremely high image density that the penetrameter hole shows. The majority of penetrameter sensitivity requirements are very close to the limits of perceptibility. They are there to ensure that the system is meeting minimum requirements.

Improper techniques used to improve image quality include locating the IQI on the film side of the object without indicating its location with a lead letter "F"; placing the IQI closer to the center of the beam than the area of interest; changing the marking on the IQI to falsify its thickness; or enhancing the hole image on the film emulsion using a pencil or black felt pen.

5.6.4 Radiographic Film Identification

In order to avoid confusion and assure traceability, all radiographs must have proper identification and meet the following requirements:

- Film must be related to specific part or area.
- Film position must be accurately indicated.
- Identification markings should not be repeated.

There are several acceptable approaches that are used to accomplish this including:

- Flashing information of film,
- Lead tape with numbers/letters embossed, and
- Lead numbers/letters affixed to a designated area on the part.

The primary goal of the identification is to permit exact locations to be determined from the radiograph. Actual locations of discontinuities must be able to be accurately positioned using the related location marker's position.

5.7 Film Viewing Considerations

Viewing conditions are of utmost importance. The examination of the finished radiograph should be done under conditions which afford maximum visibility of detail together with a maximum of comfort and a minimum of fatigue for the interpreter. Subdued lighting in the viewing area is preferable to total darkness. The room lighting must be arranged so that there are no reflections from the surface of the film being interpreted. Adequate table surface must be provided on either side of the viewer to accommodate film and to provide a writing surface for recording the interpretation. Quick and easy access to a densitometer, reference radiographs, applicable codes, standards, and specifications should also be provided. In addition, it is important for the film interpreter to be free of distractions, in order to maintain concentration.

If the interpretation of the radiographic image is to be meaningful, it is essential that proper viewing equipment, in good working condition, be used. If slight density variations in the radiographs are not observed, rejectable conditions may go unnoticed. In many cases, various types of discontinuities are barely distinguishable even with the use of optimized techniques and fine-grained film. In order to optimize the interpreter's ability to properly evaluate the radiographic image, ideal viewing conditions and suitable equipment are absolutely necessary.

5.7.1 High Intensity Illuminators

A radiograph that meets the density requirements of the Code will permit only a small fraction of the incident light to pass through it.

A film that permits 1 percent of the incident light to be transmitted will have a density of 2.0.

Following the same procedure, it can be seen that a film density of 3 permits only 0.1 percent of the incident light to pass through and a density of 4.0, a mere 0.01 percent.

Typically, radiographic density requirements through the area of interest range between 2.0 (1 percent light transmission) and 4.0 (0.01 percent light transmission). This explains the need for a high intensity viewing light.

There are many types and styles of high intensity illuminators, although they are generally classified into four groups: spot viewers, strip film viewers, area viewers, and combination spot and area viewers.

Spot viewers provide a limited field of illumination, typically 3 to 4 inches in diameter. These viewers are usually the most portable and least expensive.

The strip film viewer permits interpretation of film including 3.5 by 17 inches, 4.5 by 17 inches, 4 by 10 inches, 5 by 7 inches, and the 35

mm or 70 mm sizes. The viewing area is rectangular and the area of illumination may be adjusted to conform to the film dimension by employing metal or cardboard masks.

The area viewers are designed to accommodate large films up to 14 by 17 inches. The illumination is generally provided by fluorescent lights or a bank of photo-flood bulbs. The fluorescent light intensity may not have suitable brightness to permit effective examination through the higher densities and this could result in a serious limitation.

The combination spot and area viewers provide the interpreter with spot capability while allowing the viewing of a large area of film. A switch determines which light source will be activated.

5.7.1.1 Heat

Since light of high intensity also generates significant amounts of heat, it is necessary that the illuminator have a means of dissipating or diverting the heat to avoid damaging the radiographic film while viewing. This is accomplished in most cases by a cooling fan.

Light sources in typical illuminators consist of one or more photo-flood bulbs. Other light sources such as flood lights and tungsten halogen bulbs are also used.

5.7.1.2 Diffusion

To eliminate variation in the intensity of the light, it is also important that the light be diffused over the area used for viewing. This is accomplished with a diffusing glass, usually positioned between the light source and the viewing area, or with a white plastic screen at the front of the viewer.

5.7.1.3 Intensity Control

Another essential feature of the illuminator is the variable intensity control. This permits subdued intensity when viewing lower densities, and maximum intensity as required for the high density portions of the radiograph.

5.7.1.4 Masks

Masks can be extremely helpful when attempting to evaluate a small portion of a larger radiograph, or when the radiograph is physically small. The objective is to illuminate that portion of the radiograph identified as the area of interest, while masking other light from the eyes of the interpreter. Some spot viewers are equipped with an iris diaphragm that permits the spot size to be varied with the simple adjustment of a lever. This feature is especially helpful when small areas or fine details must be examined.

5.7.1.5 Precautions

The illuminator's front glass or screen which touches the film and should always be clean and free of blemishes on both sides. Scratches, nicks, dirt, or other imperfections on the front glass or screen will cast shadows on the radiograph, causing unnecessary distractions.

Another precaution will help minimize film scratches. The front of the viewer should be carefully examined to ensure that there are no sharp edges or other obstructions; these could cause scratches to the sensitive surface of the radiograph as it is moved or positioned on the viewer.

5.7.1.6 Magnifiers

Normally, radiographs can be effectively evaluated without the aid of magnification devices. There may be occasions, however, when such devices are helpful. For example, if the object being radiographed contains very small discontinuities, magnification may be essential. This application will generally require the use of fine-grained film that can be suitably magnified. Some of the coarser grained films are difficult to view with magnification because the graininess is also enlarged. This can make discernment of slight density changes nearly impossible.

There is a wide assortment of magnifiers appropriate for the evaluation of radiographs. The most common is the hand held magnifying glass, available in many shapes, sizes and powers. For convenience, a gooseneck magnifier may be employed. Because this magnifier is self-standing and attached to a weighted metal base, it leaves the interpreter's hands free during use. One device that offers magnification and measuring capabilities is a comparator with an etched glass reticule.

If any form of magnification is employed, it should be done with caution and limited to only those applications where it is necessary.

5.7.1.7 Other Viewing Accessories

Additional accessories that aid the interpreter and should be available in the film reading area, include (but are not limited to):

- Supply of wax pencils for marking the film;
- Rulers (the most appropriate would be clear, flexible plastic);
- A small flashlight to reflect light off the radiographic film to assist in the identification of surface artifacts such as scratches, roller marks, dirt, etc.;
- Gloves, usually cotton or nylon, to minimize direct contact between the film and the fingers of the interpreter; and
- Charts, tables, and other technical aids that will assist in the prompt establishment of density range, determination of geometric unsharpness, and other data relating to the applicable codes or specifications.

5.8 Interpretation of Radiographs

Radiographic interpretation requires characterization of the images on the radiograph. Determining the cause of these indications requires a thorough understanding of the material and fabrication processes plus extensive experience in the viewing of radiographs.

Radiographic interpretation is a judgment based on the location, size, and shape of an indication to determine its cause. Obviously the skills and experience of the interpreter play a key role.

5.8.1 False Indications (Artifacts)

A number of indications due to incorrect storage, handling, or processing can occur in a finished radiograph. They may make interpretation impossible.

It is worth noting that a great many artifacts appear on one side of the film only. Therefore, if an artifact is suspected, the film should be examined on both sides, using reflected light. Images that appear on one side only cannot be associated with conditions in the object being radiographed.

There are a number of artifacts; the following are some of the more common types:

Pressure marks - These are lighter density areas, if the film experiences pressure before exposure; or darker, if after exposure.

Finger Marks - These are caused during handling. In the areas affected, development is retarded, thereby producing light areas on the radiograph that resemble fingerprints.

Developer Marks - These marks are caused by developer being splashed onto the film before development. Developer marks usually appear as areas of increased density on the radiograph.

Fixer Marks - These are splashes of fixer solution on the film prior to development, which causes clear areas even where the film has been exposed.

Scratches or Abrasions - These are damages to the emulsion, which are caused by negligent handling.

Static Marks - Static marks are caused by the release of static electricity, which exposes the emulsion. They form a tree or fern-like appearance. Once again extreme care is required when handling, especially if the film has been stored under conditions of low humidity,

Screen Marks - These are thin lines, which are caused by scratches on the intensifying screens.

Uneven Development - This is caused by lack of agitation during development. Sometimes this shows up as streaks running parallel to the side of the film that was vertical during development, especially if it has only been agitated in one direction.

Reticulation - Gelatin is affected by sudden temperature changes and wrinkling of the surface may occur. Fine reticulation can be mistaken for graininess because it has a fine network or leather- like appearance. It will not normally occur if the temperature difference between the tanks is less than about 20°F.

Fog - This is usually described as a density change not due to deliberate exposure. It can be overall or localized. It may be due to:

- A faulty safe light,
- Accidental exposure to ionizing radiation during storage,

- Aging of the film,
- Faulty processing - excessive time, increased agitation or temperature, etc. It can also be "dichroic", which occurs when fixation and development are allowed to continue simultaneously. It is recognized by a reddish tint when viewed by transmitted light and a green appearance under reflected light. The use of stop bath will prevent this completely,
- Water spots - caused by droplets of water remaining on the film or running off the hangers. The use of a wetting agent should prevent this; however, care should be taken when putting wet film into the drying cabinet.

5.8.2 Radiographic Images of Discontinuities

5.8.2.1 Weld Discontinuities

The following is a partial list of weld discontinuities and their appearance radiographically:

Cracks - Cracks normally show as dark, irregular, wavy or jagged lines and may have fine, hairline indications branching off the main crack indication.

Slag - Slag inclusions appear as dark irregular shapes of varying lengths and widths.

Porosity - Porosity shows as rounded well-defined high-density spots with well-defined contours.

Undercut - Undercut shows as an increase in density adjacent to the weld toe or root smoothly changing across the weldment and parallel with the weld edges.

Lack of Penetration - Incomplete penetration typically appears as a sharp, dark, continuous or intermittent line at the root of the weld. This condition results when the root bead does not totally penetrate and cause fusion.

Lack of Fusion - Lack of fusion normally shows as a thin, straight dark line parallel to the weld. Lack of fusion occurring between the weld and the side wall generally appears straight on one side and irregular on the other side. It will typically appear some distance from the weld centerline.

Root Concavity - Root concavity is a broad, denser region following along the root area, which is the result of insufficient weld metal in the root.

Root Convexity - Root convexity is an excessive protrusion of the root that results in a lighter region; this is opposite of root concavity.

Tungsten Inclusions - Tungsten inclusions appear as very light, almost white, indications because of tungsten's higher radiation absorption.

5.8.2.2 Casting Discontinuities

Shrinkage - Shrinkage appears as irregularly shaped zones of varying densities, which often

appear to be interconnected.

Cold Shuts - Cold shuts appear as faint lines or linear areas of varying length due to the interruption of the metal flow, resulting in partial freezing. It subsequently forms an oxide coating on the surface, which prevents fusion as the incoming molten metal continues to fill the mold.

Centerline Shrinkage - The radiographic appearance is of a continuous, irregular zone usually branching or in the form of a network.

Micro Shrinkage - The radiographic appearance is a slightly more dense area and will generally look cloudy or mottled. In some cases, the fine network may occur in layers, which produces dark streaks on the radiograph.

Hot Tears - Hot tears appear as dark, ragged, defined irregular lines and may have a number of branches of varying densities.

Inclusions - Indication of irregular shape and size result from entrapped low or high density material such as slag or sand.

Cracks - Cracks normally appear as dark, irregular, intermittent or continuous lines, usually quite well defined.

Gas Porosity - These are very small cavities and appear radiographically as small rounded, widely distributed, dark images.

Gas Hole - This is a larger cavity, which appears radiographically as a dark, rounded, smooth outline image.

Gas Voids - Gas voids appear as large, rounded, dark indications, normally with smooth edges.

Gas Wormhole - This is a tube-like gas cavity and can appear either as a rounded or an elongated image, dependent on the angle of view.

Unfused Chaplets - A chaplet is a very thin metallic support for a core and is generally melted by, and absorbed within, the molten metal. When this does not happen, the image of the unmelted chaplet can be easily distinguished as a dark circular image approximately the same diameter as the core support on the radiograph.

5.9 Code Considerations

In all NDE methods, the Code should be used in the preparation of procedures. Contractual requirements usually dictate the specific requirements that are applicable to a particular component.

The radiographic interpreter must be capable of interpreting and applying specified acceptance criteria and be knowledgeable in the technique used to make the exposure and its effects on the image. To properly determine technique acceptability, the interpreter should know the component or part and understand the manufacturing process.

Based on this information parameters needed to determine technique acceptability include:

- Thickness of part determines the penetrameter requirements and required/permitted radiation energy;
- Reinforcement determines the need for shims;
- Welding process provides an indication of what types of discontinuities are expected;
- Configuration has a direct bearing on exposure/viewing technique selected (i.e., double wall, single wall, panoramic, etc.);
- Accessibility affects technique (e.g., placement of penetrameters); and
- Surface finish may aid or hinder interpretation.

The radiographic interpreter should also be knowledgeable of the effects of the following radiographic variables on the radiographic image:

- Source size,
- Source-to-film distance,
- Source placement,
- Film placement,
- Radiographic coverage required,
- Film selection,
- Screens, and
- Film processing technique and processing variables.

Radiographic film interpretation is more than knowing and understanding the applicable codes and standards and the proper application of acceptance standards. A knowledge of the processes, forming techniques, etc., as well as RT, in general, is essential.

NOTE: Prior editions of the ASME Code contained an Article 3 that addressed the RT of castings. The 1998 edition eliminated Article 3 and includes the RT of castings in Article 2.

5.10 Safety Concerns

The penetrating characteristics of ionizing radiation that is so useful in examining materials and components for internal flaws also create safety concerns. Because radiation exposure to individual workers and the public is potentially hazardous, it must be controlled. Radiation areas must be restricted to properly monitored personnel who have been trained and qualified to use radiation producing equipment.

Additional requirements are imposed for isotope radiography:

- Radioactive material license is required.
- Transportation and storage of radioactive materials must be controlled.

5.11 Advantages and Limitations of Radiographic Examination

5.11.1 Advantages

The key advantages of RT are:

- Can be used with most materials,
- Provides a permanent record,
- Reveals the internal nature of structures,
- Discloses fabrication errors,
- Reveals structural discontinuities, and
- Provides relatively high sensitivity.

5.11.2 Limitations

RT has the following limitations:

- It may provide incomplete coverage on specimens of complex geometry.
- The specimen must lend itself to two-side accessibility.
- Laminar and tight angular discontinuities are difficult if not impossible to detect.
- Safety considerations imposed by X and gamma rays must be considered.
- RT is relatively expensive.
- Discontinuity orientation must be favorable to the beam of radiation.

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6.0 Digital Radiographic Imaging

6.1 Introduction to Digital Radiography

Digital imaging uses various detectors for the collection of the x-ray and forming the digital image. Some of the typical detectors in use today are the real time systems using charged coupled devices (ccd), amorphous selenium panels, amorphous silicon panels, storage phosphor imaging plates and linear diode arrays. The ability to develop these into useful tools in the industrial radiography field can be partially credited to the improvements in the computer systems used today. In the 1980's, a 512 X 512 pixel image created problems for display and storage but today we can typically handle 1500 X 2000 pixel images with relatively inexpensive computer systems. The main advantages of the digital systems currently being used are easier and cheaper archival than film, lower cost than film, no chemicals to process the detectors and lower of costs of radiograph production.

6.2 Imaging Detectors

6.2.1 Charge Couple Devices (CCD's)

Charged couple devices are typically small and contain high pixel densities. Combined with micro-focus x-ray equipment, they are capable of 50 μm or smaller with a display of 4096 X 4096 pixels. CCD's are made from a crystalline silicon structure and typically are restricted in sizes up to about 6 inches in diameter or less which restricts the field of view. CCD's have excellent light collection efficiency when "tiling" is not used to increase the field of view.

6.2.2 Amorphous Selenium Panels

The amorphous selenium panels use a thin film transistor readout circuitry combined with a selenium photoconductive layer of material as a means to detect the x-rays. Once the selenium layer converts the x-rays to electron hole pairs it is processed and sent to the thin film transistor then provides the readout of the charge on a pixel by pixel basis. The amorphous selenium panel uses direct conversion and due to the high voltage bias field applied to the selenium layer it creates a vertical field line. This field line is parallel to the x-ray beam and prevents the charge from lateral scattering and limiting the scatter. This effect allows for high resolution of the image.

6.2.3 Amorphous Silicon Panels

Amorphous Silicon panels also use a thin film transistor but are combined with a

amorphous silicon layer which has a phosphor layer deposited on the silicon layer. The conversion process is not as good as the CCD but is capable of a much greater field of view with this arrangement. The size of the pixel in both the selenium and silicon panels is limited by the use of the thin film transistors and the data and scan lines required for the operation of circuitry.

6.2.4 Storage Phosphors

Storage phosphors are a flexible material that has a photostimulable phosphor material called europium activated barium fluorobromide (BaFBr:Eu) applied to the flexible base. When exposed to radiation the phosphor material phosphoresces but some of the charge is retained in the phosphor material. This retained charge is released when stimulated by a infrared or red laser light. This released charge is of the same emission wavelength as the initial was released when struck with the x-rays. This screen must be processed through the laser scanner to release the charge and transmit the electrical signal is sent to the computer processor to store and rebuild the image of the part. These systems have good spatial resolution and contrast sensitivity and are used widely in production radiography.

6.2.5 Linear Arrays

Linear arrays are detectors that have pixels in one dimension or a small rectangular array or pixels in 32 X 1024 arrangements. Linear arrays are collimated to match the size of the detector which dramatically reduces the scatter field that reaches the array. The linear arrays scan the image one line or a small group of lines at a time. The image is rebuilt in the computer processor after all the scan lines are received by the processor.

6.3 ASME Section V Procedural Requirements

ASME Section V requires that the use of digital image acquisition requires that procedures address the following information;

- Image digitizing parameters such as modulation transfer function (MTF), line pair resolution, contrast sensitivity, and dynamic range
- Image display parameters such as format, contrast and magnification
- Image processing parameters that are used
- Storage information such as identification, data compression and media

6.3.1 System Performance Measurements

A system calibration must be performed measuring the MTF, contrast sensitivity and the dynamic range of the system. A system performance shall be performed and monitored at the beginning and end of each shift to minimize the probability of time dependant performance variations. This requires that an optical line pair pattern is run to verify the MTF and that the optical density step wedge or contrast sensitivity gage (SE 1647) be exposed to determine the contrast sensitivity. If the system

would display 10 line pairs per mm and 2% contrast sensitivity this would be stated as 2%-0.10 mm sensitivity. This also equates to a pixel size of .05 mm. The dynamic range is defined by one manufacturer as the wall thickness range where the thinner wall thickness is measured at 80% of the maximum gray value of the detector and the thicker wall thickness by a contrast sensitivity of 2%. This percentage value may be 1% or as defined by the user requirements.

ASME Section V requires the dynamic range be determined by measuring the density strip on the Target in Figure VI-A-1 and measure the last visible step at each end of the step wedge. It shall be measured to the nearest 0.50 optical density.

6.4 Training

ASME Section V Article 2 Appendix VI requires that Level II and Level III have an additional 40 hours of classroom training in the use of digital image processing and one month experience in addition to the standard training requirements to reach the designation of level II radiographer. The training and experience must be recorded and maintained in the technicians certification file.

6.5 Summary

Digital radiography is relatively new and requires care and diligence in performing the required system performance checks. All parts of the system have the capability of degradation and must be monitored at all times. The image requirements must still display the same sensitivity requirements of film radiography such as 2-2T sensitivity. The images must be stored in a manner that the original image details cannot be changed or manipulated. If the original image is manipulated in any manner it must be saved in a different file name. Each user will possibly have different requirements and the system shall be selected on the user's needs such as sensitivity, field of view, and processing parameters.

Table 5-1 Half Value Layer (HVL) and Tenth Value Layer (TVL) Tables

HALF VALUE LAYER (HVL) AND TENTH VALUE LAYER (TVL) TABLES

ENERGY	LEAD		CONCRETE		STEEL	
	HVL (ins)	TVL (ins)	HVL (ins)	TVL (ins)	HVL (ins)	TVL (ins)
Xrays 50kV	0.003"	0.010"	0.355"	0.551"	0.019"	0.059"
Xrays 100kV	0.012"	0.040"	0.669"	2.126"	0.078"	0.216"
Xrays 150 kV	0.012"	0.040"	0.866"	2.756"	0.157"	0.512"
Xrays 200kV	0.018"	0.055"	1.023"	3.386"	0.236"	0.748"
Xrays 250kV	0.040"	0.126"	1.102"	3.543"	0.472"	1.417"
Xrays 300kV	0.059"	0.193"	1.181"	4.016"	0.590"	1.770"
rays Ir 192	0.216"	0.748"	1.692"	5.512"	0.510"	1.693"
rays Co60	0.433"	1.575"	2.480"	7.992"	0.787"	2.638"

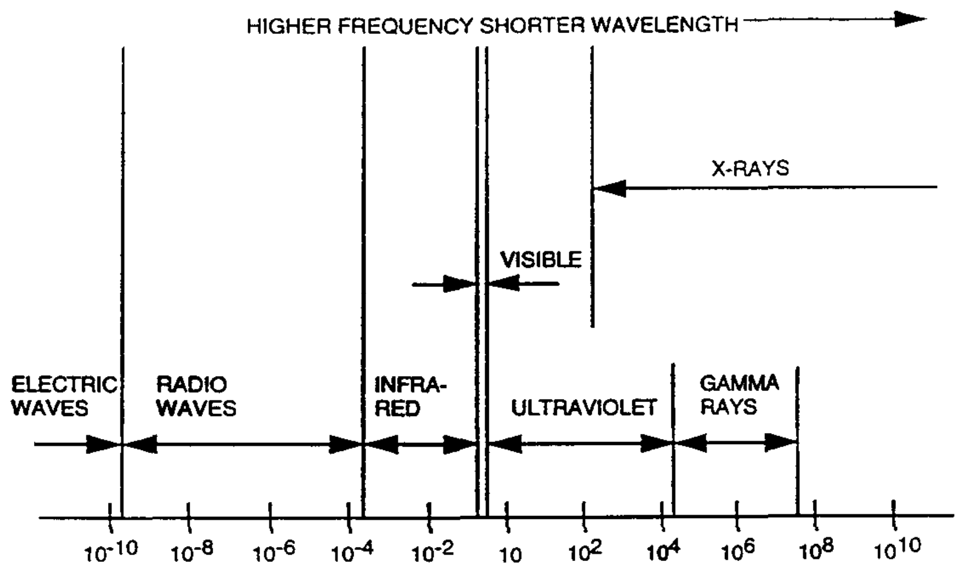


Figure 5-1 Electromagnetic Spectrum

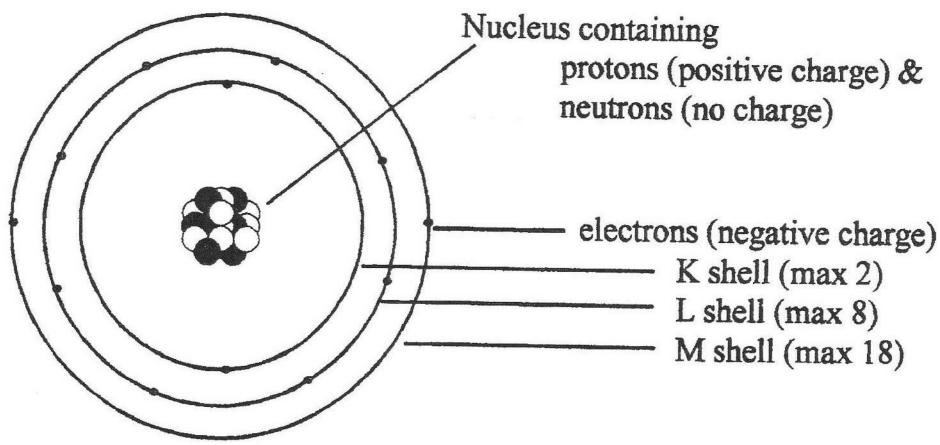


Figure 5-2 Structure of the Atom

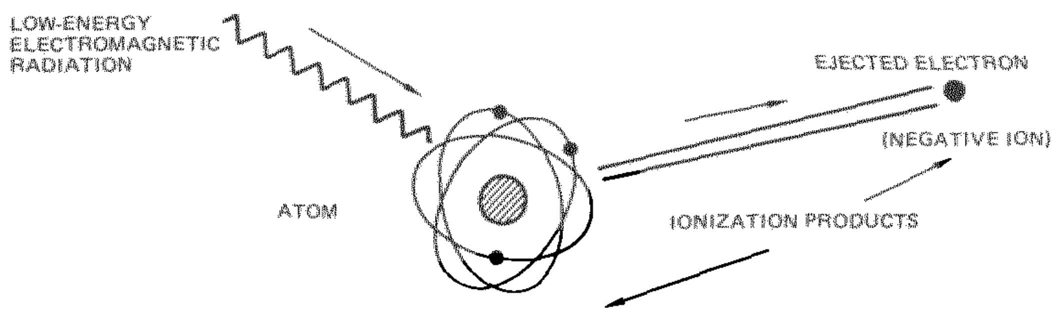


Figure 5-3 Photoelectric Effect

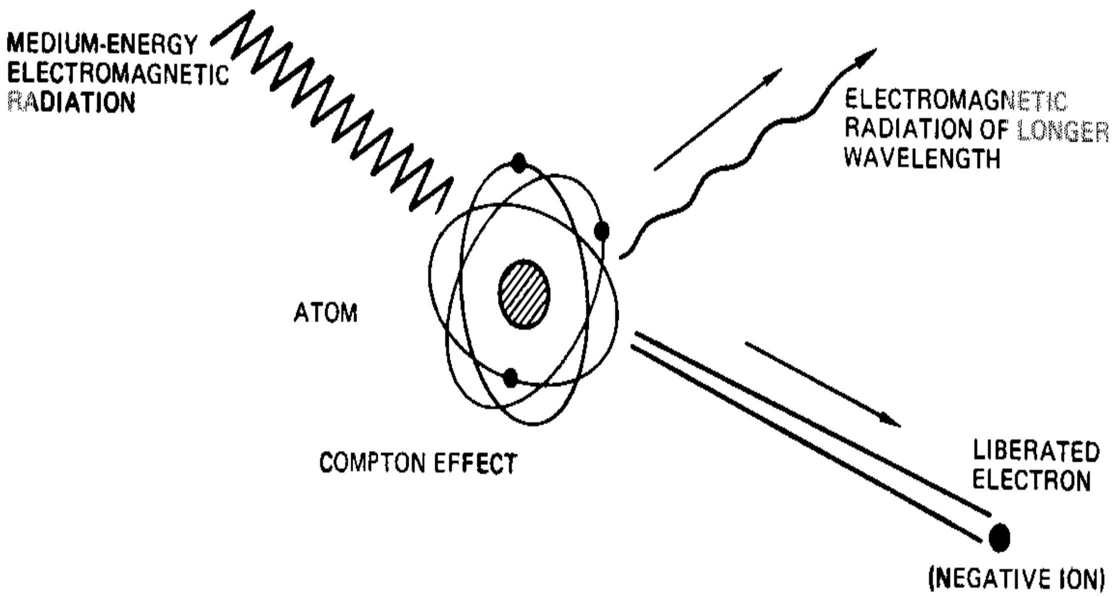


Figure 5-4 Compton Effect

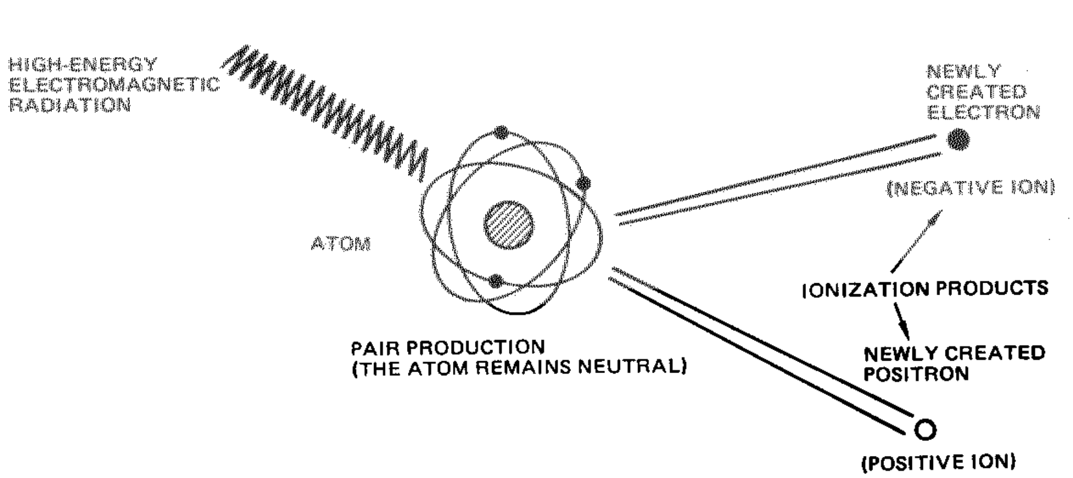


Figure 5-5 Pair Production

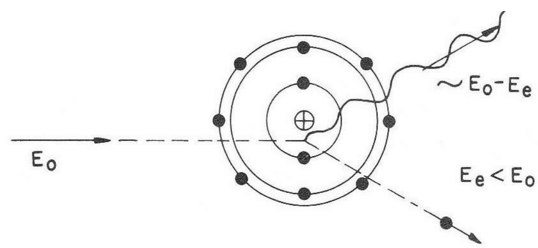


Figure 5-6 Bremsstrahlung (Braking) X-rays

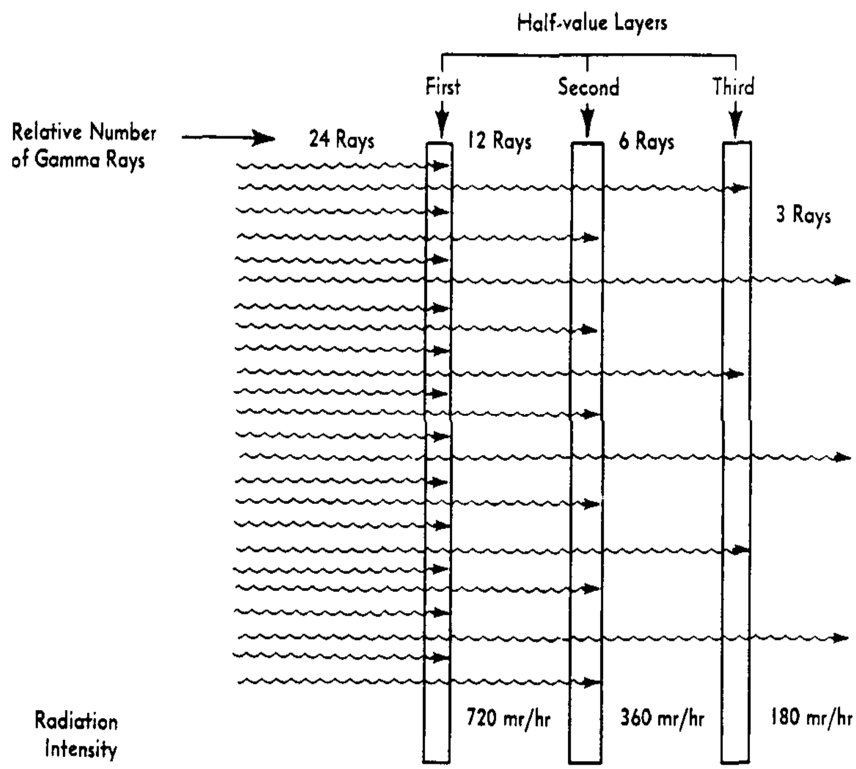


Figure 5-7 Half Value Layers

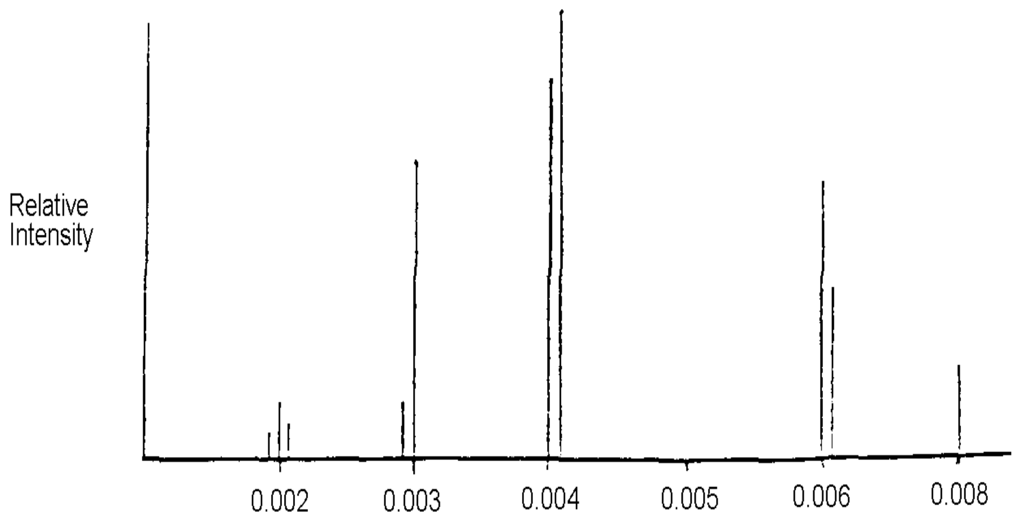


Figure 5-8 Energy Spectrum for Ir 192

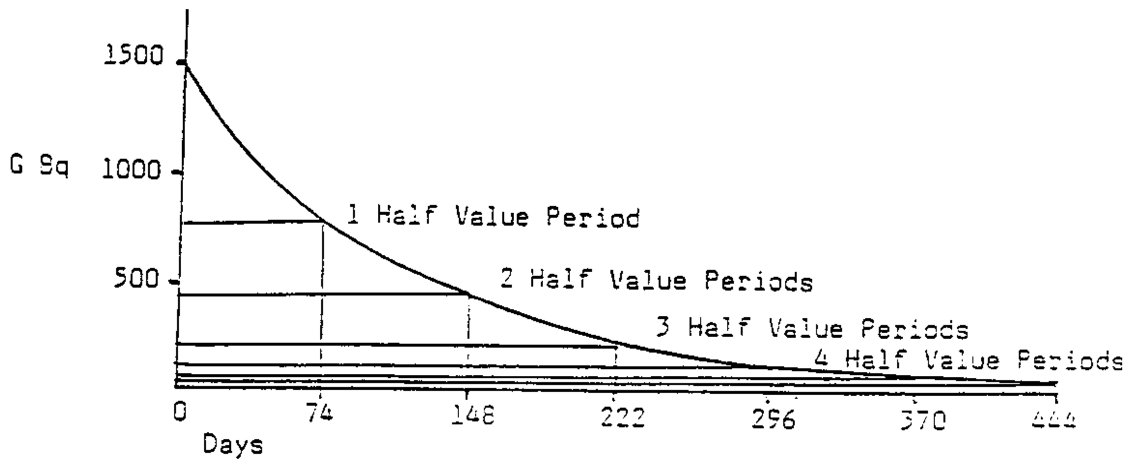


Figure 5-9 Ir 192 Decay Chart

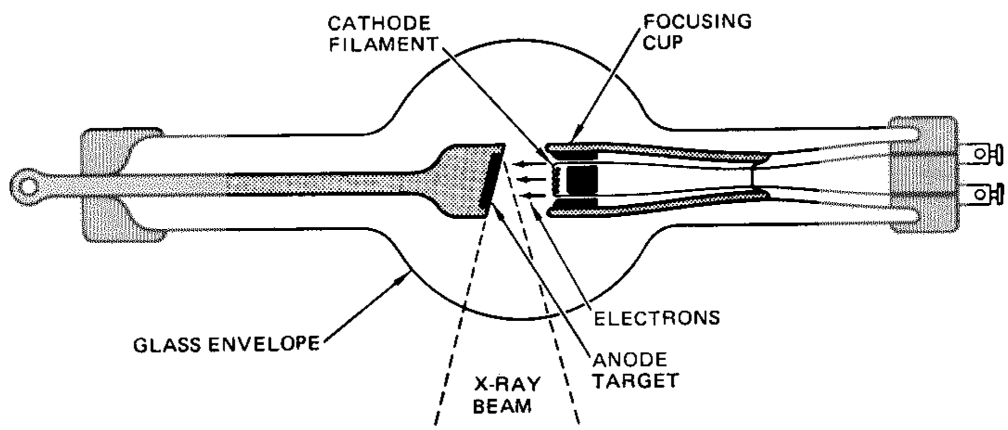


Figure 5-10 Typical X-ray Tube

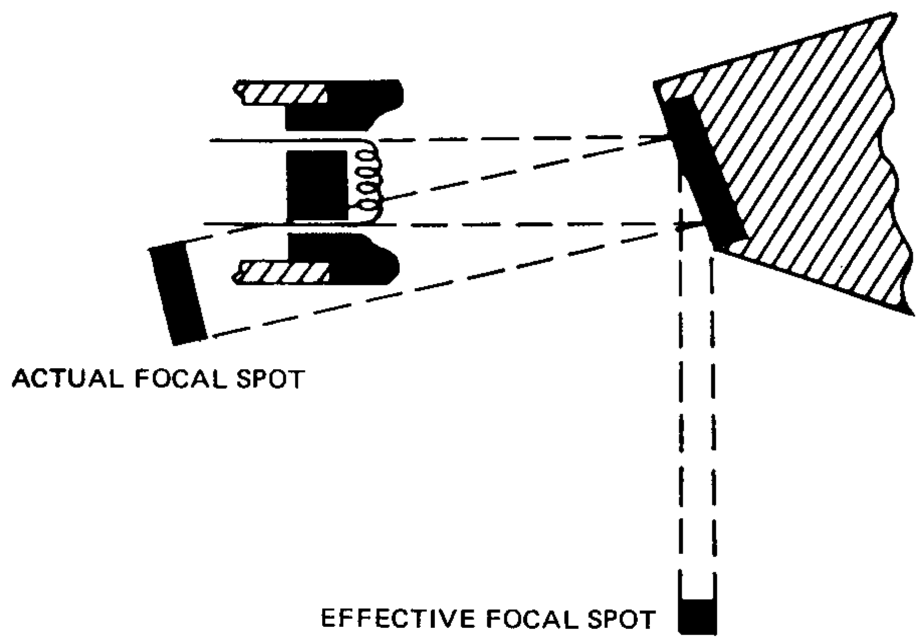


Figure 5-11 The Benson Focus Principle

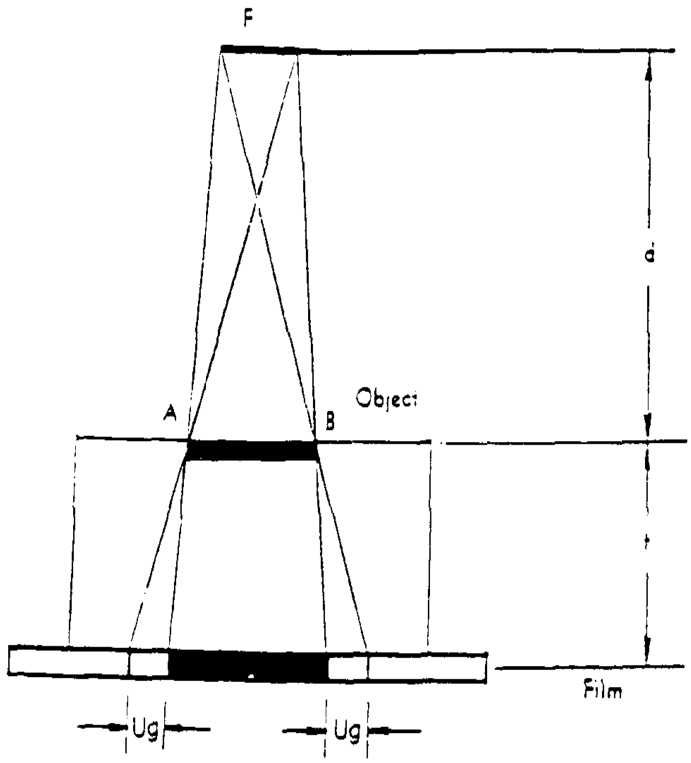


Figure 5-12 Effect of Source-to-Film Distance

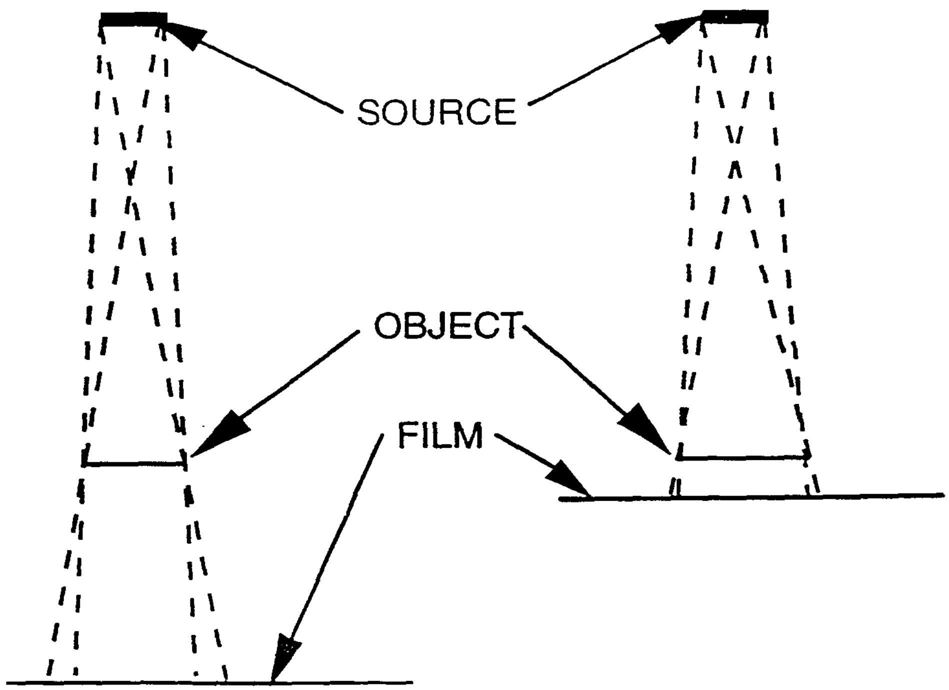


Figure 5-13 Effect of Object-to-Film Distance

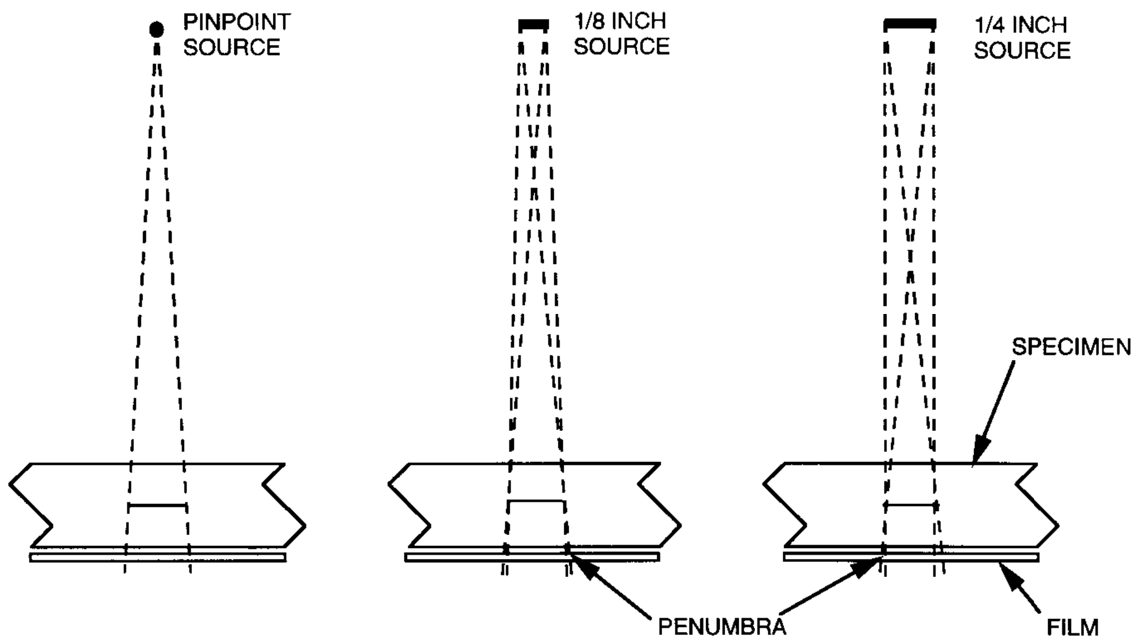


Figure 5-14 Effect of Source or Focal Spot Size

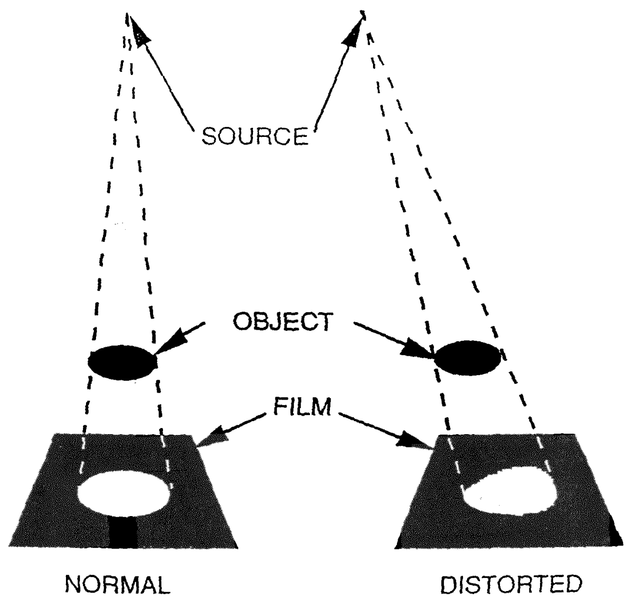


Figure 5-15 Effect of Source Location

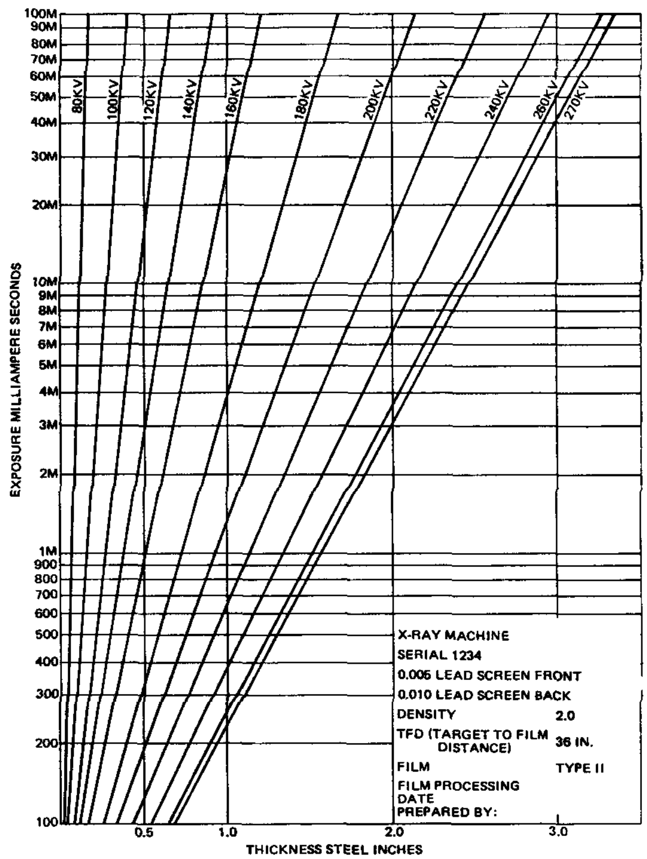


Figure 5-16 Exposure Chart

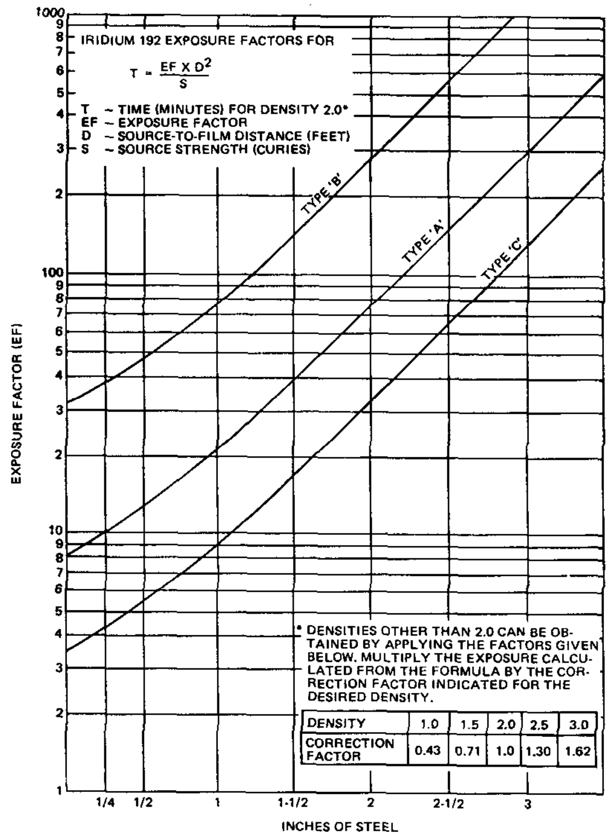


Figure 5-17 Exposure Chart for Iridium 192 Source

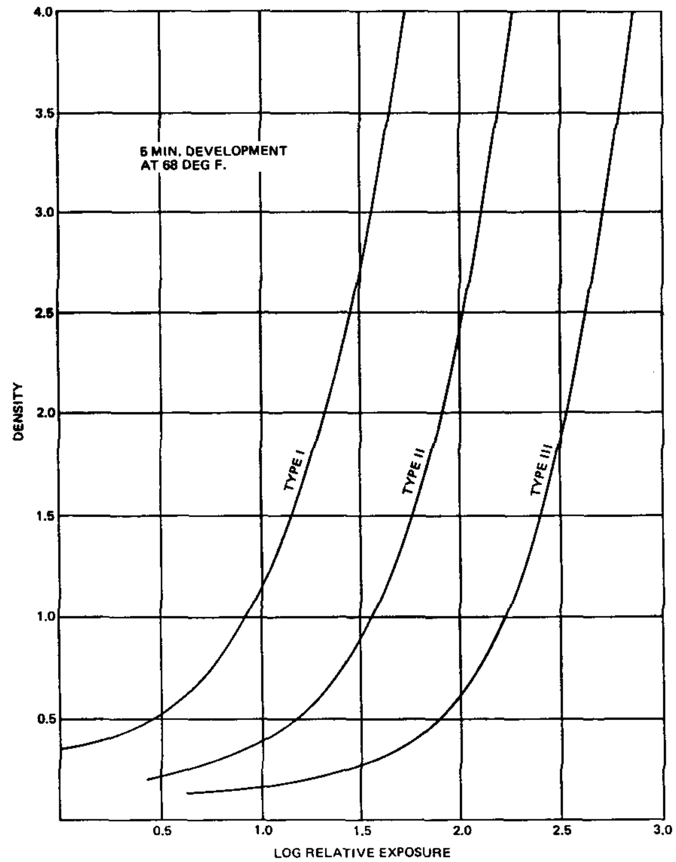


Figure 5-18 Characteristic Curves

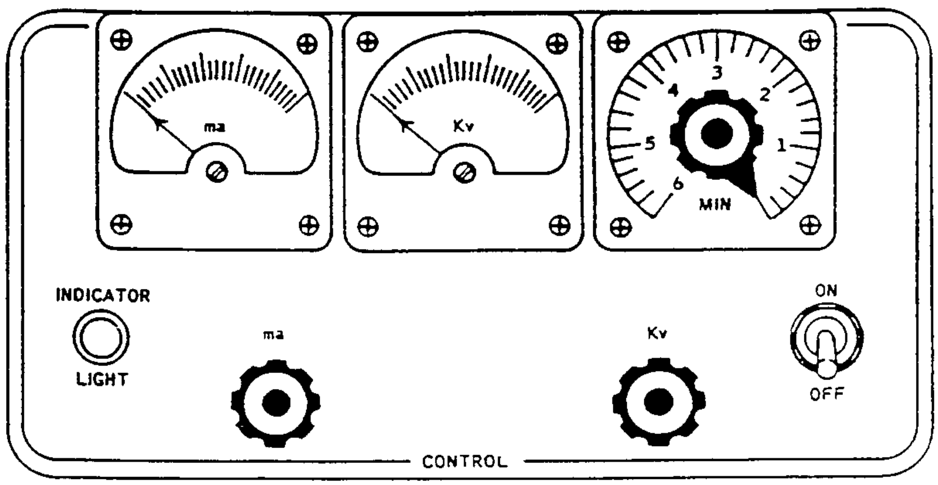


Figure 5-19 Typical X-ray Control Panel

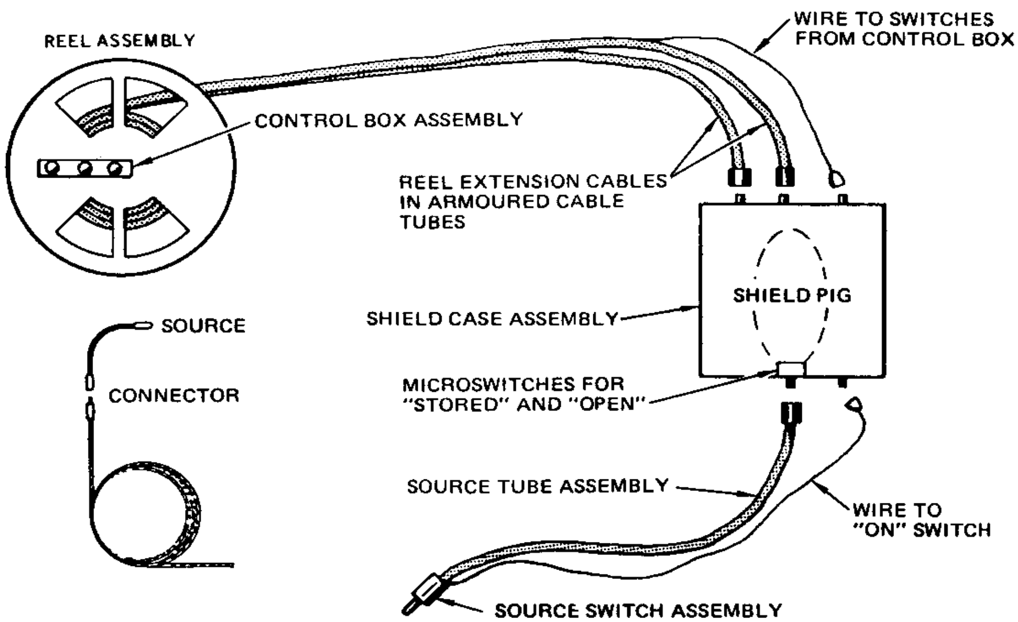


Figure 5-20 Typical Isotope Camera

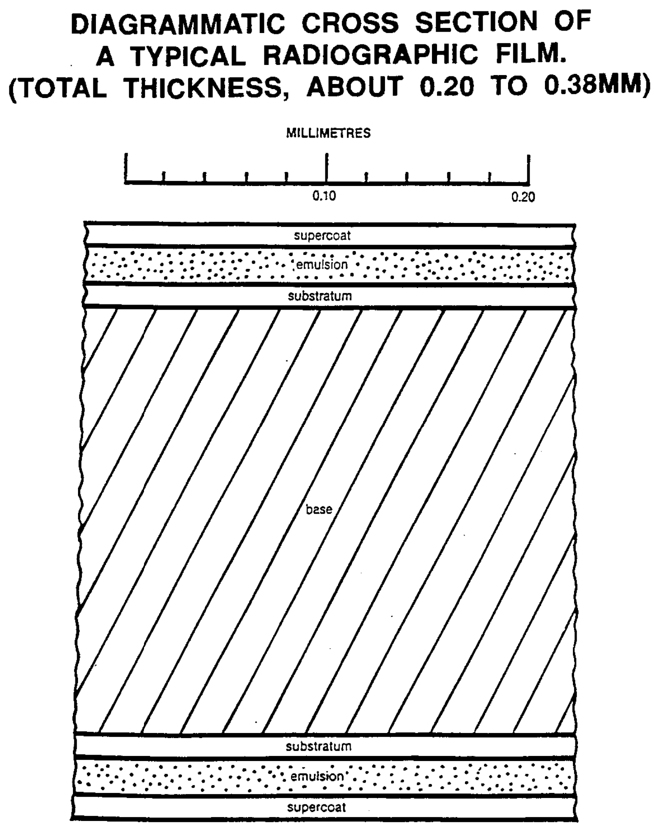


Figure 5-21 Film Structure

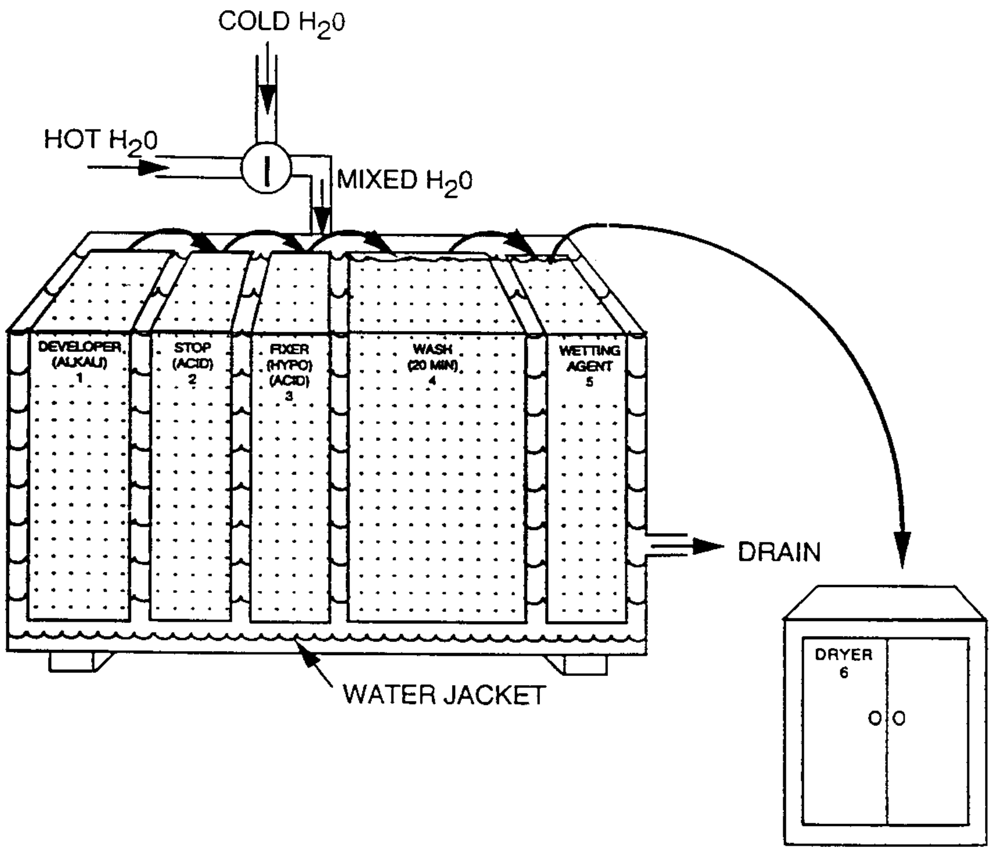


Figure 5-22 Manual Film Processing Steps

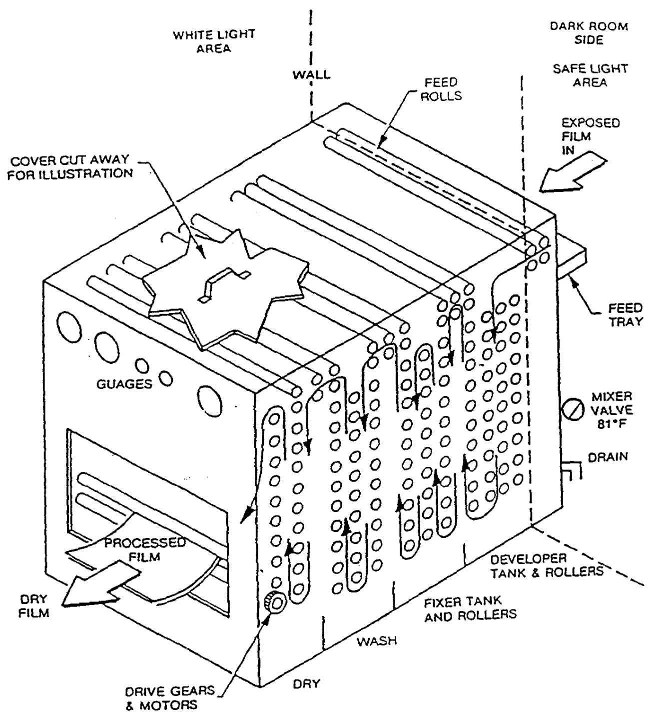


Figure 5-23 Automatic Processor

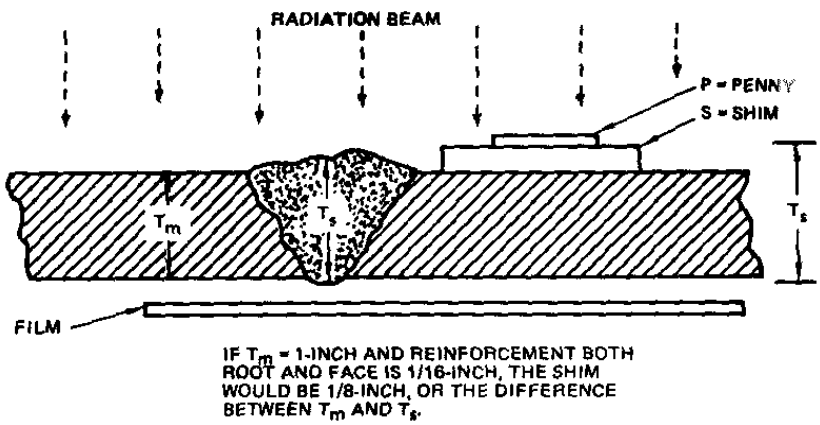


Figure 5-24 Single Wall Exposure/Single Wall Viewing

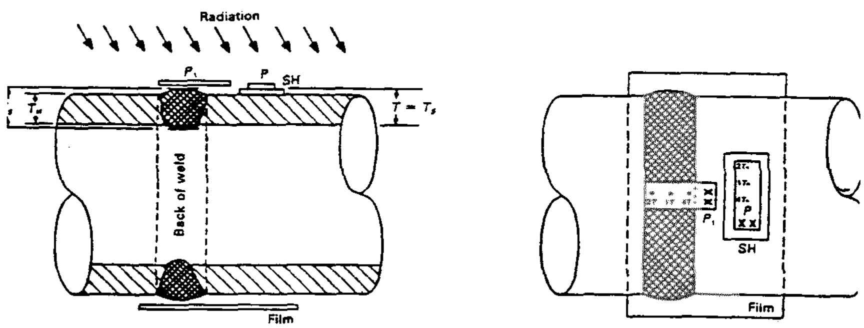


Figure 5-25 Double Wall Exposure/Double Wall Viewing

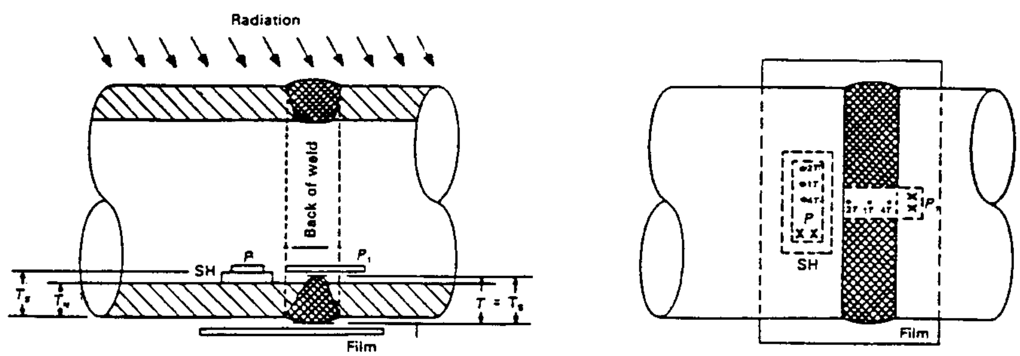


Figure 5-26 Double Wall Exposure/Single Wall Viewing

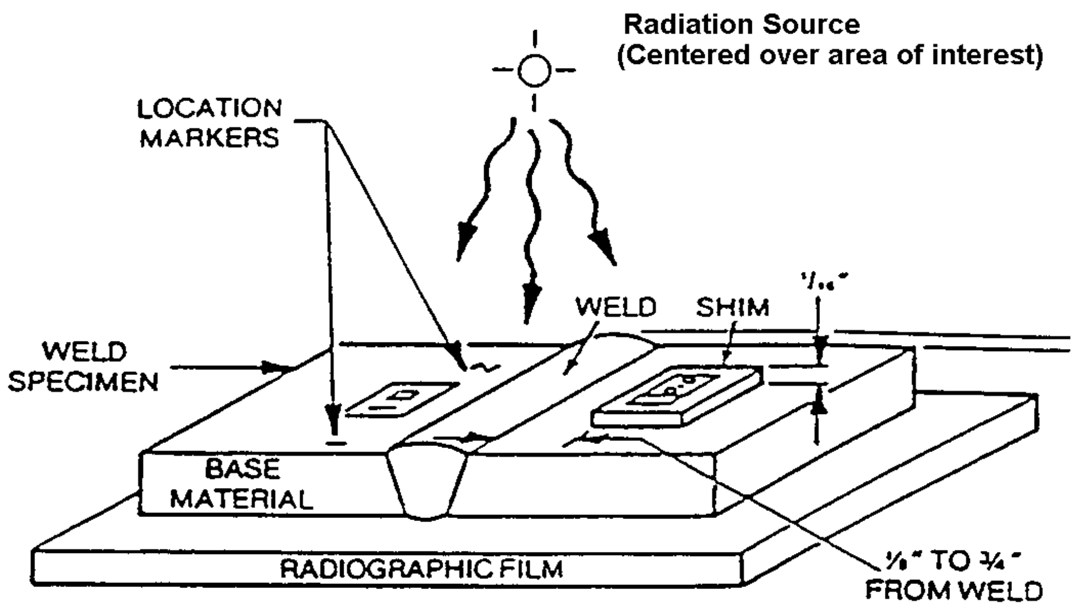
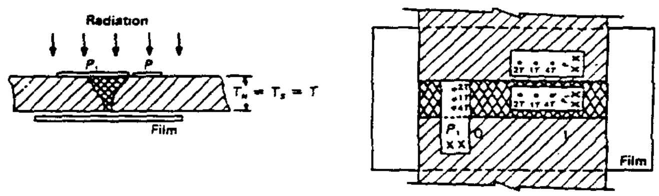
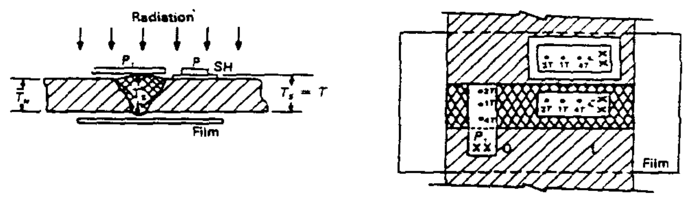


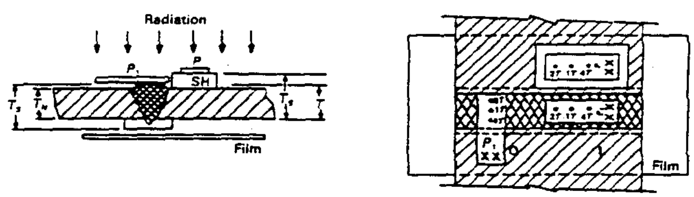
Figure 5-27 Use and Location of Shims



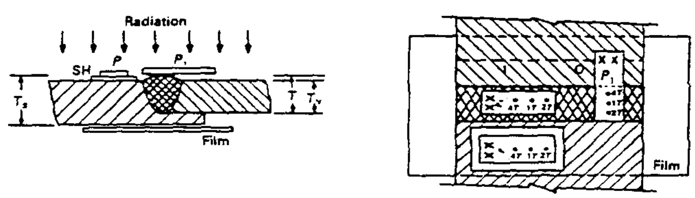
(a) Single Wall, No Reinforcement, No Back-Up Strip



(b) Single Wall, Weld Reinforcement, No Back-Up Strip



(c) Single Wall, Weld Reinforcement, Back-Up Strip



(d) Single Wall, Integral Backing Ring, Weld Reinforcement

Figure 5-28 Use and Location of Penetrameters (Example 1)

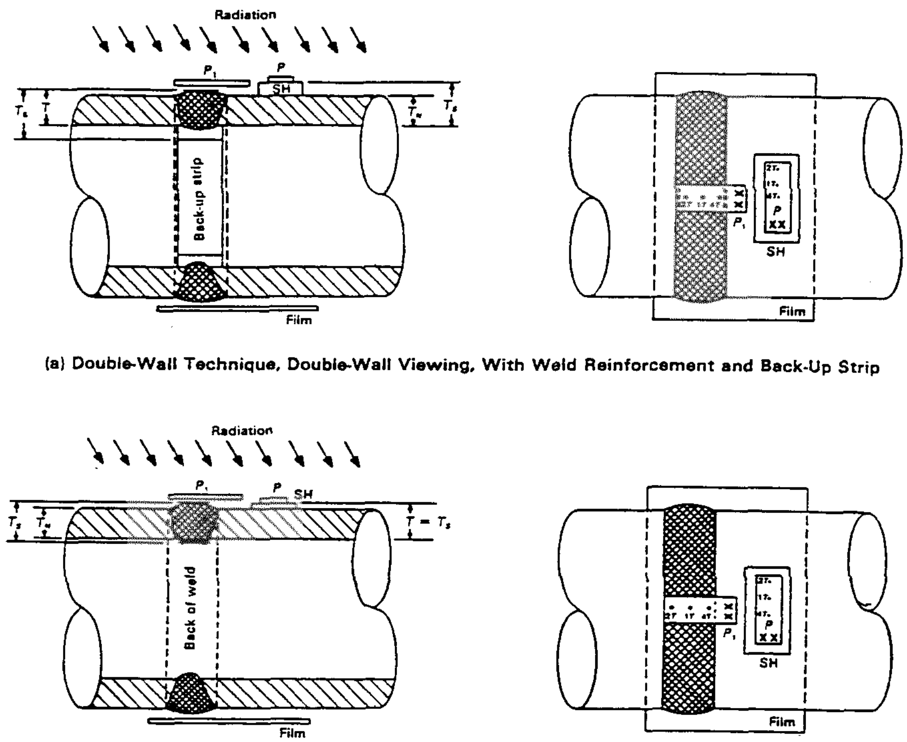
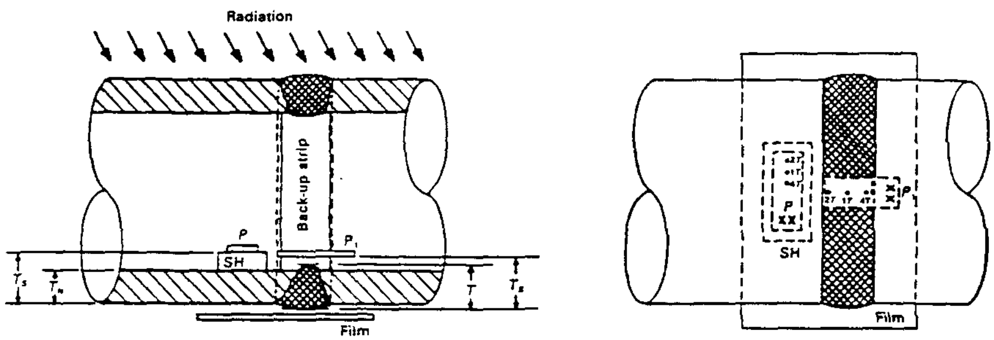


Figure 5-29 Use and Location of Penetrameters (Example 2)



(a) Double-Wall Technique, Single-Wall Viewing, Back-Up Strip

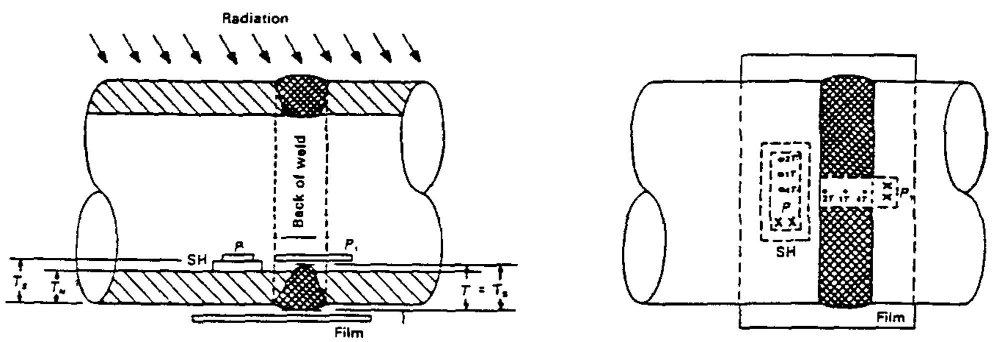
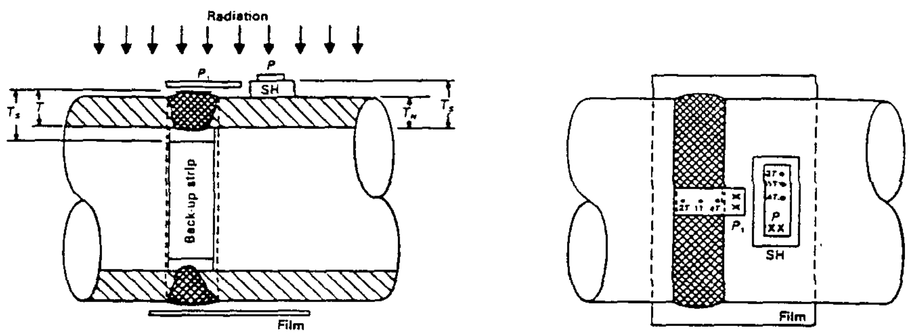


Figure 5-30 Use and Location of Penetrameters (Example 3)



(a) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and Back-Up Strip

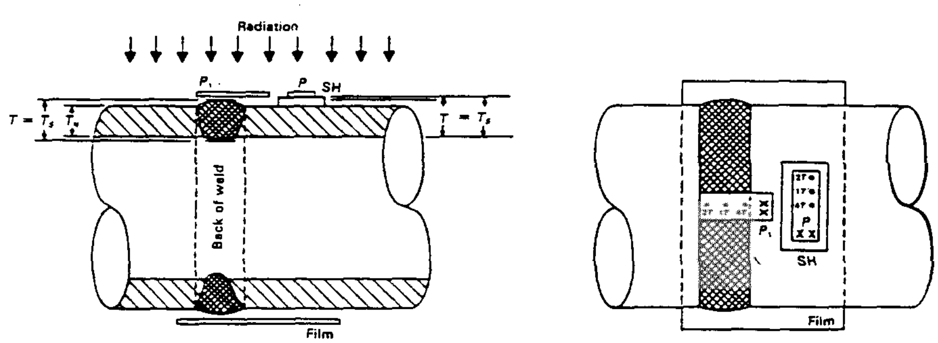


Figure 5-31 Use and Location of Penetrameters (Example 4)

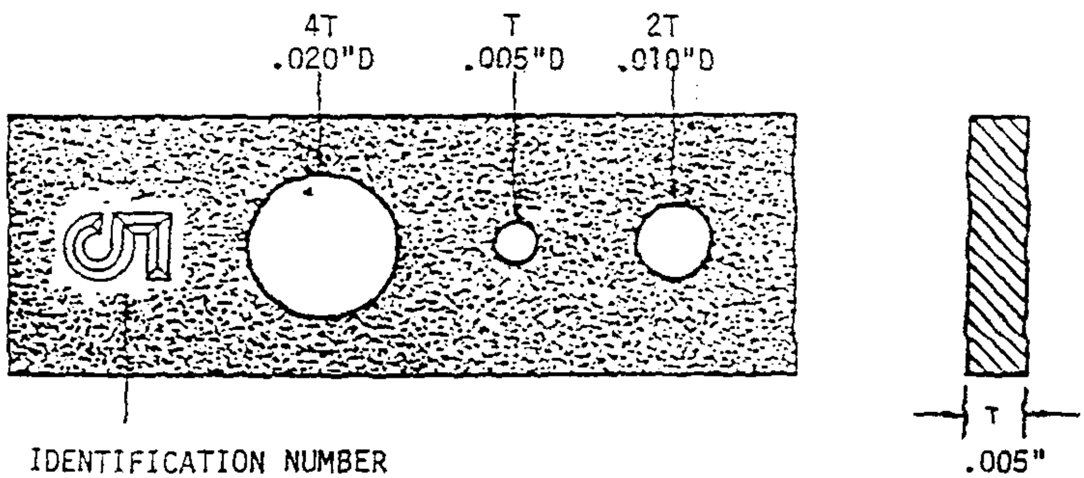

4T
.020"D
T
.005"D
2T
.010"D
IDENTIFICATION NUMBER
T
.005"

Figure 5-32 ASME/ASTM IQI

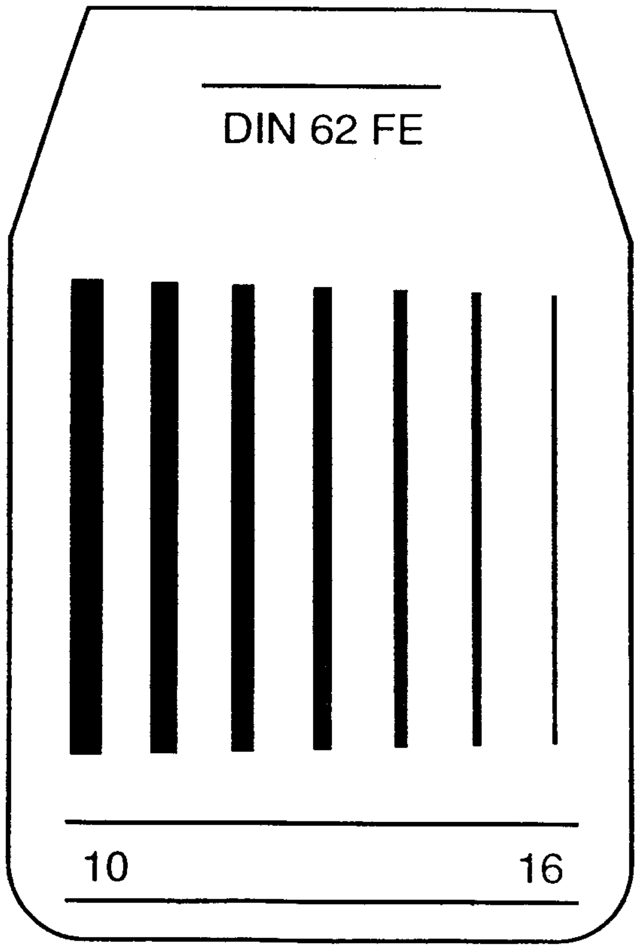


Figure 5-33 Wire Type IQI