NASA CR 61231

N68 28793

CLASSROOM TRAINING HANDBOOK - RADIOGRAPHIC TESTING

Prepared under Contract NAS 8-20185 by

Convair Division
General Dynamics Corporation
San Diego, Calif.

for George C. Marshall Space Flight Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

[redacted]

PREFACE

Classroom Training Handbook – Radiographic Testing (5330.19) is one of a series of training handbooks designed for use in the classroom and practical exercise portions of Nondestructive Testing. It is intended that this handbook be used in the instruction of those persons who have successfully completed Programmed Instruction Handbook – Radiographic Testing (5330.14, Vols. I – V). Radiography, Vols. I – V

Although formal classroom training is not scheduled at the present time, this handbook contains material that is beneficial to personnel engaged in Nondestructive Testing.

NASA's programs involve tightly scheduled procurement of only small quantities of space vehicles and ground support equipment, requiring the extreme in reliability for the first as well as later models. The failure of one article could result in mission failure. This requirement for complete reliability necessitates a thoroughly disciplined approach to Nondestructive Testing.

A major share of the responsibility for assuring such high levels of reliability lies with NASA, other Government agencies, and contractor Nondestructive Testing personnel. These are the people who conduct or monitor the tests that ultimately confirm or reject each piece of hardware before it is committed to its mission. There is no room for error -- no chance for reexamination. The decision must be right -- unquestionably -- the first time.

General technical questions concerning this publication should be referred to the George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory, Huntsville, Alabama 35812.

The recipient of this handbook is encouraged to submit recommendations for updating and comments for correction of errors in this initial compilation to George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory (R-QUAL-OT), Huntsville, Alabama 35812.

ACKNOWLEDGMENTS

This handbook was prepared by the Convair Division of General Dynamics Corporation under NASA Contract NAS8-20185. Assistance in the form of process data, technical reviews, and technical advice was provided by a great many companies and individuals. The following listing is an attempt to acknowledge this assistance and to express our gratitude for the high degree of interest exhibited by the firms, their representatives, and other individuals who, in many cases, gave considerable time and effort to the project.

Aerojet-General Corp.; Agfa-Geveart Co. of America, Inc.; Aircraft X-Ray Co.; Automation Industries, Inc., Sperry Products Division; Avco Corporation; Babcock & Wilcox Co.; Balto Electric Corp.; The Boeing Company; The Budd Co., Instruments Division; Douglas Aircraft Co., Inc.; E. I. DuPont De Nemours & Co., Inc.; Eastman Kodak Company, Radiography Markets Division; General Analine & Film Corp.; Grumman Aircraft; Lockheed Aircraft Corp.; The Martin Co. (Denver); McDonnell Aircraft Corp.; C. H. F. Muller Gmbh, Rontgenwerk; North American Aviation, Inc.; Phillips Electronic Instruments; Picker X-Ray Corp.; Professor Harry Richardson, L.S.U.; Rohr Corporation; Richard Seifert & Co. Rontgenwerk; Southern California Cancer Center; Southwest Research Institute; St. Louis Testing Laboratories, Inc.; Technical Operations, Inc.; Uresco, Inc.; X-Ray Products Corp.

[redacted]

CLASSROOM TRAINING HANDBOOK
RADIOGRAPHIC TESTING

CHAPTER 1: INTRODUCTION
TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

100 GENERAL

The complexity and expense of space programs dictate fabrication and inspection test procedures that insure reliability of space vehicles and associated ground equipment. Nondestructive testing (testing without destroying) provides many of these procedures. Radiography is one of the most effective methods of nondestructive testing, and it is with radiography that this handbook is concerned.

101 PURPOSE

The purpose of this handbook is to provide the fundamental knowledge of radiography required by quality assurance and test personnel to enable them to: ascertain that the proper test technique, or combination of techniques, is being used to assure the quality of the finished product; interpret, evaluate, and make a sound decision as to the results of any radiographic test; and recognize those areas of doubtful test results that require either retest or assistance in interpretation and evaluation.

102 DESCRIPTION OF CONTENTS

1. ARRANGEMENT

The material contained in this handbook is presented in a logical sequence and consists of:

a. Chapter 1: Introduction and testing philosophy.

b. Chapter 2: Radiographic principles, description of X- and gamma rays.

c. Chapter 3: Radiographic equipment, industrial X- and gamma ray equipment, gamma ray sources, and equipment description.

d. Chapter 4: Radiographic film, characteristics of film, film processing and required equipment.

e. Chapter 5: Safety considerations, X-ray, gamma ray, and electrical.

f. Chapter 6: Specialized applications, exposure calculations, physical arrangements of specimens and X- or gamma ray equipment, and a listing of possible causes of unsatisfactory radiographs.

g. Chapter 7: Comparison and selection of NDT processes.

2. LOCATORS

The first page of each chapter consists of a table of contents for the chapter. Major paragraphs, figures and tables are listed in each table of contents.

103 INDUSTRIAL APPLICATIONS OF RADIOGRAPHY

Because of the penetration and absorption capabilities of X- and gamma radiation, radiography is used to test a variety of non-metallic products, and metallic products such as welds, castings, forgings, and fabrications. Since it is capable of revealing discontinuities (variations in material composition, or density) in a variety of dissimilar materials, radiographic testing is one of the primary nondestructive test methods in use today.

104 BASIC RADIOGRAPHIC TESTING

Radiographic testing usually requires exposing film to X- or gamma rays that have penetrated a specimen, processing the exposed film, and interpreting the resultant radiograph. There are many variables in these procedures and successful completion of any test is dependent upon understanding and control of the variables. Details of the requirements for, and the variables concerned with, radiographic testing are discussed in this handbook.

105 ADVANTAGES AND LIMITATIONS OF RADIOGRAPHIC TESTING

1. ADVANTAGES

Some of the advantages of radiographic testing as a quality assurance procedure are as follows:

a. Can be used with most materials.

b. Provides a permanent visual image record of the test specimen on film when desired.

c. Reveals the internal nature of material.

d. Discloses fabrication errors and often indicates necessary corrective action.

e. Reveals structural discontinuities and assembly errors.

2. LIMITATIONS

There are both physical and economic limitations to the use of radiographic testing. Geometric exposure requirements make it impracticable to use radiographic testing on specimens of complex geometry. When proper orientation of radiation source, specimen, and film cannot be obtained, radiographic testing is of little use. Similarly, any specimen which does not lend itself readily to two-side accessibility cannot be inspected by this method. Since radiographs are patterned by material density differences in the specimen, they are of little value in detecting small discontinuities that are not parallel to the lines of radiation. Laminar type discontinuities are, therefore, often undetected by radiographic testing. If laminar type discontinuities are suspected in a specimen, the radiation source, the specimen, and the film must be oriented to present the greatest possible discontinuity density to the rays. The greatest dimension of the suspected discontinuity must be parallel to the radiation beam. Safety considerations imposed by X- and gamma ray use must also be considered as a limitation. Compliance with safety regulations, mandatory in radiographic testing, is time consuming and requires costly space utilization and construction practices. Radiographic testing is a relatively expensive means of nondestructive testing. It is most economical when it is used to inspect easily handled material of simple geometry with high rates of test. It becomes expensive when it is used to examine thick specimens that require equipment of high energy potential.

106 DESTRUCTIVE AND NONDESTRUCTIVE TESTING

1. GENERAL

Specimens tested by destructive test methods usually become bent, twisted, notched, chipped or broken during the testing, and are worthless for further use. Consequently, destructive testing can test only a certain portion of the articles fabricated and it must be assumed that the remainder are equal in quality to those tested. Nondestructive testing, however, determines the quality of a specimen without destroying it, permitting testing of all articles and materials that are to be used.

2. NONDESTRUCTIVE TEST METHODS

Five methods of nondestructive testing are currently in common use: magnetic particle; liquid penetrant; eddy current; ultrasonic; and radiographic. Each method has peculiar capabilities and limitations qualifying it for specific uses. In each instance of nondestructive test, it is necessary to analyze the test specimen and determine which test method will best obtain the desired results. In many instances more than one method may be required.

[redacted]

107 TESTING PHILOSOPHY

The basic reason for nondestructive testing (NDT) is to assure maximum reliability of the space vehicle. Since the vehicle and associated ground equipment are fabricated of many articles that are readily tested by radiography, it is the task of responsible personnel to determine whether radiographic test results insure the required reliability. To accomplish this task, standards have been set and test results must come up to these standards.

108 PERSONNEL

It is imperative that personnel responsible for radiographic testing be trained and highly qualified with a technical understanding of the test equipment, the item under test (specimen), and the test procedures. Quality assurance personnel must be equally qualified. To make optimum use of radiography, NDT personnel conducting tests must continually keep abreast of new developments. There is no substitute for knowledge.

109 TESTING CRITERIA

When required by appropriate documentation, every vehicle and support article must be tested using applicable Nondestructive Testing techniques. The criteria is part of a building block test philosophy which dictates that each item must be tested individually before it is required to perform in sub-assemblies which are in turn tested individually before they are required to perform in assemblies. Using this approach, unsatisfactory and faulty articles are discovered at the earliest possible time, resulting in higher system reliability and reduced cost.

110 TEST PROCEDURES

Approved procedures for radiographic testing are formulated from analysis of the test specimen, review of past history, experience on like or similar specimens, and information available concerning similar specimen defects. It is the responsibility of personnel conducting or checking a test to insure that test procedures are adequately performed, and that the test objective is accomplished. Procedures found to be incorrect or inadequate must be brought to the attention of responsible supervision for correction and incorporation into revised procedures.

111 TEST OBJECTIVE

1. The objective of radiographic nondestructive testing is to insure product reliability by providing a means of:

   a. Obtaining a visual image of the interior of materials.

   b. Disclosing the nature of material without impairing usefulness of the material.

[redacted]

c. Separating acceptable and unacceptable material in accordance with predetermined standards.

d. Evidencing errors in manufacturing processes.

e. Revealing structural discontinuities, mechanical failures, and assembly errors.

2. No test is successfully completed until an evaluation of the test results is made. Evaluation of test procedures and results requires understanding of the test objective.

112 SAFETY CONSIDERATIONS

Because radiation cannot be detected by any of the five senses, strict compliance with safety regulations is required. Radiographic NDT processes require the use of X- and gamma ray sources generating great amounts of radiation. Radiation can cause damage to, or destruction of, the cells of living tissue, so it is essential that personnel are adequately protected. Radiographic test and quality assurance personnel must be continually aware of the radiation hazard and cognizant of safety regulations. TAKE NO CHANCES.

[redacted]

CHAPTER 2: PRINCIPLES
TABLE OF CONTENTS

PRECEDING PAGE BLANK NOT FILMED. [redacted]

CHAPTER 2: PRINCIPLES

200 GENERAL

This chapter provides a general review of the radiant energy phenomena that permits the use of radiography in industry. Much of the material is basic and academic in nature, but an understanding of it is required of the radiographer.

201 PENETRATION AND DIFFERENTIAL ABSORPTION

X- and gamma rays possess the capability of penetrating materials, even those that are opaque to light. In passing through matter, some of these rays are absorbed. The amount of absorption at any point is dependent upon the thickness and density of the matter at that point; therefore, the intensity of the rays emerging from the matter varies. When this variation is detected and recorded, usually on film, a means of seeing within the material is available. Radiography consists of using the penetration and differential absorption characteristics of radiant energy to examine material for internal discontinuities. Figure 2-1 illustrates the absorption characteristics of radiation as used in the radiographic process. The specimen absorbs

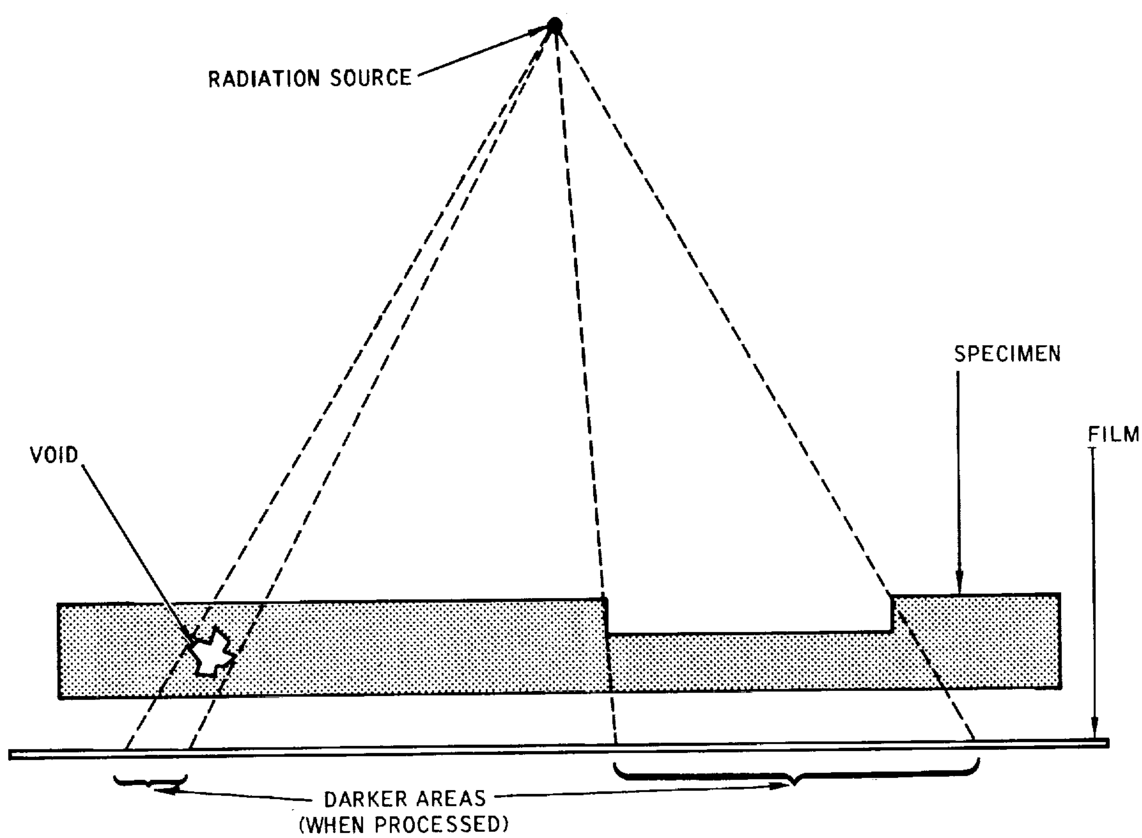


Figure 2-1. Basic Radiographic Process

[redacted]

radiation but, where it is thin or where there is a void, less absorption takes place. The latent image produced in the film, as the result of the radiation passing through the specimen, becomes a shadow picture of the specimen when the film is processed. Since more radiation passes through the specimen in the thin and void areas, the corresponding areas of the film are darker.

202 GEOMETRIC EXPOSURE PRINCIPLES

1. GENERAL

To produce a radiograph there must be a source of radiation, a specimen to be examined, and film. Figure 2-2 is a diagram of a radiographic exposure showing basic geometric relationships between the radiation source, the object under examination (specimen), and the film upon which the specimen image is recorded. These relationships are caused by X- and gamma rays obeying the laws of light. The enlargement of the image is caused by the film not being in contact with the specimen. The ratio of the specimen diameter (D_o) to the image diameter (D_f) is equal to the ratio of the source-to-specimen distance (d_o) to the source-to-film distance (d_f). For the radiographic image to be the same size as the specimen, the film is placed close to the specimen and the radiation source is placed as far from the film as is practical.

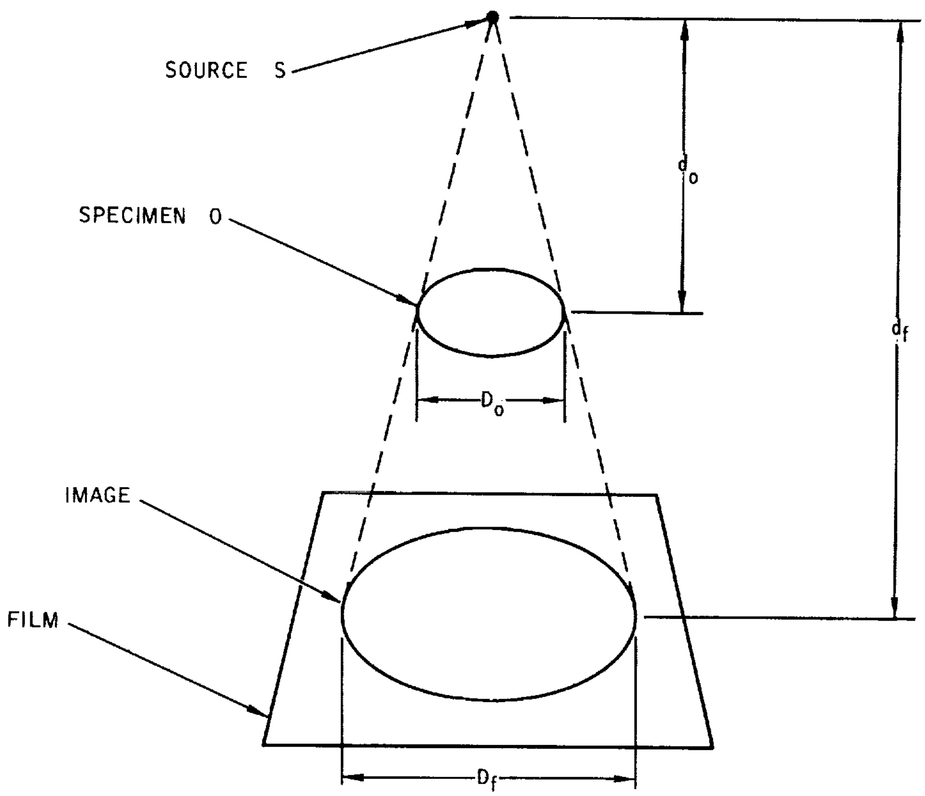


Figure 2-2. Image Enlargement

2. FILM IMAGE SHARPNESS

As shown in Figure 2-3, the sharpness of the film image is determined by the size of the radiation source and the ratio of the source-to-specimen distance and specimen-to-film distance. Diagram A shows a small geometrical unsharpness (penumbra) when

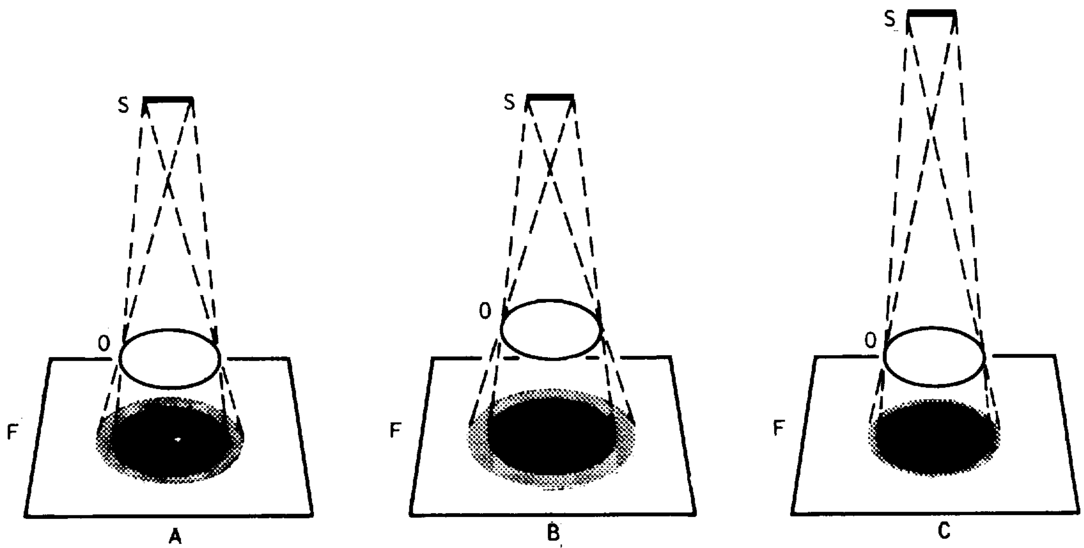


Figure 2-3. Image Sharpness, Penumbral Shadow

the specimen "O" is close to the film "F". Diagram B shows much greater geometrical unsharpness, when the source-to-film distance remains unchanged but the specimen-to-film distance is increased. Diagram C shows a much smaller geometrical unsharpness when the specimen-to-film distance is the same as in A but the source-to-film distance is increased. Optimum geometrial sharpness of the image is obtained when the radiation source is small, the distance from the source to the specimen is relatively great, and the distance from the specimen to the film is small. Figure 2-4 illustrates the decrease in geometrical unsharpness with a decrease in source size.

3. FILM IMAGE DISTORTION

Two possible causes of film image distortion are shown in Figure 2-5. If the plane of the specimen and the plane of the film are not parallel, image distortion will result, as it will if the radiation beam is not directed perpendicular to the plane of the film. Whenever distortion of the film image is unavoidable, as a result of physical limitations, it must be remembered that all parts of the image are distorted; otherwise, an incorrect interpretation of the radiograph may be made.

[redacted]

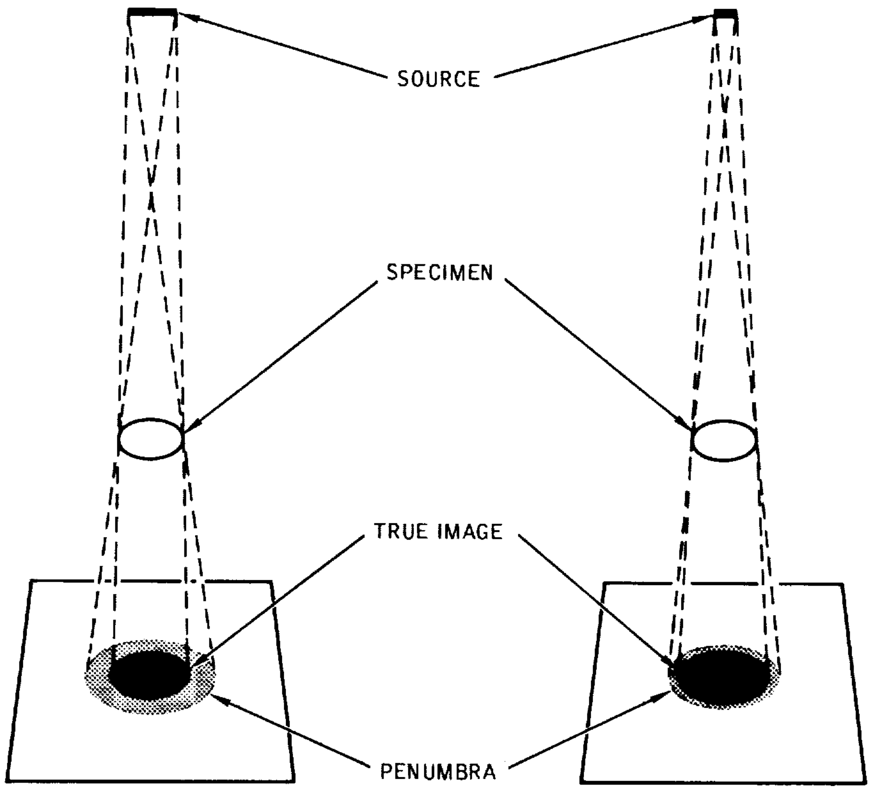


Figure 2-4. Effect of Source Size on Image Sharpness

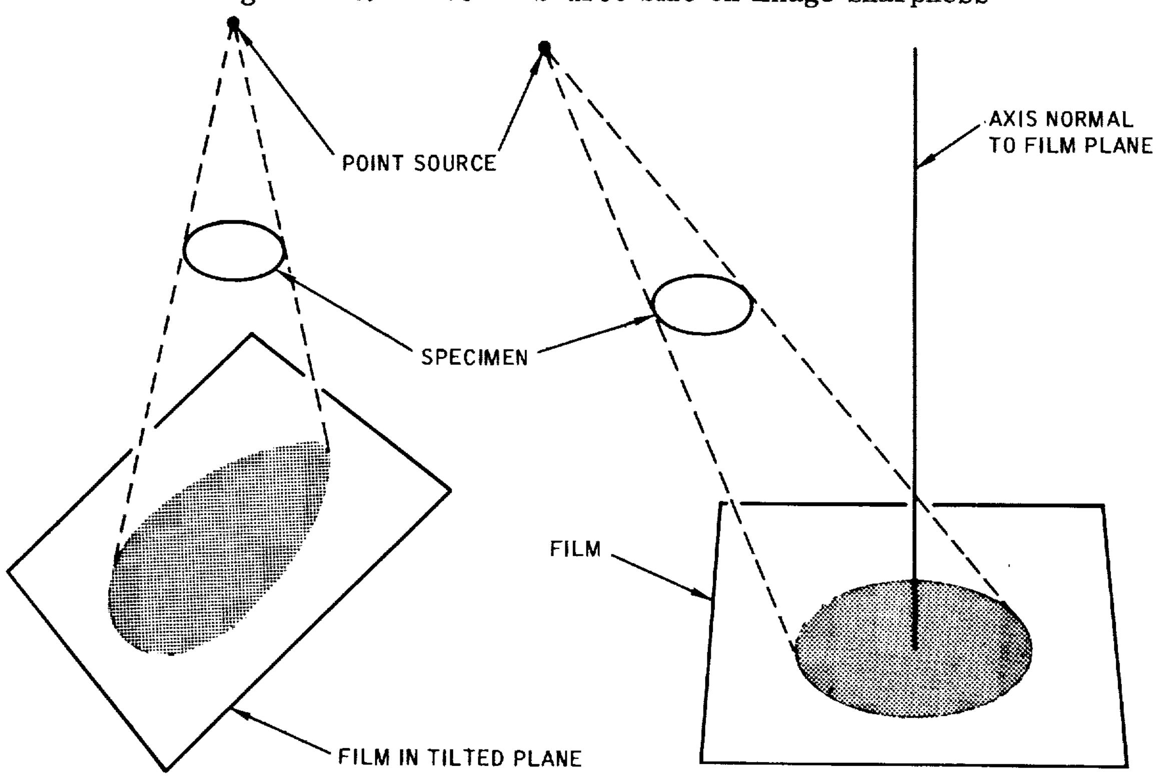


Figure 2-5. Image Distortion

203 X- AND GAMMA RADIATION

1. GENERAL

As shown in Figure 2-6, X- and gamma rays comprise the high energy, short wavelength portion of the electromagnetic wave spectrum. Throughout the spectrum, X- and gamma rays have the same characteristics, and X- and gamma rays of the same wavelength have identical properties.

2. RADIANT ENERGY CHARACTERISTICS

Radiographic nondestructive testing is based on the following characteristics of X- and gamma rays.

a. They are electromagnetic with energy indirectly proportional to their wavelength.

b. They have no electrical charge and no mass.

c. They travel in straight lines at the velocity of light.

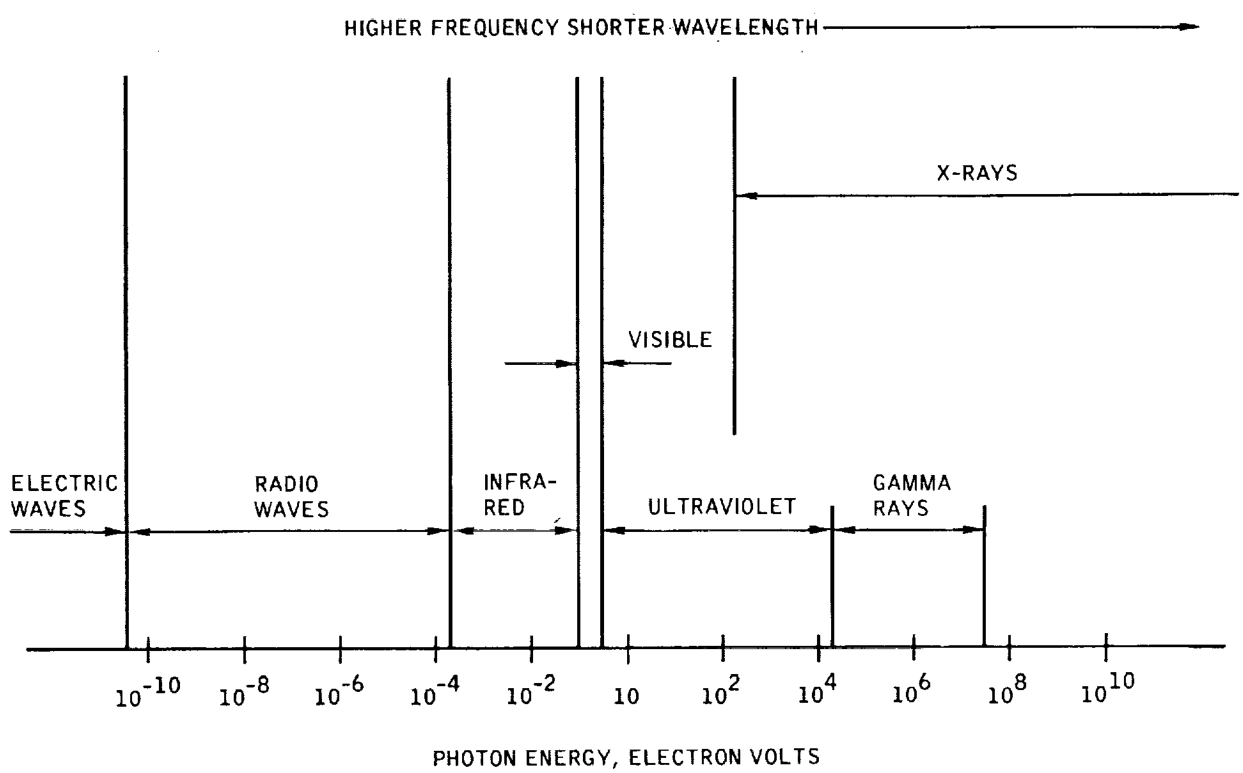


Figure 2-6. The Electromagnetic Spectrum

d. They can penetrate matter, the depth of penetration being dependent upon the energy of the rays.

e. They are absorbed by matter, the percentage of absorption being directly proportional to matter density and thickness, and indirectly proportional to ray energy.

f. They are scattered by matter, the amount of scatter being directly proportional to matter density, and indirectly proportional to ray energy.

g. They can ionize matter.

h. They can expose film by ionization.

i. They can produce fluorescence in certain materials.

j. They are invisible and incapable of detection by any of the senses.

3. X-RAYS

X-rays and electromagnetic waves of lower energy are generated when rapidly moving (high-energy) electrons interact with matter. When an electron of sufficient energy interacts with an orbital electron of an atom, a characteristic X-ray may be generated. It is called characteristic because its energy is determined by the characteristic composition of the disturbed atom. When electrons of sufficient energy interact with the nuclei of atoms, bremsstrahlung (continuous X-rays) are generated. They are called continuous because their energy spectrum is continuous and is not entirely dependent upon the disturbed atoms' characteristics. To create the conditions required for the generation of X-rays, there must be a source of electrons, a target for the electrons to strike, and a means of speeding the electrons in the desired direction.

a. Electron Source. All matter is composed in part of negatively charged particles called electrons. When a suitable material is heated, some of its electrons become agitated and escape the material as free electrons. These free electrons will surround the material as an electron cloud. In an X-ray tube the source of electrons is known as the cathode. A coil of wire (the filament) is contained in the cathode and functions as the electron emitter. When a voltage is applied across the filament, the resultant current flow heats it to electron emission temperatures.

b. Electron Target. X-rays are generated whenever high velocity electrons collide with any form of matter, whether it be solid, liquid, or gas. Since the atomic number of an element indicates its density, the higher the atomic number of the chosen target material the greater the efficiency of X-ray generation. The greater the density of the material the greater the number of X-ray generating collisions. In practical applications of X-ray generation, a solid material of high atomic number, usually tungsten, is used for the target. In an X-ray tube, the target is a portion of the tube anode. (See Figure 2-7.)

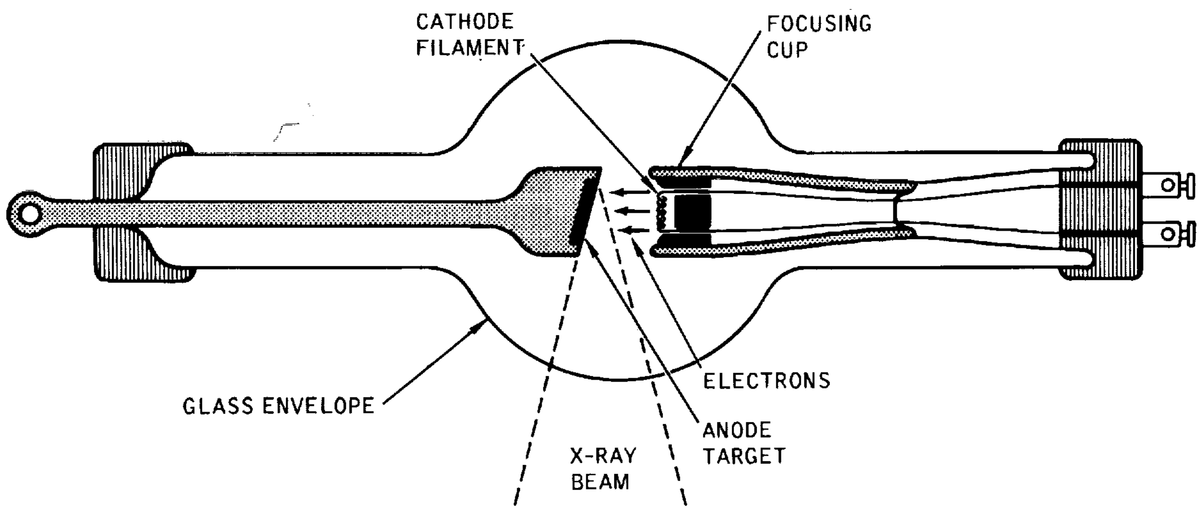


Figure 2-7. Basic X-Ray Tube

c. Electron Acceleration. The electrons emitted at the cathode of an X-ray tube are negatively charged. Following the fundamental laws of electrical behavior they are repelled by negatively charged objects and attracted to positively charged objects. By placing a positive charge on the anode of an X-ray tube, and a negative charge on the cathode, free electrons are speeded from the cathode to the anode. All X-ray tubes use this basic principle. X-ray tubes, and associated equipment and electrical circuits, are designed in many different forms determined by the need of repelling the electrons from the cathode, attracting them to the anode, and accelerating them in their path.

d. Intensity. The number of X-rays created by electrons striking the target is one measure of the "intensity" of the X-ray beam. Intensity is therefore dependent upon the amount of electrons available at the X-ray tube cathode. If all other factors remain constant, an increase in the current through the tube filament will increase the cathode temperature, cause emission of more electrons, and thereby increase the intensity of the X-ray beam. Similarly, though to a lesser degree, an increase in the positive voltage applied to the tube anode will increase the beam intensity because more of the electrons available at the cathode will be attracted to, and collide with, the target. Because the intensity of the generated beam is almost directly proportional to the flow of electrons through the tube, the output rating of an X-ray machine is often expressed in milliamperes of current flow. This same direct proportion establishes tube current as one of the exposure constants of an X-ray radiography.

e. Inverse Square Law. The intensity of an X-ray beam varies inversely with the square of the distance from the radiation source. X-rays, like visible light rays, diverge upon emission from their source and cover increasingly large areas as the distance from the source increases. This relationship, illustrated in Figure 2-8, is known as the Inverse Square Law. It is a major consideration in computing radiographic exposures and safety procedures. Mathematically the inverse square law is expressed as follows:

$$\frac{I_1}{I} = \frac{D^2}{D_1^{\,2}}$$

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

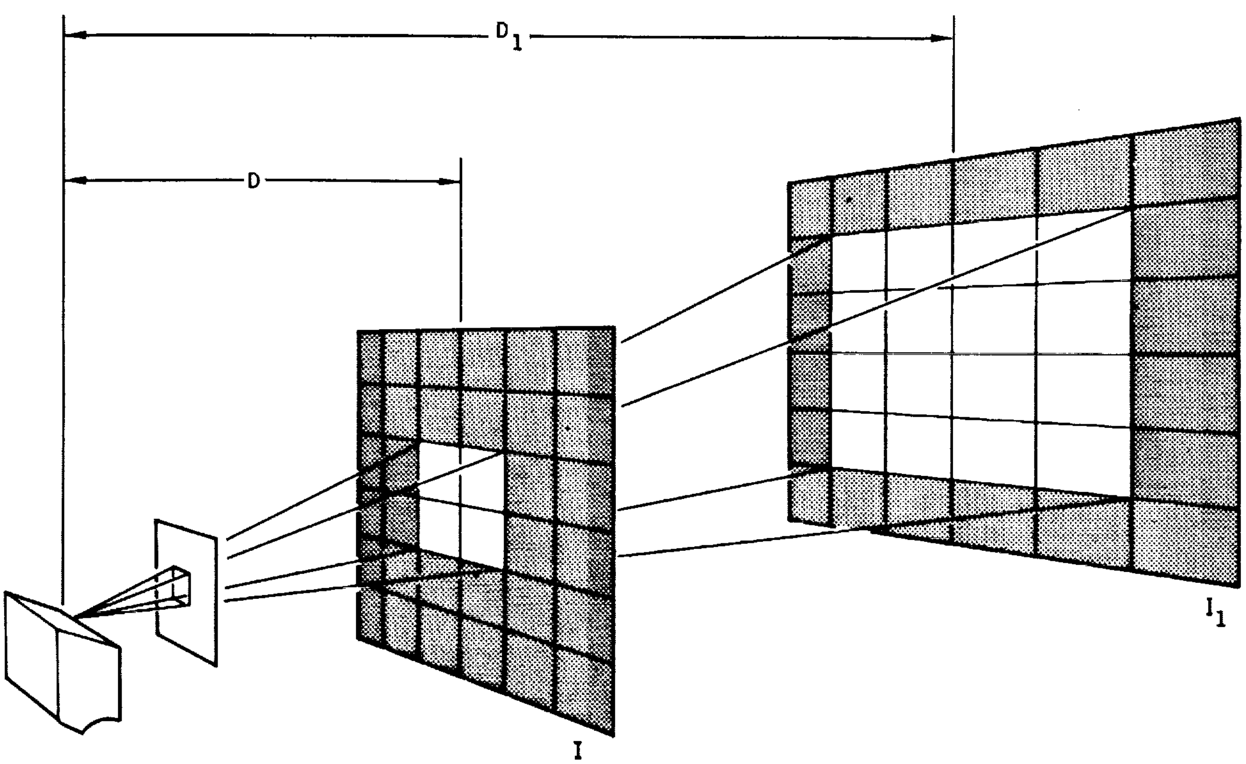


Figure 2-8. Diagram of the Inverse Square Law

f. X-ray Quality Characteristics. Radiation from an X-ray tube consists of the previously mentioned characteristic and continuous rays. The characteristic rays are of small energy content and specific wavelengths as determined by the target material. The spectrum of continuous rays covers a wide band of wavelengths and is of generally higher energy content. (See Figure 2-9.) The continuous rays are of most use in radiography. Since the wavelength

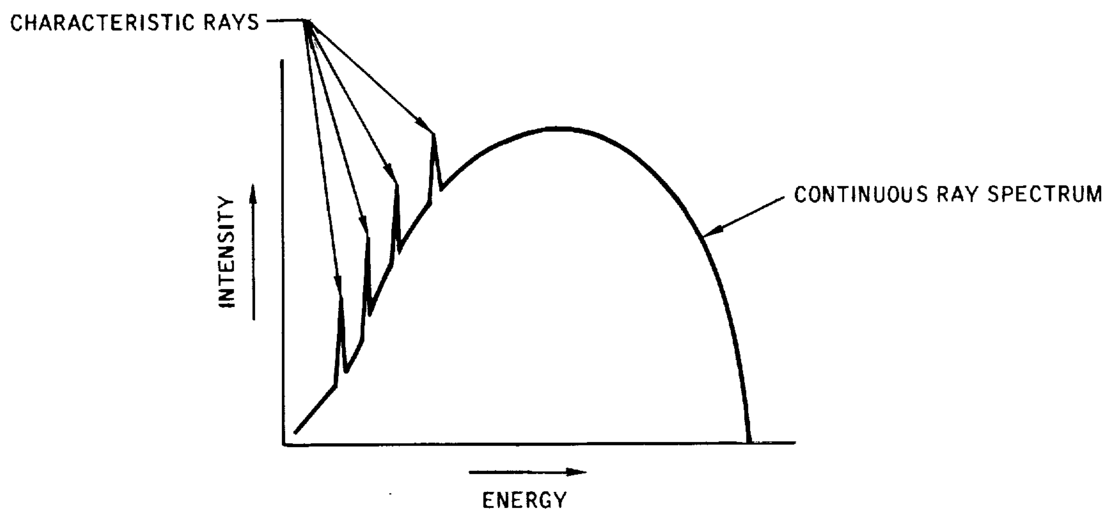


Figure 2-9. X-Ray Spectrum

of any one X-ray is partially determined by the energy (velocity) of the electron whose collision with the target caused the ray, an increase in applied voltage will produce X-rays of shorter wavelength (more energy). Figure 2-10 illustrates the effect of a change in applied voltage on the X-ray

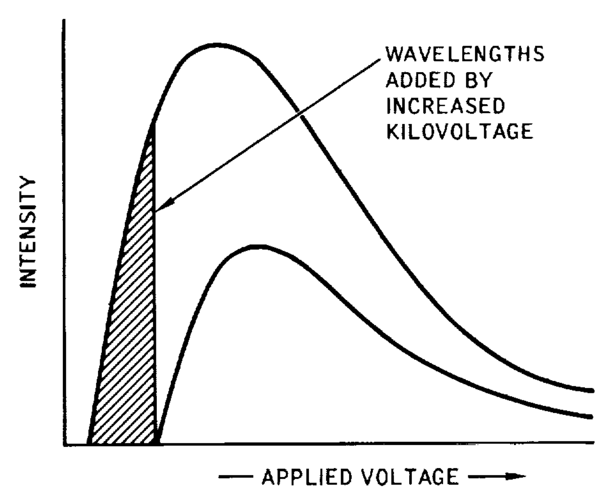


Figure 2-10. Effect of Increasing Voltage on the Quality and Intensity of an X-Ray Beam

beam. An increase in applied voltage increases the intensity (quantity of X-rays) as shown, but of more importance to the radiographer is the generation of the higher energy rays with greater penetrating power. High energy (short wavelength) X-rays are known as hard X-rays, and low energy (longer wavelength) X-rays are known as soft X-rays.

Figure 2-11 illustrates the effect of a change in tube current on an X-ray beam. Variation in tube current varies the intensity of the beam, but the

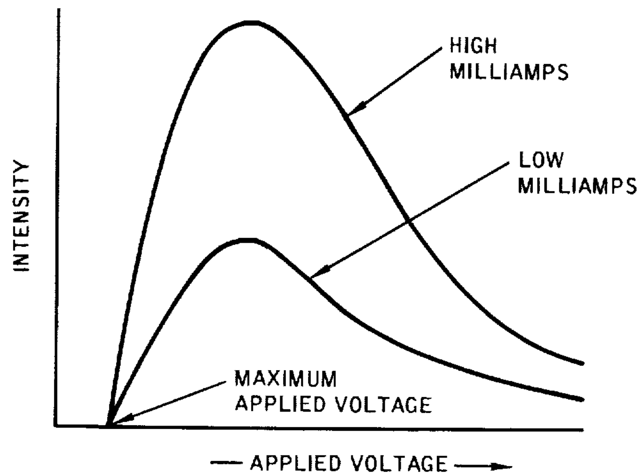


Figure 2-11. Effect of a Change in Tube Current on an X-Ray Beam

spectrum of wavelengths produced remains unchanged. Table 2-1 shows the intensity/hard/soft/ X-ray relationships to variations in tube current and applied voltage.

Table 2-1. Effects of KV and MA

	LOW MA	HIGH MA
LOW KV	LOW INTENSITY SOFT X-RAYS	HIGH INTENSITY SOFT X-RAYS
HIGH KV	LOW INTENSITY HARD X-RAYS	HIGH INTENSITY HARD X-RAYS

g. Interaction With Matter. To appreciate the interaction of X-rays with matter it is necessary to consider the properties of matter that make the interaction possible. Matter is composed of numerous tiny particles called atoms. Substances composed wholly of identical atoms are known as elements, and substances containing two or more elements are known as compounds. The atom, once considered to be the smallest particle of matter, is now considered to be composed of even tinier particles. The fundamental particles of interest in radiography are shown in Table 2-2.

Table 2-2. Fundamental Particles

PARTICLE	DESCRIPTION
PROTON	A PARTICLE CARRYING A UNIT POSITIVE ELECTRICAL CHARGE. ITS MASS IS APPROXIMATELY ONE ATOMIC MASS UNIT.
NEUTRON	A PARTICLE, ELECTRICALLY NEUTRAL, HAVING APPROXIMATELY THE SAME MASS AS THE PROTON.
ELECTRON	A PARTICLE CARRYING A UNIT NEGATIVE ELECTRICAL CHARGE. ITS MASS IS 1/1840 ATOMIC MASS UNIT.
POSITRON	A PARTICLE CARRYING A UNIT POSITIVE ELECTRICAL CHARGE AND HAVING THE SAME MASS AS AN ELECTRON.
THE ATOMIC MASS UNIT (AMU) IS 1/12 THE MASS OF THE CARBON-12 ATOM. IT IS AN ARBITRARILY CHOSEN UNIT.	

(1) Nuclear Atomic Concept. The nuclear atomic concept conceives the atom as consisting of a small relatively heavy nucleus (protons and neutrons) about which electrons revolve in orbit. The volume of that portion of an atom outside the nucleus is very large compared to the volume of the nucleus, or of the electrons; therefore, the greatest part of any atom is empty space. The difference in atoms of different elements is the number of protons and neutrons in the nucleus, the number of electrons in the orbital shells, and the difference in weight. Electrically, the atom is normally in balance, the number of protons in the nucleus being equal to the number of electrons in orbit.

(2) Ionization. Any action which disrupts the electrical balance of an atom and produces ions is termed ionization, . Atoms and free (not part of any atom) subatomic particles, with either a positive or negative charge, are called ions. Free electrons are negative ions and free particles carrying positive charges (e.g. protons) are positive ions. X-rays passing through matter will alter the electrical balance of atoms through ionization. The energy of the ray may dislodge an

[redacted]

electron from an atom and the temporarily free electron attach itself to another atom. The first atom positively charged, and the second atom negatively charged are respectively positive and negative ions, an ion pair. In this manner X-rays cause ionization in all material in their path. X-rays have no mass or weight and may be considered as photons (bundles of energy) traveling an electromagnetic path at at the speed of light. In passing through matter, X-rays lose energy to atoms by ionization processes known as photoelectric absorption, Compton scattering and pair production.

(3) Photoelectric Absorption (Figure 2-12). When X-rays (photons) of relatively low energy pass through matter, the photon energy may be transferred to an orbital electron. This phenomena is known as photoelectric effect or absorption. Part of the energy is expended in ejecting the electron from its orbit and the remainder imparts velocity to the electron. This energy transfer is the photoelectric effect and usually takes place with low energy photons of 0.5 mev. or less. The photoelectric process absorbs all of the energy of the photon. It is this absorption effect that makes radiography possible.

(4) Compton Scattering (Figure 2-12). When higher energy photons, 0.1 to 3.0 mev., pass through matter, Compton scattering occurs. This is the term for the interaction of the photon with orbital electrons when all of the photon energy is not lost to an electron. Part of the photon energy is expended in dislodging an orbital electron and imparting velocity to it, and the remainder, as a lower energy photon, continues onward at an angle to the original photon path. This process, progressively weakening the photon, is repeated until photoelectric effect completely absorbs the photon.

(5) Pair Production. Pair production occurs only with very high energy photons of 1.02 mev. or more. At these energy levels when the photon approaches the nucleus of an atom it changes from energy to an electron-positron pair. Positrons carry a positive charge, have the same mass as electrons, and are extremely short lived. They combine at the end of their path with electrons to emit two 0.51 mev photons subject to Compton scattering and photoelectric effect.

(6) Scatter Radiation. The three processes, photoelectric absorption, Compton scattering, and pair production, all liberate electrons that move with different velocities in various direction. Since X-rays are generated whenever free electrons collide with matter, it follows that X-rays in passing through matter cause the generation of secondary

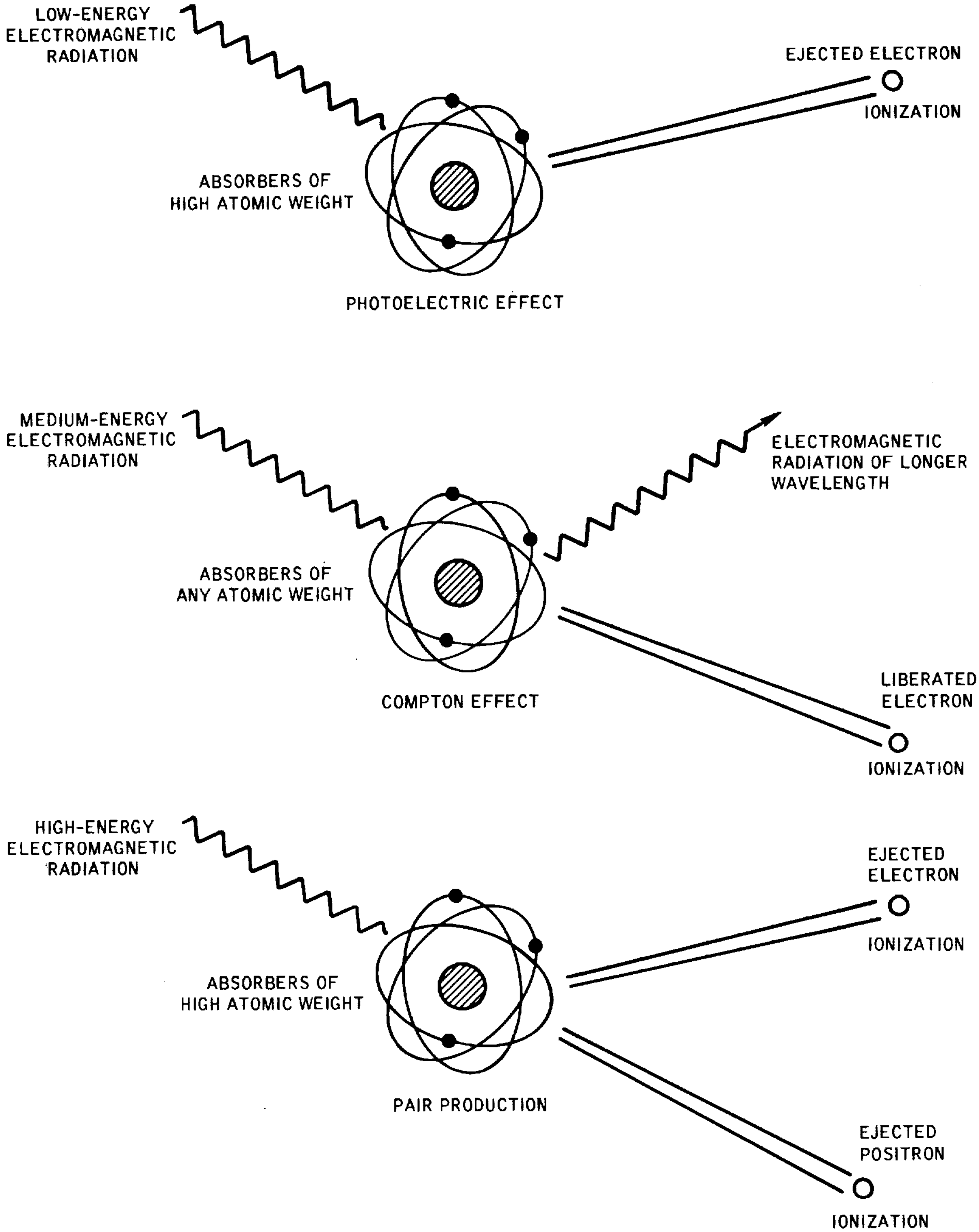


Figure 2-12. Ionization by Electromagnetic Radiation

X-rays. These secondary X-rays are a minor component of what is known as scatter radiation, or scatter. The major component of scatter is the low-energy rays represented by photons weakened in the Compton scatter process. Scatter radiation is of uniformly low-level-energy content and of random direction.

(a) Internal Scatter. Internal scatter is the scattering that occurs in the specimen being radiographed (Figure 2-13). It is reasonably uniform throughout a specimen of one thickness, but

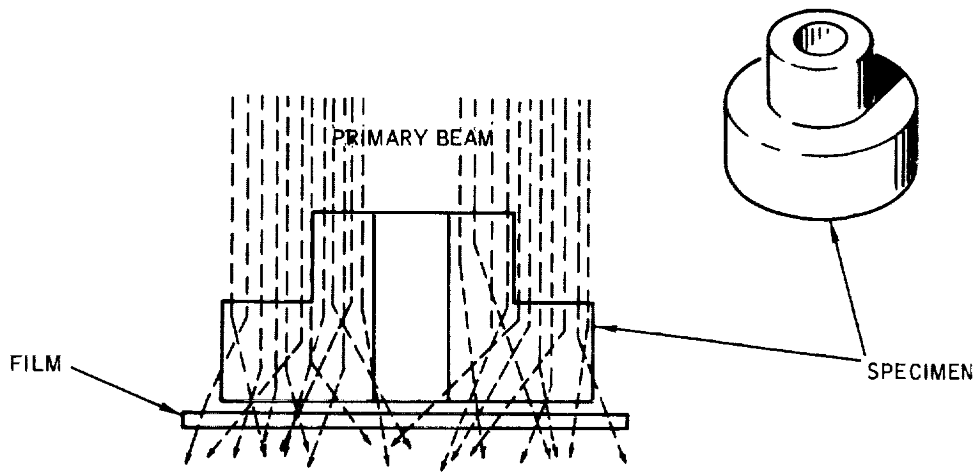


Figure 2-13. Internal Scatter

affects definition by blurring the image outline. The scatter radiation shown in Figure 2-13 obscures the edges of the specimen and the hole through it. The increase in radiation passing through matter due to scatter in the forward direction is known as buildup.

(b) Side Scatter. Side scatter is the scattering from walls, or objects in the vicinity of the specimen, or from portions of the specimen, that causes rays to enter the sides of the specimen (Figure 2-14). As shown, side scatter obscures the image outline just as internal scatter does.

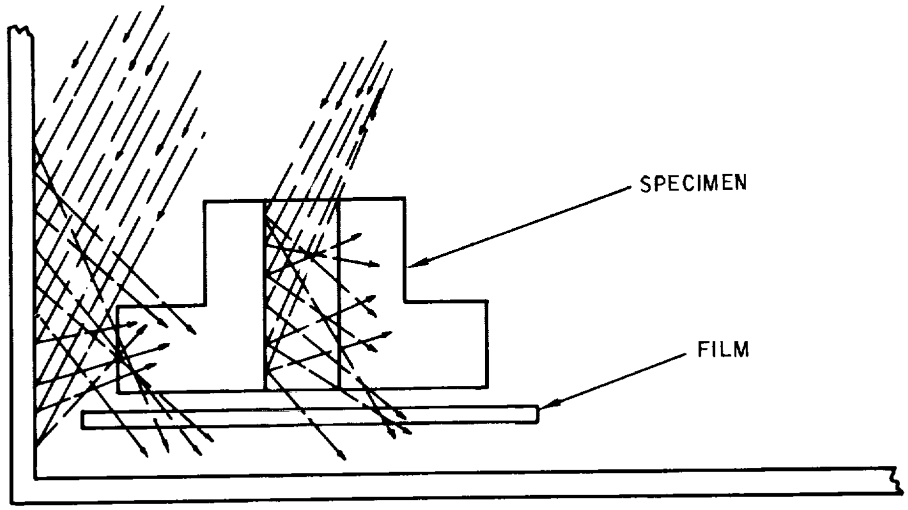


Figure 2-14. Side Scatter

(c) Back Scatter. Back scatter is the scattering of rays from surfaces or objects beneath or behind the specimen (Figure 2-15). Back scatter also obscures the specimen image.

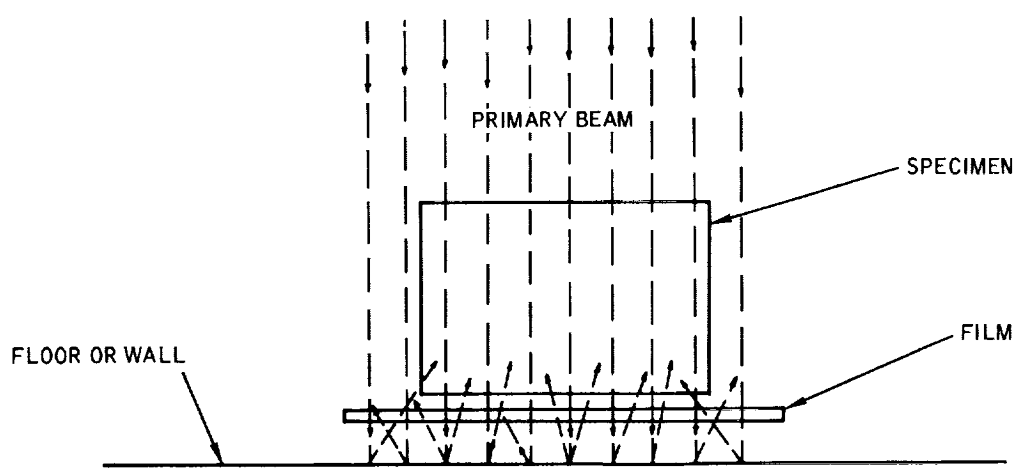


Figure 2-15. Back Scatter

4. GAMMA RAYS

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

[redacted]

The wavelength and intensity of gamma waves are determined by the source isotope characteristics, and cannot be controlled or changed.

a. Natural Isotope Sources. Every element whose atomic number is greater than 82 has a nucleus that will probably disintegrate because of its inherent instability. Radium, the best known, and most used, natural radioactive source is typical of all radioactive substances. Radium and its daughter products release energy in the form of:

(1) Gamma Rays. Short wavelength electromagnetic radiation of nuclear origin.

(2) Alpha Particles. Helium nuclei, consisting of two protons and two neutrons, with a double positive charge.

(3) Beta Particles. Negatively charged particles having mass and charge equal in magnitude to those of the electron.

NOTE: The penetrating power of alpha and beta particles is relatively negligible, it is the gamma rays that are of use to the radiographer.

b. Artificial Sources. There are two sources of man-made radioactive isotopes (radioisotopes). Atomic reactor operation involving the fission of Uranium 235 results in the production of many different isotopes usable as radiation sources. Cesium 137, one of the radioisotopes used in radiography, is obtained as a by-product of nuclear fission. The second, and most common, means of creating radioisotopes is by bombarding certain elements with neutrons. The nuclei of the bombarded element are changed, usually by the capture of neutrons, and thereby may become unstable or radioactive. Commonly used radioisotopes obtained by neutron bombardment are, Cobalt 60, Thulium 170, and Iridium 192. The numerical designator of each of these isotopes denotes its mass number and distinguishes it from the parent isotope, and other isotopes of the same element. Artificially produced isotopes emit gamma rays, alpha particles, and beta particles in exactly the same manner that natural isotopes do.

c. Gamma Ray Intensity. Gamma ray intensity is measured in roentgens per hour at one foot (rhf), a measure of radiation emission over a given period of time at a fixed distance. The activity (amount of radioactive material) of a gamma ray source determines the intensity of its radiation. The activity of artificial radioisotope sources is determined by the effectiveness of the neutron bombardment that created the isotopes. The measure of activity is the curie (3.7×10^{10} disintegrations per second).

[redacted]

d. Specific Activity. Specific activity is defined as the degree of concentration of radioactive material within a gamma ray source. It is usually expressed in terms of curies per gram or curies per cubic centimeter. Two isotope sources of the same material with the same activity (curies) having different specific activities will have different dimensions. The source with the greater specific activity will be the smaller of the two. For radiographic purposes, specific activity is an important measure of radioisotopes, since the smaller the radioactive source the greater the sharpness of the resultant film image. (See Figure 2-4.)

e. Half Life. The length of time required for the activity of a radioisotope to decay (disintegrate) to one-half of its initial strength is termed "half life." The half life of a radioisotope is a basic characteristic, and is dependent upon the particular isotope of a given element. In radiography, the half life of a gamma ray source is used as a measure of activity in relation to time, and dated decay curves similar to that shown in Figure 2-16, are supplied with radioisotopes upon procurement.

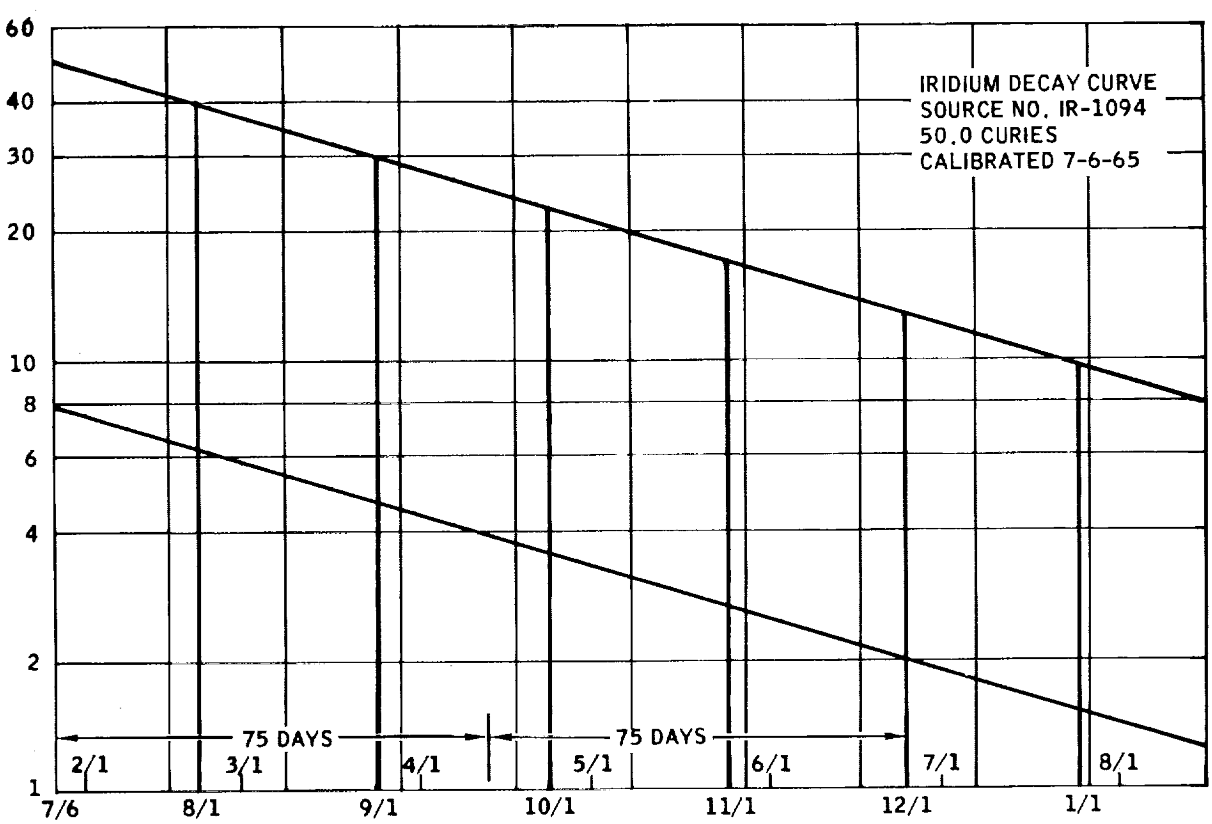


Figure 2-16. Dated Decay Curve

[redacted]

f. Inverse Square Law. Gamma rays and X-rays have identical propagation characteristics because they both conform to the laws of light. Just as it does with X-rays the intensity of gamma ray emission varies inversely with the square of the distance from the source (Figure 2-8).

g. Gamma Ray Quality Characteristics. Radiation from a gamma ray source consists of rays whose wavelengths (energy) are determined by the nature of the source. Each of the commonly used radioisotopes have specific uses due to their fixed gamma energy characteristics. Table 2-3 lists the most used radioisotopes and the energy of their gamma ray emissions.

Table 2-3. Gamma Ray Energy

ISOTOPE	GAMMA RAY ENERGY MEV
COBALT 60	1.33, 1.17
IRIDIUM 192	0.31, 0.47, 0.60
THULIUM 170	0.084, 0.052
CESIUM 137	0.66

h. Gamma Ray Interaction With Matter. The ionization, absorption, scattering, and pair production caused by gamma ray interaction with matter are identical with those of X-rays.

[redacted]

CHAPTER 3: EQUIPMENT
TABLE OF CONTENTS

CHAPTER 3: EQUIPMENT

300 GENERAL

Radiographic equipment as discussed in this chapter is limited to radiation source equipment that generates either X- or gamma radiation. Additional equipment required to produce a radiograph or other visual representation of a test specimen is covered in later chapters.

301 X-RAY EQUIPMENT (Figure 3-1)

1. GENERAL

In the previous chapter the three basic requirements for the generation of X-rays were listed: a source of free electrons; a means of moving the electrons rapidly in the desired direction; and a suitable material for the electrons to strike. The design of modern X-ray equipment is a result of refinements in the methods of satisfying these requirements.

2. X-RAY TUBE

The productive portion of X-ray equipment is the tube. The remaining components of an X-ray machine are designed to support the function of the tube, or to meet safety requirements. The tube basically consists of two electrodes, the cathode and the anode, enclosed in a high vacuum envelope of pyrex type glass. The filament portion of the cathode functions as a source of free electrons, and the anode as the target upon which the electrons strike. Associated with the tube is equipment which heats the filament; speeds and controls the resultant free electrons in a beam path to the anode; removes the heat generated by the X-ray generation process; and shields the equipment and surrounding area from unwanted radiation. As shown in Figure 3-2 there are many variations in the size and shape of X-ray tubes.

a. Tube Envelope. The tube envelope is constructed of glass that has a high melting point because of the extreme heat generated at the anode. Structurally, the envelope has sufficient strength to resist the implosive force of the high vacuum interior. The shape of the envelope is determined by the electrical circuitry used with the tube, and the desired tube use. Electrical connections through the envelope to the tube's electrodes are made in either of two ways. Through insulation material able to withstand the temperature, pressure and electrical forces of the X-ray generating process, or by connection to the envelope itself. Electrical connections to the envelope are accomplished by the use of metal alloys that have a coefficient of thermal expansion similar to that of the glass. The alloy is fused with the glass and becomes part of the envelope. A high vacuum environment for the tube ele-

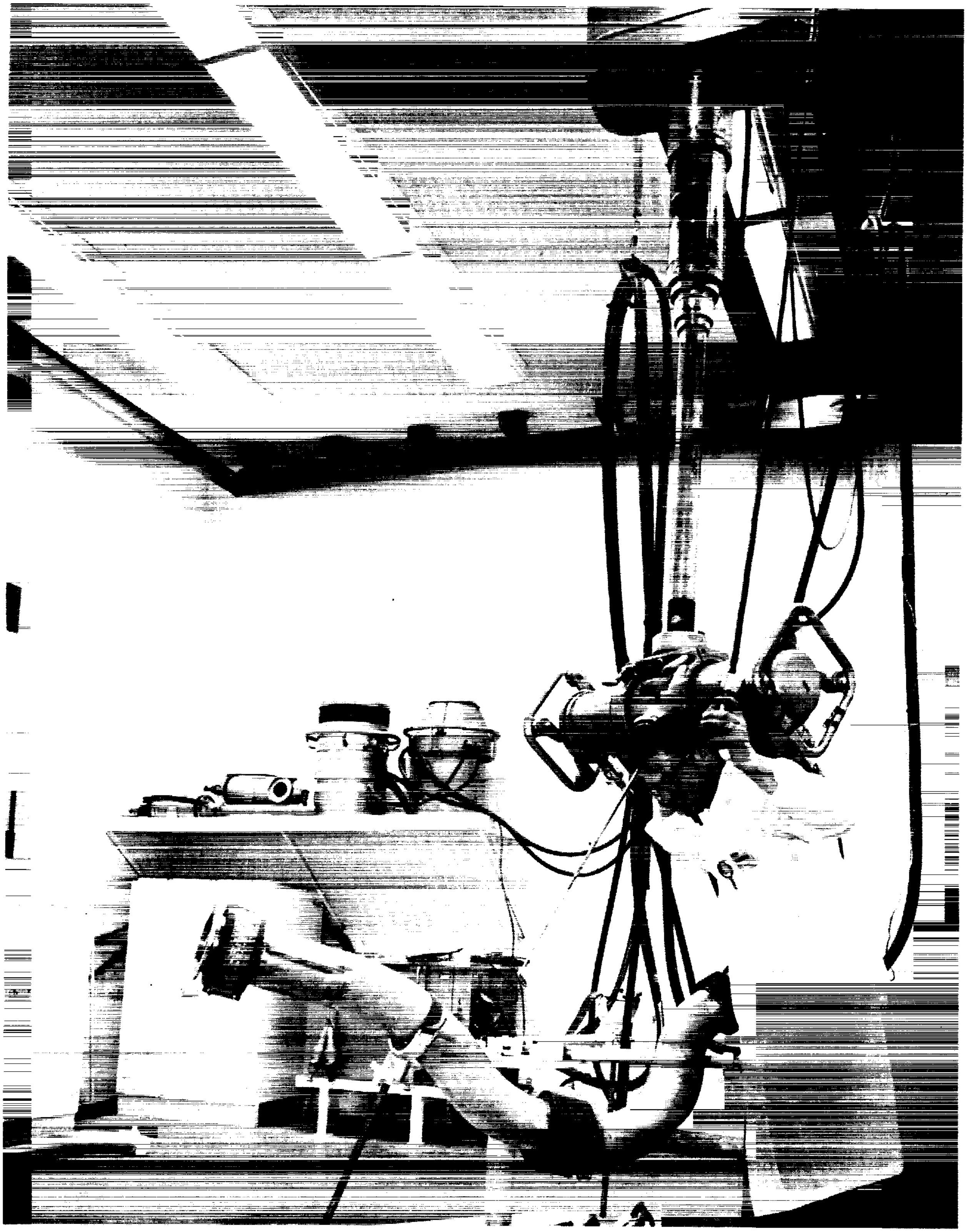
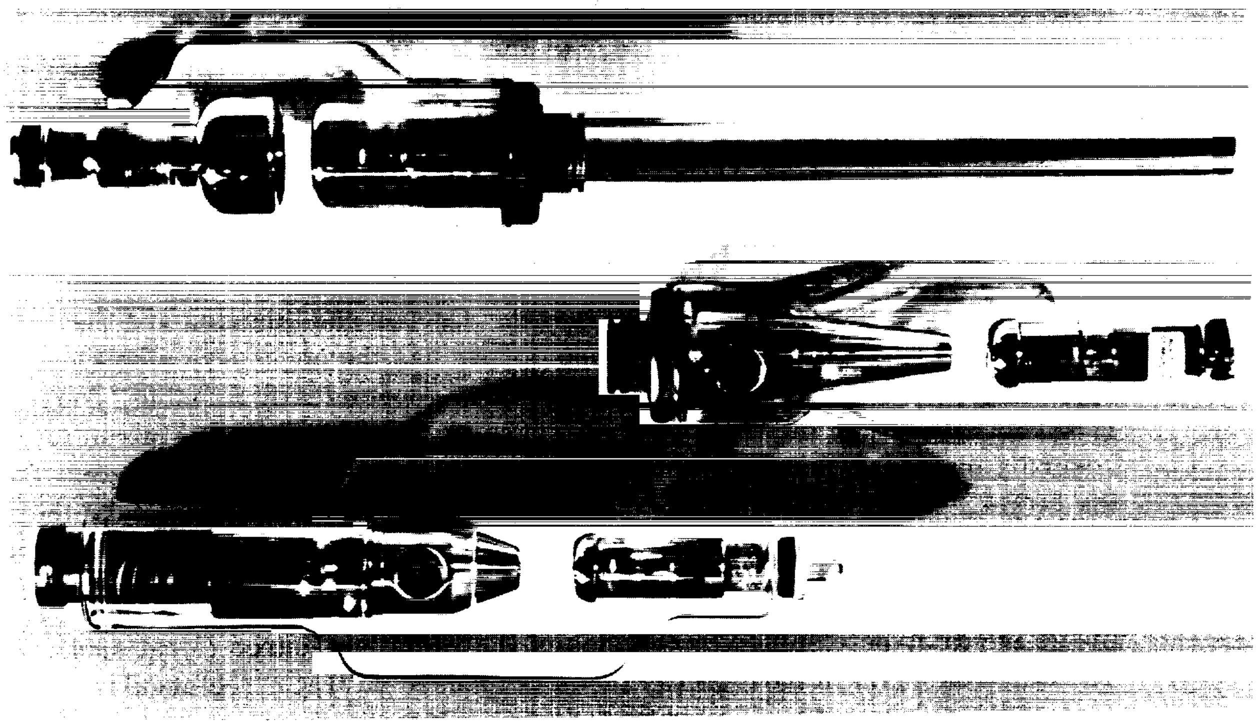


Figure 3-1. X-Ray Equipment



COURTESY AGFA-GEVAERT, INC.

Figure 3-2. X-Ray Tubes

ments is necessary to:

(1) Prevent oxidation of the electrode materials.

(2) Permit ready passage of the electron beam without ionization of gas within the tube.

(3) Provide electrical insulation between the electrodes.

b. Cathode. The cathode of the X-ray tube incorporates a focusing cup and the filament. Usually constructed of very pure iron and nickel, the focusing cup functions as an electrostatic lens whose purpose is to direct the electrons in a beam toward the anode. The electron emitting portion of the cathode is the filament, which is brought to the required high temperature by the flow of electrical current through it. The filament is usually a coil of tungsten wire since tungsten has the desired electrical and thermal characteristics. The placement of the filament within the focusing cup, and the shape of the cup, determine the dimensions of the electron beam and the resultant area of X-ray emission at the target.

c. Filament Heating. Due to the electrical characteristics of tungsten, a small flow of current through the filament suffices to heat it to temperatures which cause electron emission. Any change in the voltage applied to the filament varies the filament current and the number of electrons emitted. A change in the number of electrons emitted changes correspondingly the electron flow (current) through the tube. On most X-ray machines, control of tube current is obtained by regulating, through transformer action, the voltage applied across the filament.

d. Anode. The anode of the X-ray tube is a metallic electrode of high electrical and thermal conductivity. Usually it is made of copper with that portion directly facing the cathode being tungsten, gold, or platinum. It is these latter materials that function as the target. Copper and tungsten are the most common anode materials because copper has the necessary electrical and thermal characteristics and tungsten is an economically feasible, dense material with a high melting point. A dense target material is required to assure a maximum number of collisions, when the electron beam strikes the target. Material with a high melting point is necessary to withstand the heat of X-ray generation.

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

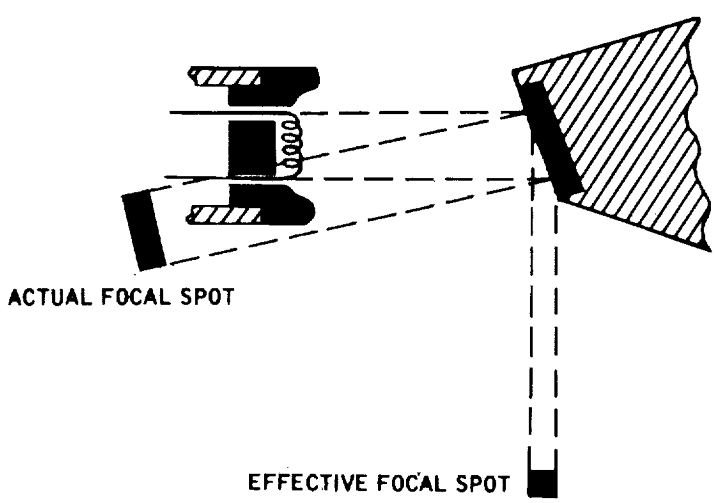


Figure 3-3. Effective vs Actual Focal Spot

f. X-ray Beam Configuration. X-rays are radiated in all directions from the tube target and once created cannot be focused or otherwise directed. The direction of useful X-radiation is determined by the target positioning at the tube anode, and the placement of lead shielding about the tube. With selected positioning of the target, and variations in shielding placement, almost any beam configuration desired can be obtained. See Figure 3-4.

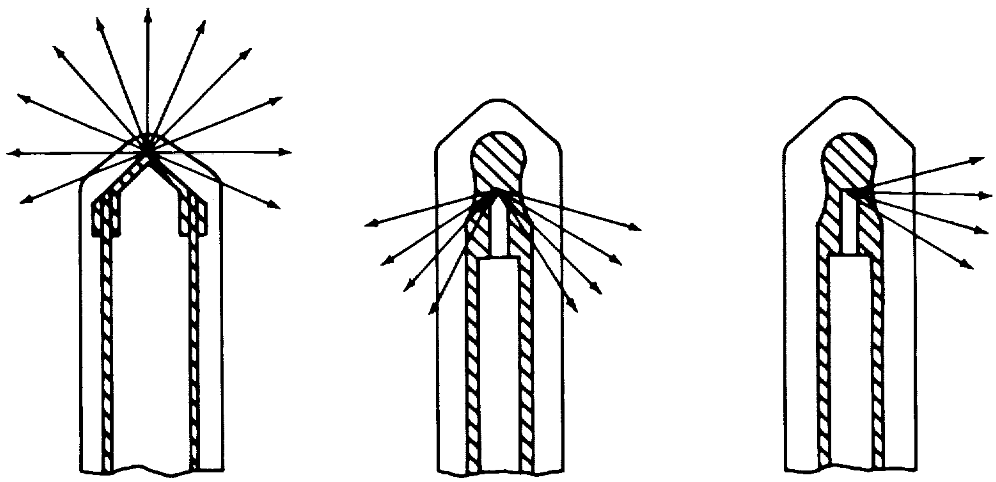


Figure 3-4. X-Ray Beam Configuration

g. Accelerating Potential. The operating voltage (difference in electrical potential between the cathode and anode) applied to an X-ray tube determines the penetrating effect of X-radiation. (Figure 2-10.) In short, the higher the voltage the greater the electron velocity, and the shorter the wavelengths of the generated X-rays. The high voltage necessary to generate short waves of great penetrating power is obtained from transformers, electrostatic generators or accelerators.

(1) Iron Core Transformers. The majority of X-ray equipment used in industrial radiography uses iron core transformers to produce required high voltages. A typical self rectifying high voltage circuit for X-ray equipment is shown in Figure 3-5. The basic limiting factors to iron core transformer use are their size and weight. Iron core transformers are used to produce voltages up to 400 kvp, usually in self rectified circuits; however, they are often used with half and full wave rectifiers, voltage doublers, and constant potential circuits. Iron core transformers in modern X-ray equipment are either mounted in tubehead tank units with the tube, or are separately housed.

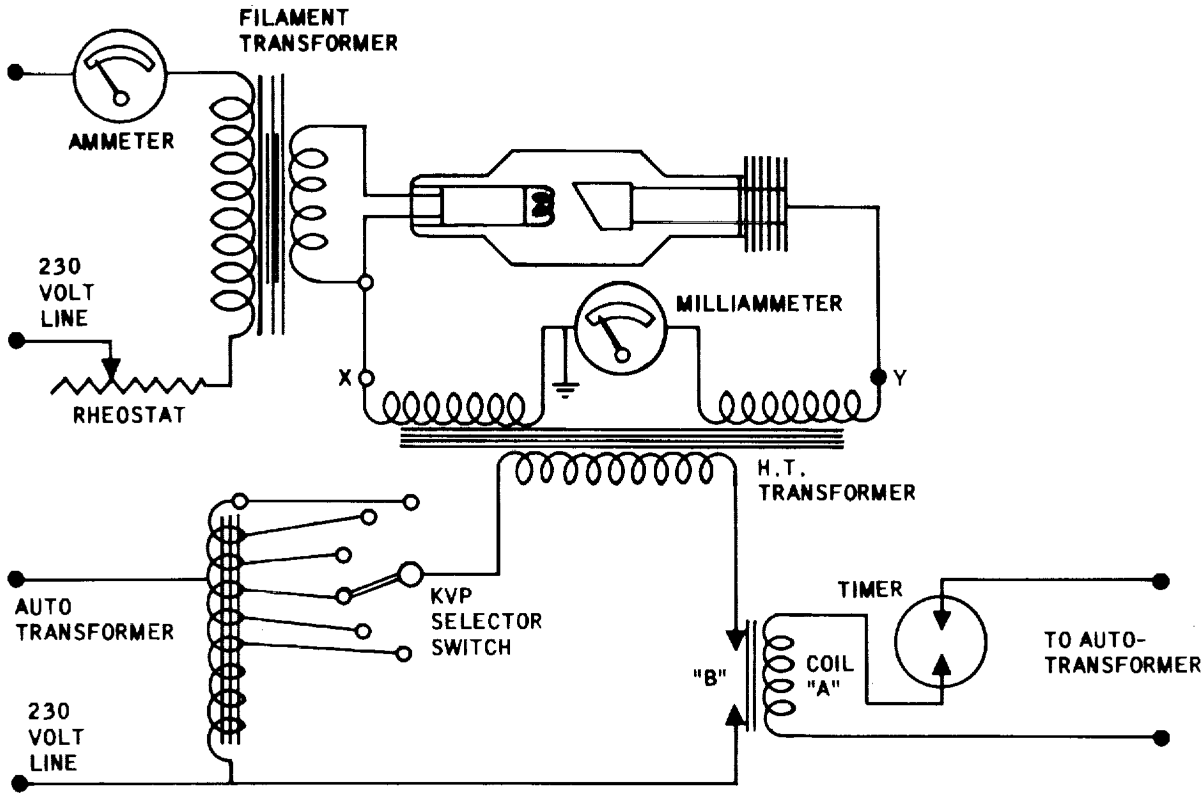


Figure 3-5. Basic High Voltage Circuit

(2) Resonant Transformers. In the 250-to 4000-kvp range the resonant transformer (Figure 3-6) is effectively employed. Similar to iron core transformers, resonant transformers produce high voltage from a low voltage input, but the use of a resonant secondary lends itself to a compact lightweight design. The X-ray tube is mounted in the central axis of the transformer.

(3) Electrostatic Generators. Electrostatic generator X-ray equipment is designed to operate in the 500- to 6000-kvp range. (See Figure 3-7.) Two motor-driven pulleys drive a non-conducting charging belt. Electrons from the charging point pass to the belt, and are transferred to the corona cap at the corona point. The accumulated high voltage at the corona cap serves to accelerate the beam of electrons emitted by the filament. The equipotential plates distribute the high voltage evenly along the length of the tube. To minimize high voltage leakage the generator is enclosed in a pressurized gastight chamber.

[redacted]

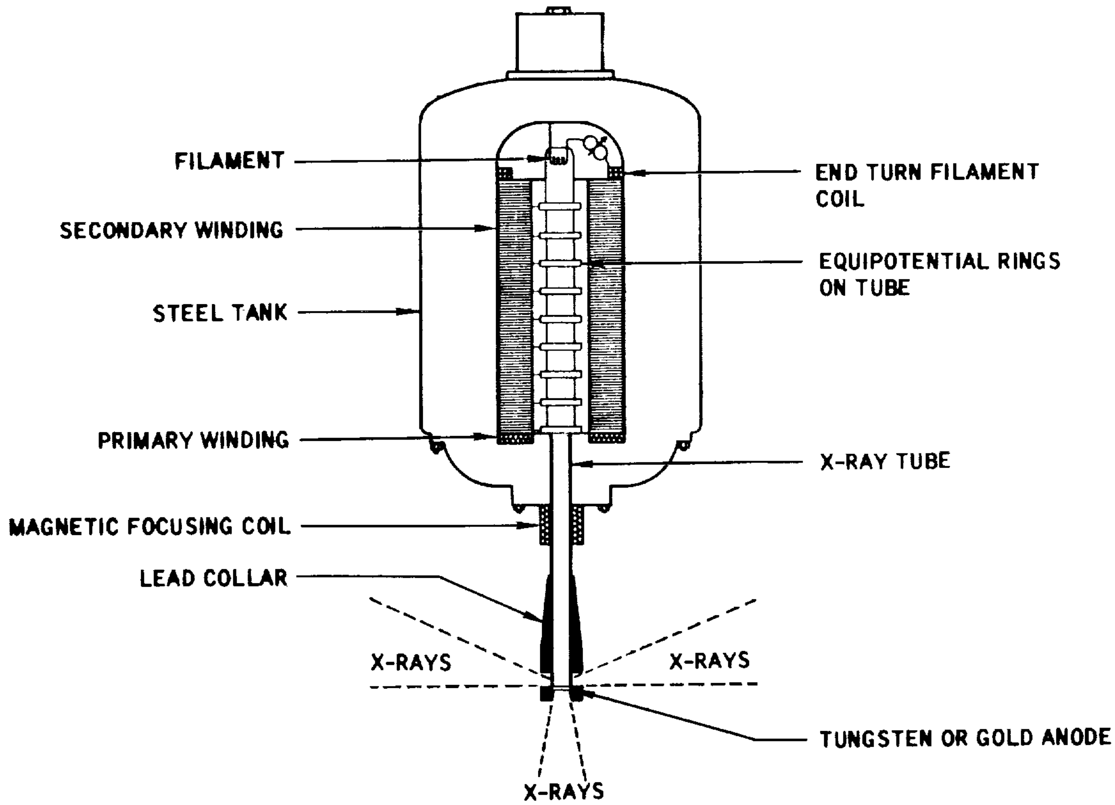


Figure 3-6. Resonant Transformer X-Ray Equipment

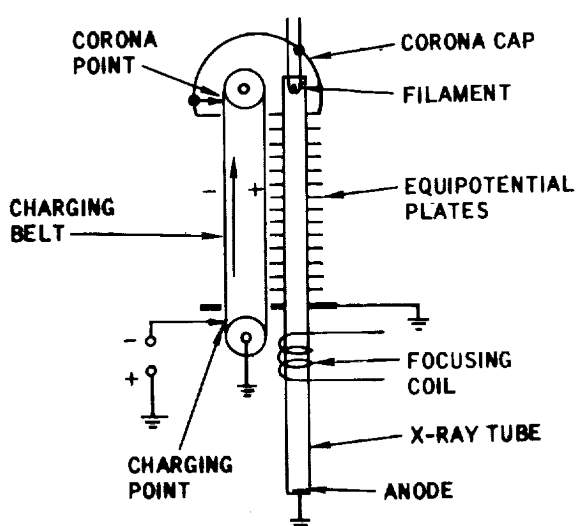


Figure 3-7. Diagram of Electrostatic Generator

(4) Linear Accelerators. Linear accelerators utilize radio frequency energy in a tuned wave guide to produce an induced field, which is directly related to the length of the wave guide sections, and the radio frequency. By selection of wave guide lengths, and use of a known frequency, electrons injected into the guide are accelerated toward the target by the action of the constantly changing induced field. Theoretically, electrons may be accelerated to velocities approaching the speed of light by this means, with resultant generation of extremely short wavelength, high energy, X-rays. In practice, the length of linear accelerator required to obtain electron velocities equivalent to those used in industrial radiography is about six feet.

(5) Betatron Accelerators. The betatron accelerates electrons in a circular path by magnetic induction. (Figure 3-8.) Its operation is based upon transformer principles since an alternating current applied to the primary (excitation) coil produces a strong variation in the magnetic field in the core of the doughnut shaped secondary. The magnets strengthen this magnetic field. As the magnetic field starts to increase in strength, electrons are injected from a hot cathode

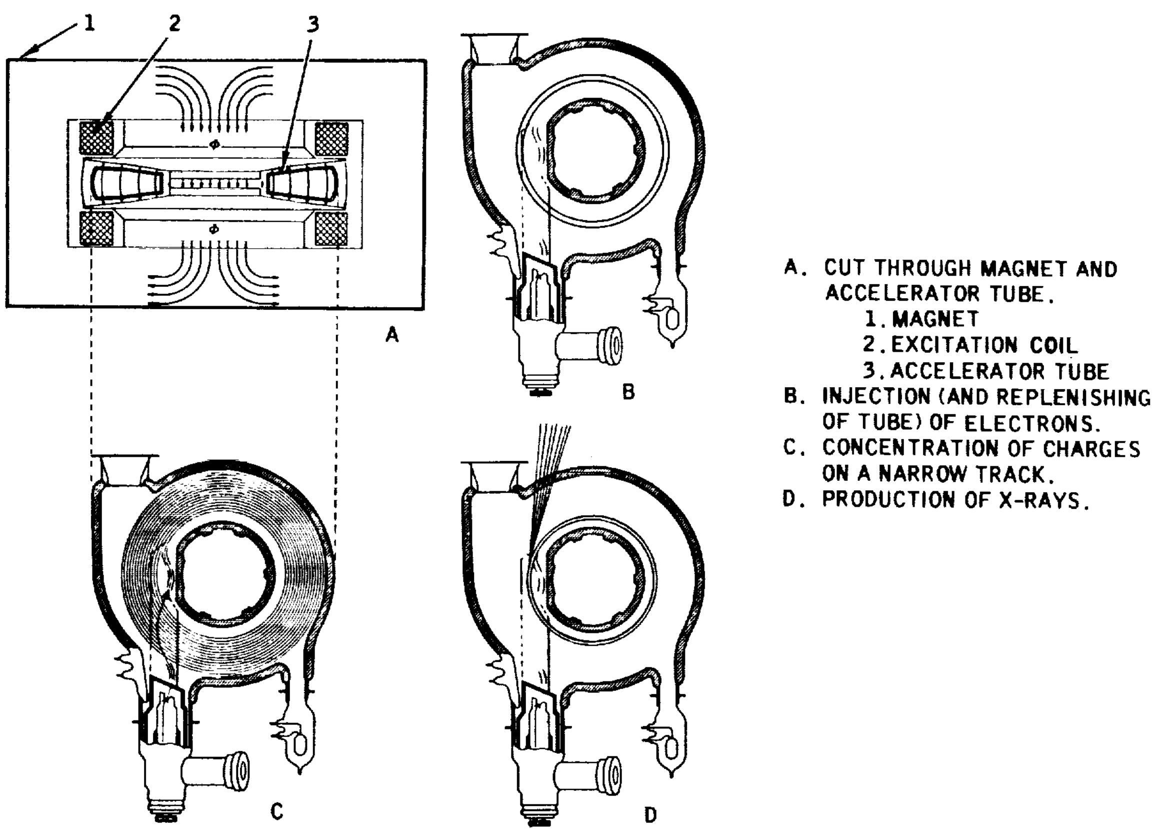


Figure 3-8. Betatron Accelerator

[redacted]

injection gun into the "doughnut." The voltage induced by the increasing field causes the electrons to accelerate. The electrons will circle within the doughnut thousands of times in one cycle of applied voltage, increasing their energy with each rotation. At the moment the magnetic field is at its peak and is about to decrease, a pulse of current is applied to an auxiliary coil which distorts the magnetic field, and ejects the electrons from their circular path. The high energy electrons strike the target and produce X-rays of extremely short wavelength and great penetration power.

3. HEAT DISSIPATION

The process of X-ray generation is very inefficient and most of the energy of the electron beam in the tube is expended in the production of heat. To avoid destruction of the tube anode, this heat must be dissipated. Heat dissipation in medium and low power equipment is usually accomplished through an external finned radiator, which is in good thermal connection with the anode, and is cooled by a flow of oil or gas about its surfaces. Higher power equipment makes use of injection cooling. The coolant, oil or water, is circulated through the hollow anode of the tube. Since the duty cycle (percentage of exposure time versus total time) of X-ray equipment is determined by the rate of anode cooling, the efficiency of equipment cannot exceed the efficiency of its cooling system.

4. EQUIPMENT SHIELDING

X-rays cannot be focused or otherwise directed and, once created, X-radiation can be controlled only by shielding. X-ray tubes, or the tubeheads in which they are contained, are shielded by lead plates or sleeves to prevent unwanted radiation spread. The design of this shielding varies with equipment, but in all cases it serves to absorb that portion of the radiation that is not traveling in the desired direction. In any X-ray equipment, the angle of coverage of the X-ray beam is a function of the target angle, the geometry of the focal spot position, and the X-ray port size as determined by shielding placement.

5. TUBEHEADS

Tubeheads (Figure 3-9), used with portable X-ray equipment, consist of an outer metallic shell with an X-ray port, and usually contain the X-ray tube, high voltage and filament transformers, insulating oil or gas, and lead shielding. Tubeheads used with permanently installed X-ray equipment contain all of the foregoing items except the transformers, which are housed in a separate unit.

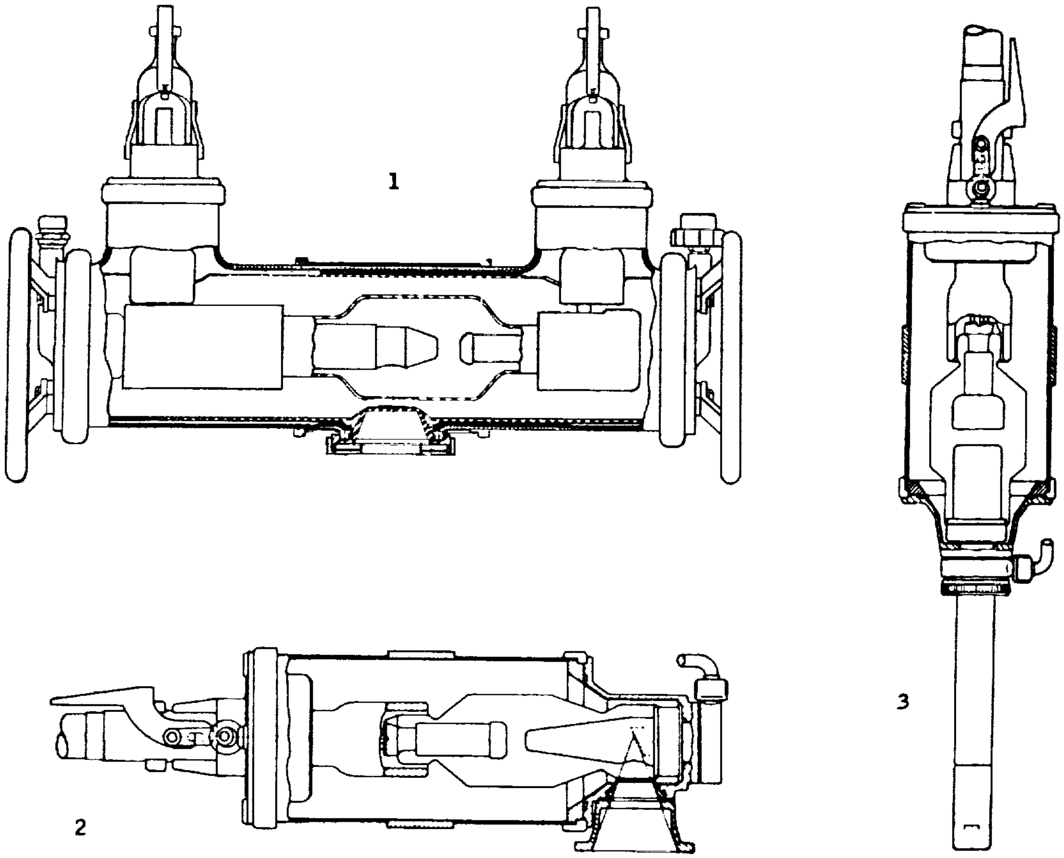


Figure 3-9. X-Ray Tubeheads

6. CONTROL PANEL

The control panel of an X-ray machine is designed to permit the operator to control the generation of X-rays so that exposures can be made simply and rapidly. The panel also provides protective electrical circuits that prevent damage to the equipment. Dependent upon the complexity of the equipment and the electrical circuitry design, the control panel will be comprised by some, or all, of the following controls and indicators:

a. Line Voltage Selector Switch. Permits equipment operation with various line voltages such as 110 volts AC, 220 volts AC, etc.

b. Line Voltage Control. Permits adjustment of line voltage to exact values.

c. Line Voltage Meter. A voltmeter indicating the line voltage, used in conjunction with the line voltage control.

d. High Voltage Control. Permits adjustment of the voltage applied across the tube.

e. High Voltage Meter. A voltmeter, usually calibrated in kilovolts, used in conjunction with the high voltage control.

f. Tube Current Control. Permits adjustment of tube current to exact values.

g. Tube Current Meter. An ammeter, usually calibrated in milliamperes, used in conjunction with tube current control.

h. Exposure Time. A synchronous timing device used to time exposures.

i. Power ON-OFF Switch. Controls the application of power to the equipment; usually applies power to the tube filament only.

j. Power ON Indicator Lamp. Visual indication that the equipment is energized.

k. High Voltage ON-OFF Switch. Controls the application of power to the tube anode.

l. High Voltage ON Indicator Lamp. Visual indication that the equipment is completely energized and X-rays are being generated.

m. Cooling ON Indicator Lamp. Visual indication that the cooling system is functioning.

n. Focal Spot Selector Control. Used with tubes having two focal spots, permits selection of desired size focal spot.

7. PROTECTIVE ELECTRICAL CIRCUITS

Internally, the control panel contains protective electrical circuits such as:

a. Overload Circuit Breaker. Provides protection for the equipment by removing power when the equipment becomes overheated as a result of component failure.

b. Overvoltage Protection Circuit. Bleeds off excess voltage due to surges in the line voltage supply.

c. Overcurrent Relay. Prevents excess current flow through the tube by controlling the filament voltage.

8. EQUIPMENT PROTECTIVE DEVICES

The electrical protective devices of the control panel serve to protect the equipment against electrical malfunctions. Additional protection is provided against excess heat or insulation failure, by:

a. Overtemperature Thermostat. Installed in the tubehead, functions to remove power from the equipment when excess heat is present.

[redacted]

b. Pressurestats. Installed in the tubehead of equipment using gas for insulation, function to remove power from the equipment when the gas pressure is below safe values.

c. Flow Switches. Installed in the oil and water circulators of equipment cooled by these means. They function by removing power from the unit when the cooling system fails.

302 GAMMA RAY EQUIPMENT

1. GENERAL

Radiation from radioactive material producing gamma rays cannot be shut off nor can it be directed or controlled. Gamma ray equipment is designed to provide radiation-safe storage, and remote handling of a radioisotope source. The United States Atomic Energy Commission (USAEC) and various state agencies prescribe safety standards for the storage and handling of radioisotopes under their control. Similar safety procedures are required for the storage and use of radium which is not under USAEC control. Chapter 5 contains radiographic safety information, and only those safety factors directly concerned with gamma ray equipment design will be mentioned in this chapter.

2. GAMMA RAY SOURCES

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

a. Radium. Radium is a natural radioactive substance having a half-life of approximately 1600 years. In practical applications, radium, because of its slow disintegration, is considered to have a constant rate of gamma ray emission. Radium itself does not produce useful gamma rays but, through decomposition, produces radon, a radioactive gas with a half-life of less than four days, and other radioactive daughter products. It is the disintegration of radon, and the other daughter products, that causes the emission of useful gamma rays. By placing radium in a gastight capsule, preventing the escape of radon, a state of equilibrium is reached whereby the amount of radon lost through disintegration is equal to the amount

[redacted]

produced by decomposition of the radium. For practical purposes, this state of balance causes a constant rate of gamma ray emission from a radium source. Pure radium is not used in radiography and most sources consist of radium sulfate packaged in either spherical or cylindrical capsules. Because of its low specific activity, radium is little used in industrial radiography.

b. Cobalt 60. Cobalt 60 is an artificial isotope created by neutron bombardment of cobalt, having a half-life of 5.3 years. Table 3-1 shows its decay rate at six month intervals during one half-life cycle. Cobalt 60 primary gamma ray emission consists of 1.33 and 1.17 mev rays similar in energy content to the output of a 2 mev X-ray machine. The radioisotope is supplied in the form of a capsuled pellet and may be obtained in different sizes. It is used for radiography of steel, copper, brass and other medium weight metals of thicknesses ranging from 1 to 8 inches. Because of its penetrating radiation, its use requires thick shielding, with resultant weight and handling difficulty.

Table 3-1. Cobalt 60 Decay Rate

	0.5 Yr.	1.0 Yr.	1.5 Yr.	2.0 Yr.	2.5 Yr.	3.0 Yr.	3.5 Yr.	4.0 Yr.	4.5 Yr.	5.0 Yr.	5.3 Yr.
% ACTIVITY	93.3	89.0	82.9	77.0	71.0	68.0	63.3	59.6	55.5	52.0	50.0

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

d. Thulium 170. Thulium 170 obtained by neutron bombardment of thulium has a half-life of approximately 130 days. The disintegration of the isotope produces 84-kev and 52-kev gamma rays, soft rays similar to the radiation of X-ray equipment operating in the 50- to 100-kvp range. It is the best isotope known for radiography of thin metals since it is capable of producing good radiographs of steel specimens less than one-half inch thick. One of the major advantages of the use of thulium 170 is its soft wave radiation, which permits its containment in small equipment units of extreme portability, since only a small amount of shielding is required. Because the pure metal is difficult to obtain, the isotope is usually supplied in capsules containing the oxide Tm_2O_3 in powder form.

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

f. Other Radioisotopes. Many other radioisotopes that are radiographically useful are not considered here because in practical applications one or another of the four discussed is superior. Table 3-2 is a summary of the characteristics of the four most-used isotopes.

Table 3-2. Isotope Characteristics

ISOTOPE	COBALT-60	IRIDIUM-192	THULIUM-170	CESIUM-137
HALF-LIFE	5.3 Yr.	75 Days	130 Days	30 Yr.
CHEMICAL FORM	Co	Ir	Tm_2O_3	CsCl
GAMMAS MEV.	1.33, 1.17	0.31, 0.47, 0.60	0.084, 0.052	0.66
	14.4	5.9	0.032*	4.2
PRACTICAL SOURCES				
CURIES	20	50	50	75
RHM	27	27	0.1	30
APPROX DIAMETER	3 mm.	3 mm.	3 mm.	10 mm.

*VARIES WIDELY BECAUSE OF HIGH SELF-ABSORPTION

[redacted]

3. ISOTOPE CAMERAS

Because of the ever-present radiation hazard, isotope sources must be handled with extreme care, and stored and locked in adequately shielded containers when not in use. Equipment to accomplish safe handling and storage of isotope sources, together with a source, is called a camera. Figure 3-10 shows a typical camera consisting of:

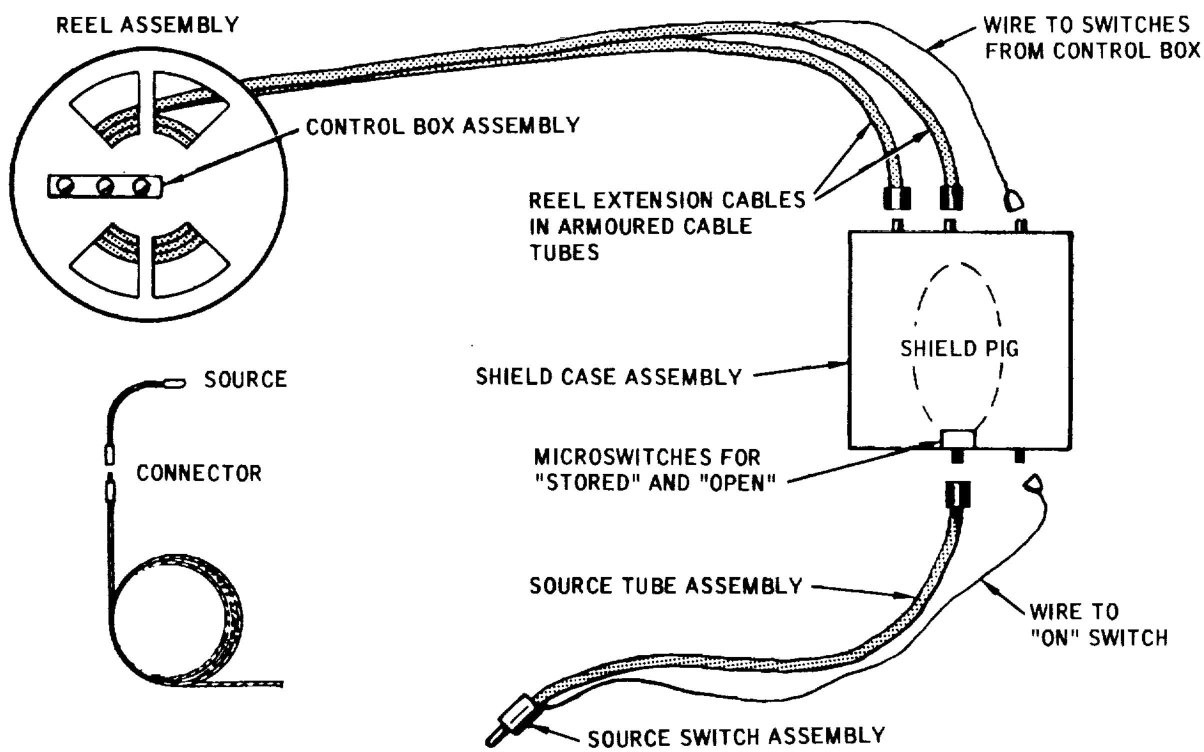


Figure 3-10. Diagram of Typical Isotope Camera

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

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

[redacted]

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

d. Source Capsule Assembly. A short length of cable with the source, in a stainless steel container attached to one end and a connector for attachment to the control cable on the other.

(1) Figure 3-11 shows operation of a typical camera.

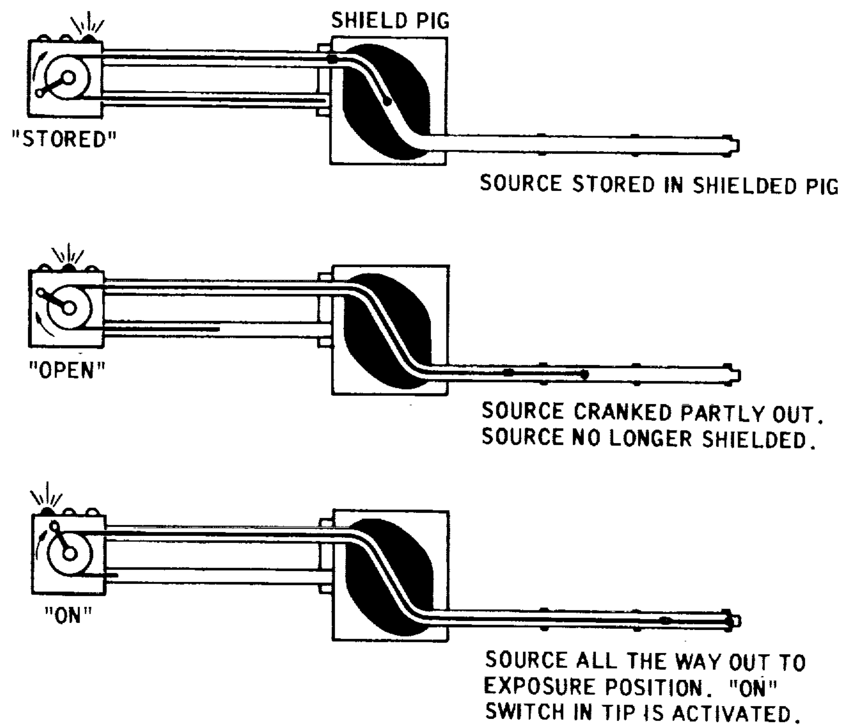


Figure 3-11. Operation of Typical Isotope Camera

(2) Cameras that use a direct reading of the length of cable extended to indicate source position, and cameras that replace the manual crank with pneumatic or electrical drive units, are only modifications of the basic design. There are, however, other types of cameras (Figure 3-12) that do not require removal of the source from the storage pig. These cameras permit exposure by removal of part of the source shielding. The required physical

movement to expose the source is initiated from remote positions, either manually with long poles, or by electric drive units.

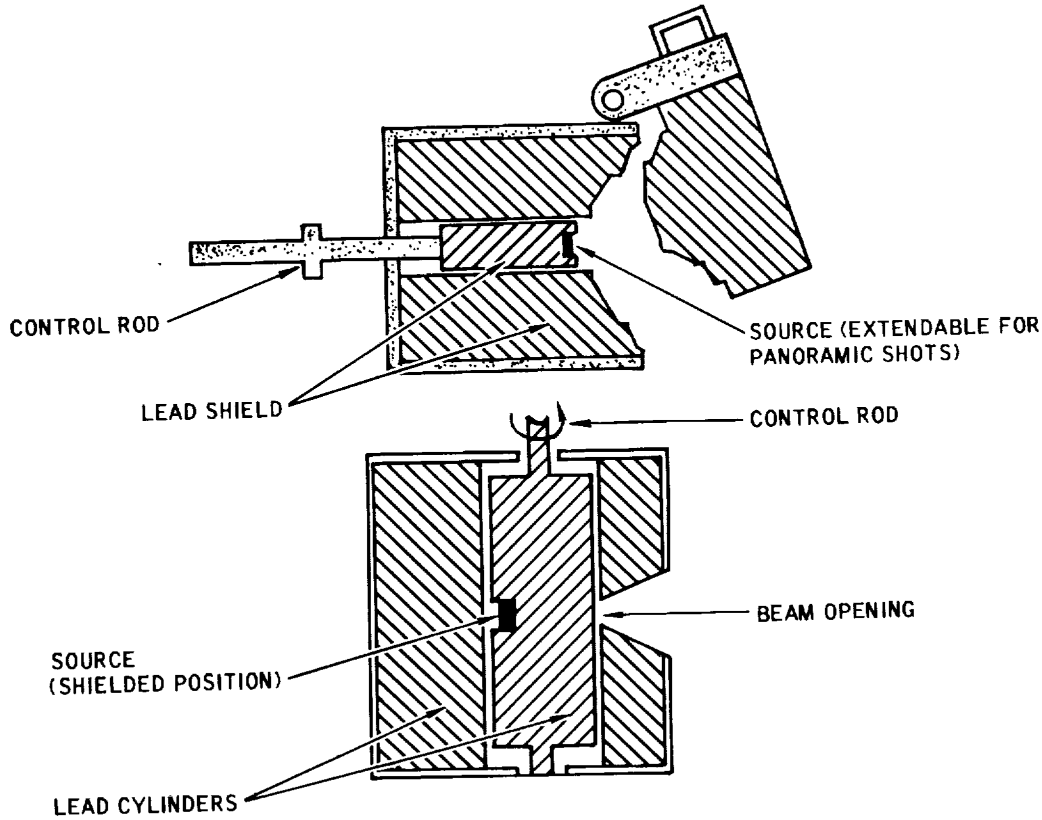


Figure 3-12. Isotope Cameras

CHAPTER 4: FILM
TABLE OF CONTENTS

 [redacted]

CHAPTER 4: FILM

400 GENERAL

This chapter provides information on the behavior characteristics and processing requirements of the film upon which images are produced by the radiographic process.

401 DESCRIPTION

Radiographic film consists of a thin, transparent plastic sheet coated on one or both sides with an emulsion of gelatin, approximately 0.001 inch thick, containing very fine grains of silver bromide. When exposed to X-, gamma, or visible light rays, silver bromide crystals undergo a reaction that makes them more susceptible to the chemical process (developing) that converts them to black metallic silver. In short, exposure to radiation creates a latent image on the film, and chemical processing makes the image visible. Since the radiation source, the specimen, and the conditions of exposure determine the amount of radiation reaching the film at any given point, the radiographer is primarily concerned with those film characteristics that fix the density and sharpness of the processed film image in the finished radiograph.

402 RADIOGRAPH USEFULNESS

The usefulness of any radiograph is measured by its impact on the human eye. When the radiographer interprets a radiograph he is seeing the details of the specimen image in terms of the amount of light passing through the processed film, (Figure 4-1). Areas of high density (areas exposed to relatively large amounts of radiation) will appear dark gray; areas of light density (areas exposed to less radiation) will appear light gray. The density difference between any two film areas is known as contrast. The sharpness of the film image is known as definition. Successful interpretation of any radiograph relies upon contrast and definition detectable by the eye.

403 RADIOGRAPHIC CONTRAST (Figure 4-2)

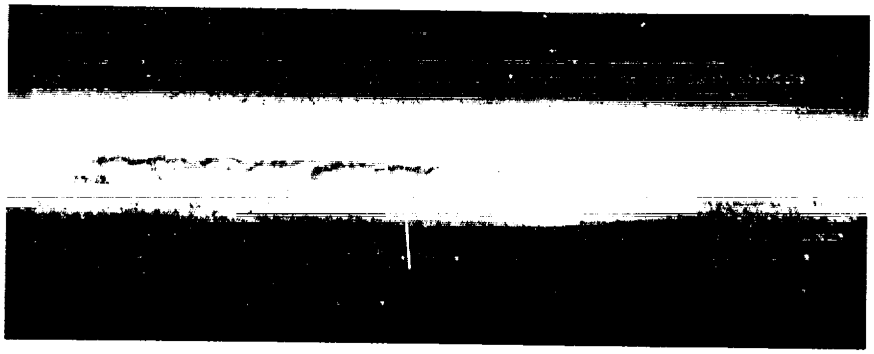
1. GENERAL

Radiographic contrast is defined as the difference of the various densities apparent on developed film. It is a combination of subject contrast and film contrast and, for any particular specimen, depends upon: radiation energy applied (penetrating quality); film contrast characteristics; exposure (the product of radiation intensity and time); use of screens; film processing; and scattered radiation.

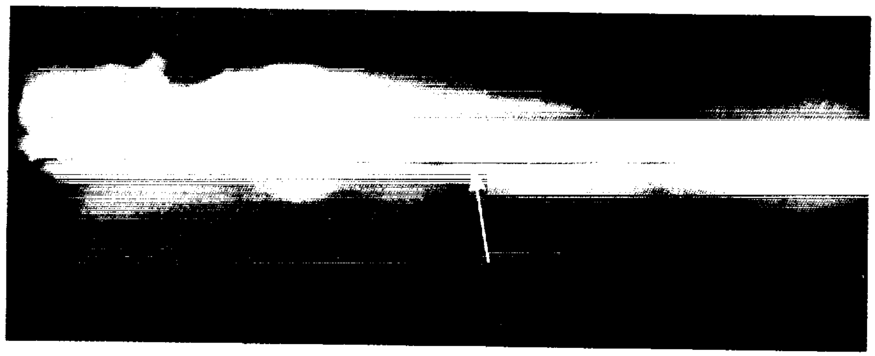
2. SUBJECT CONTRAST

Subject contrast is the ratio of radiation intensities passing through any two selected portions of a specimen. Homogeneous specimens of little thickness variation have low subject contrast. Those of large thickness variation usually have high subject contrast.

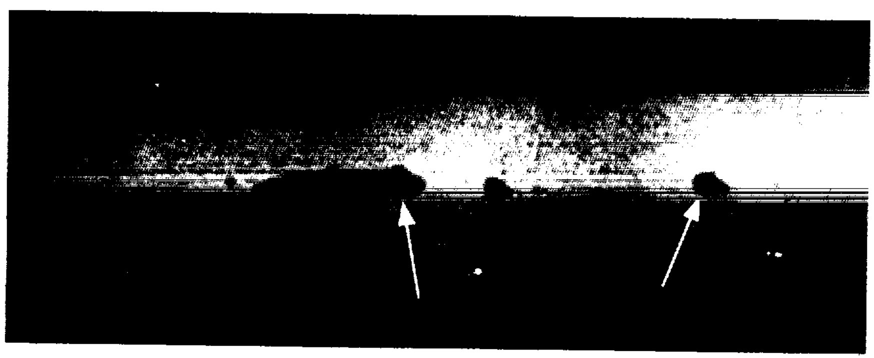
[redacted]



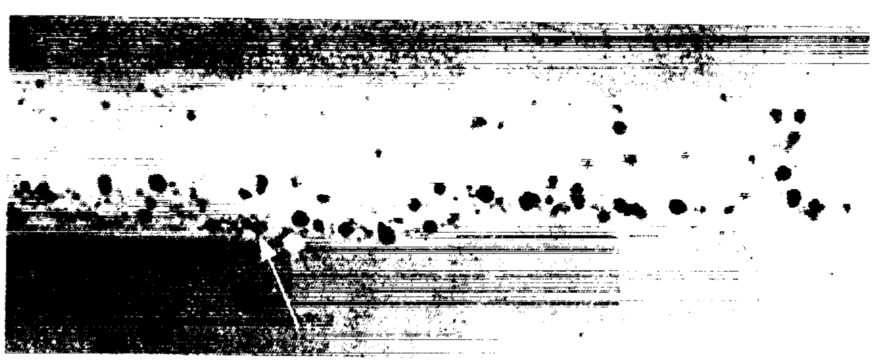
LONGITUDINAL CRACKS



LACK OF FUSION



ELONGATED VOIDS



POROSITY

Figure 4-1. Typical Radiographs

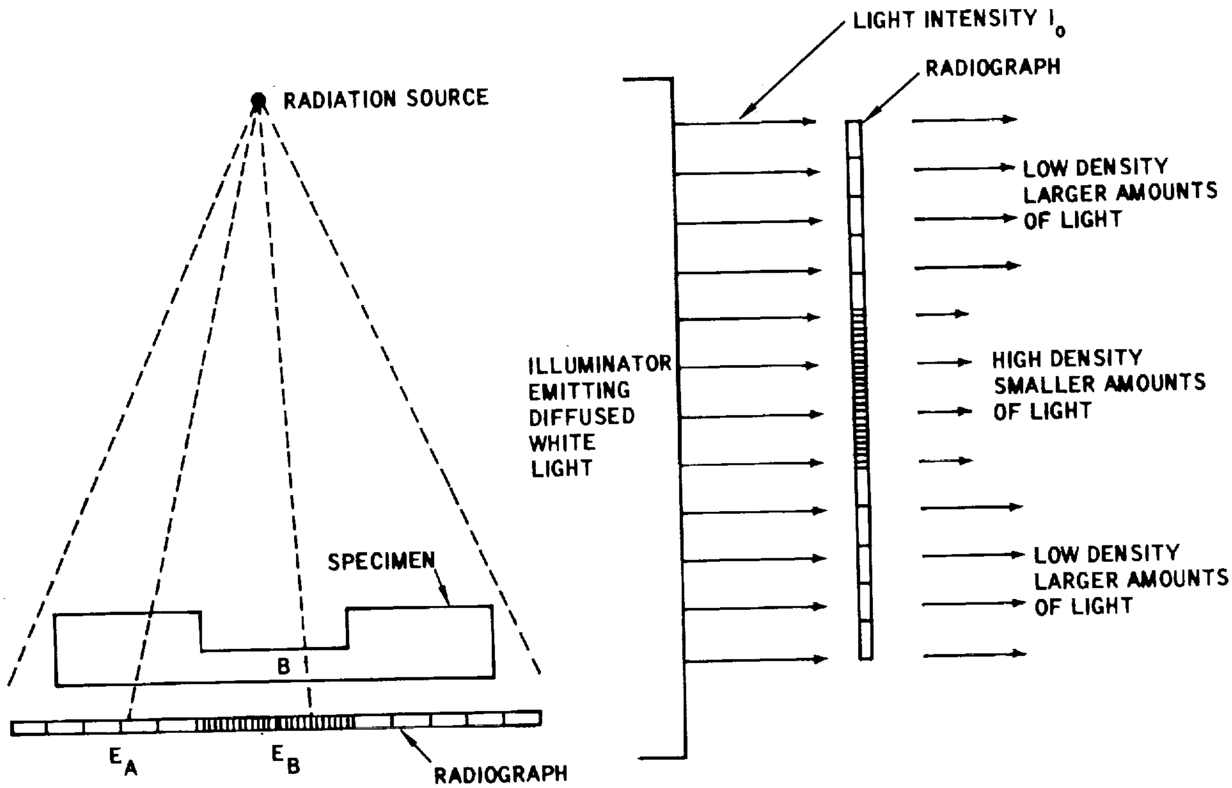


Figure 4-2. Radiographic Contrast

Subject contrast is determined by specimen density and thickness, and the radiation energy applied. Normally, as the energy of the applied radiation is lowered, the subject contrast is increased. High subject contrast is desirable except when detail is lost in the extremely dark and light areas of the radiograph.

3. FILM CONTRAST

The ability of film to detect and record different radiation exposures as differences in density is called film contrast. Radiographic film is fabricated with a variety of emulsions which give different film contrasts and other properties such as speed and graininess. The film contrast values of any particular film are usually expressed as a relationship between film exposure and the resulting film density. The relationship is expressed in the form of film characteristic curves.

4. H & D CURVES (Figure 4-3)

Exposure is defined as the product of the intensity of the radiation reaching the film and the radiation exposure time. The output of X-ray equipment is directly proportional to the tube current and time; therefore, it is also directly proportional to their product. Mathematically, $E = Mt$, where E is the exposure, M the exposure, M the tube current, and t the exposure time. It is this relationship that permits X-ray exposure, at a given kilovoltage, to be specified in terms of milliampere-minutes or milliampere-seconds without stating specific values of tube current or time. Similarly, gamma ray exposure is stated as E = Mt where E is the exposure, M the source strength, and t the exposure time. Thus, gamma ray exposures may be expressed in millicurie-hours without stating specific values of source strength or time. There are no convenient units, suitable to all X- and gamma radiation conditions, in which to express radiographic exposures. For this reason relative exposure is used as one axis in plotting the H & D curve. By this means, any exposure given a film is expressed in terms of any other exposure, producing a relative scale. For convenience, the logarithm of the relative exposure itself is used, since the use of the logarithm compresses what would otherwise be a long scale. Similar results are obtained if semilog paper is used and actual exposure is laid out on the logarithmic scale. Film density, the second axis used in plotting film characteristic curves, is laid out on a linear scale. It is the common logarithm of the ratio of light incident upon one side of a radiograph to the light transmitted through the radiograph. Expressed mathematically,

$$D = \log_{10} \frac{I_o}{I}$$

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

a. It is difficult for the human eye to distinguish between small density differ-

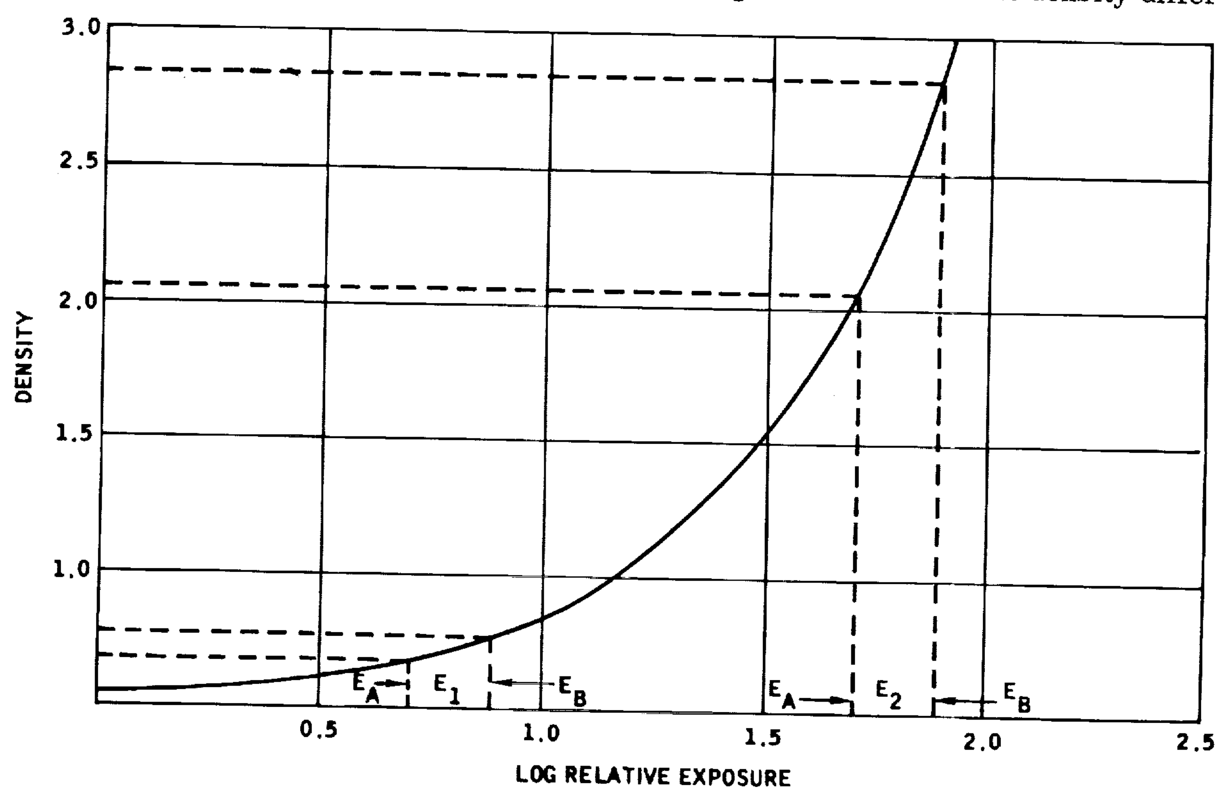


Figure 4-3. Film Characteristic Curve

ences, and there is a lower limit of contrast that the eye cannot detect. The H & D curves for most films make it readily apparent that as exposure increases, overall film density increases and, more importantly, film contrast increases. Referring to Figures 4-2 and 4-3 it is obvious that film exposure E_A is less than E_B and that it is the difference between the two that the radiograph must make clear in terms of film density. For a low exposure E_1, the difference in density between E_A and E_B is relatively small, and will probably not be discernible by the eye. By increasing the exposure to the value represented by E_2, not only is the overall density of the radiograph increased, but the density difference (radiographic contrast) between E_A and E_B is greatly increased. The resulting contrast is easily detectable by the eye. Selection of a correct exposure has used the film's contrast characteristics to amplify the subject contrast, resulting in a useful radiograph. In industrial radiography, films should always be exposed for a density of at least 1.5. The highest desirable density is limited only by the light intensity available for reading the radiograph.

b. Film speed is measured by the exposure required to obtain a desired film density. High-speed film needs only low exposure while slow-speed film requires more exposure to attain the same film density. Figure 4-4 illustrates H & D curves for three different speed films. The shape of

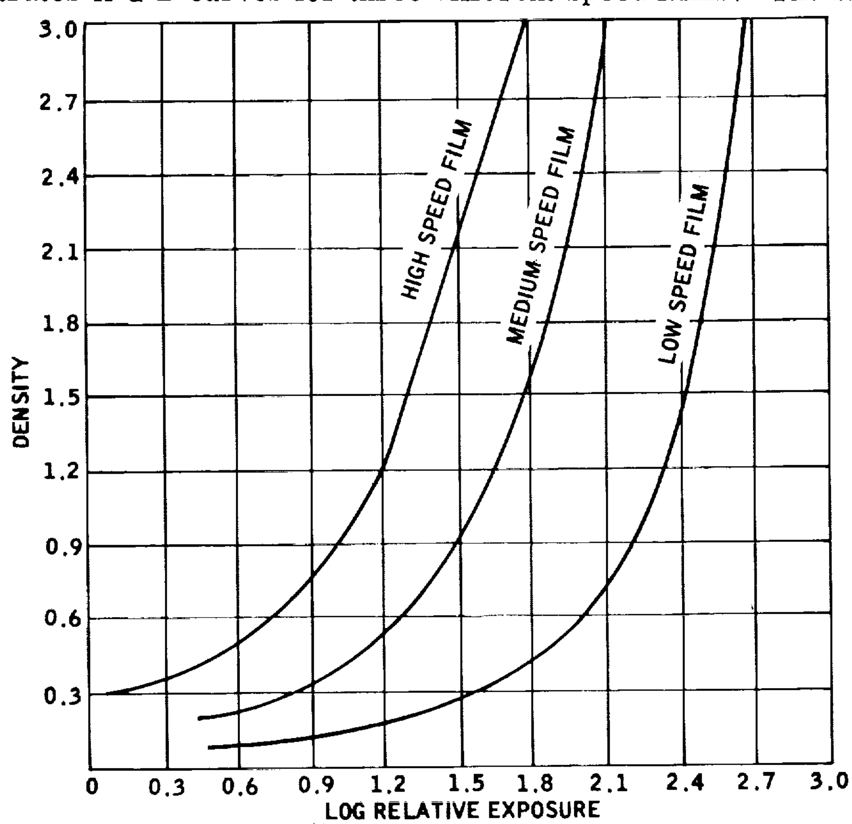


Figure 4-4. Relative Film Speed

each curve and its position on the log relative exposure axis is determined by the design of the film. Film speed is a consideration of importance since time is a cost factor in any industrial operation. Whenever other considerations, such as acceptable graininess, permit fast film may be used.

c. Graininess is the visible evidence of the grouping into clumps of the minute silver particles (grains) that form the image on radiographic film. It affects film contrast and image definition, and all film is subject to it. (See Figure 4-5.) The degree of graininess of any film is dependent upon:

(1) The fine or coarse grain structure of the film emulsion.

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

(3) Film processing, because graininess is directly related to the development process. Under normal conditions of development any increase in development time is accompanied by an increase in film graininess.

(4) The use of fluorescent screens which cause increased graininess with increase in radiation energy.

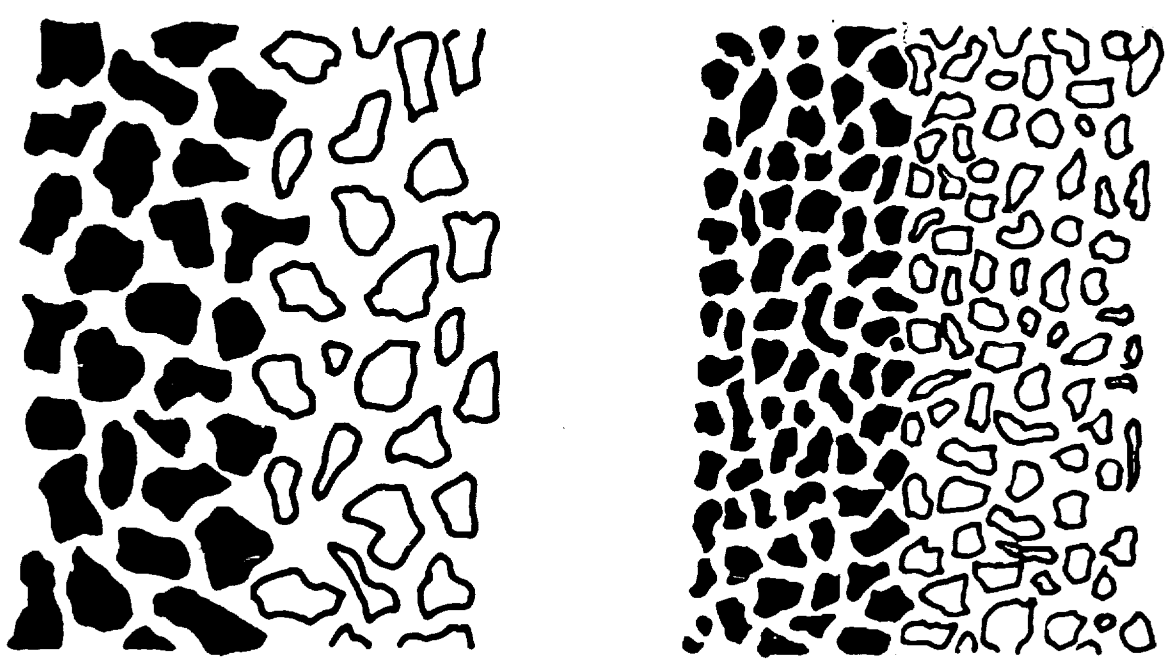


Figure 4-5. Film Grain

404 FILM SELECTION FACTORS

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

405 FILM PROCESSING

1. GENERAL

Once a radiographic exposure has been made the film must be processed so that the latent image produced by the radiation becomes visible. All of the procedures involved in making a radiograph are important since processing errors can make an otherwise worthwhile radiograph useless. Each step in film processing is dependent upon the step preceding it and in turn affects those following.

2. PROCESSING PRECAUTIONS

To obtain consistently good results, the following general precautions must be observed in processing radiographic film:

a. Maintain chemical concentrations, solution temperatures, and processing times within prescribed limits.

b. Use equipment, tanks, trays, holders etc., that withstand the chemical action of the processing solutions without contaminating the solutions.

c. Equip the darkroom with suitable safeguards and lighting controls to avoid fogging film.

d. Maintain scrupulous cleanliness.

3. TANK PROCESSING

In tank processing (Figure 4-6), the processing solutions and wash water are in tanks deep enough so that the film is suspended vertically. Prior to processing the film is removed from the film holder used during exposure. This removal is accomplished under darkroom conditions to avoid film fog. The film is grasped by its edges or corners to avoid bending, wrinkling, or crimping while handling. The film is then placed in a processing holder that holds the film firmly by each of its four corners, and is designed to fit the dimensions of the processing tanks. Once placed in the

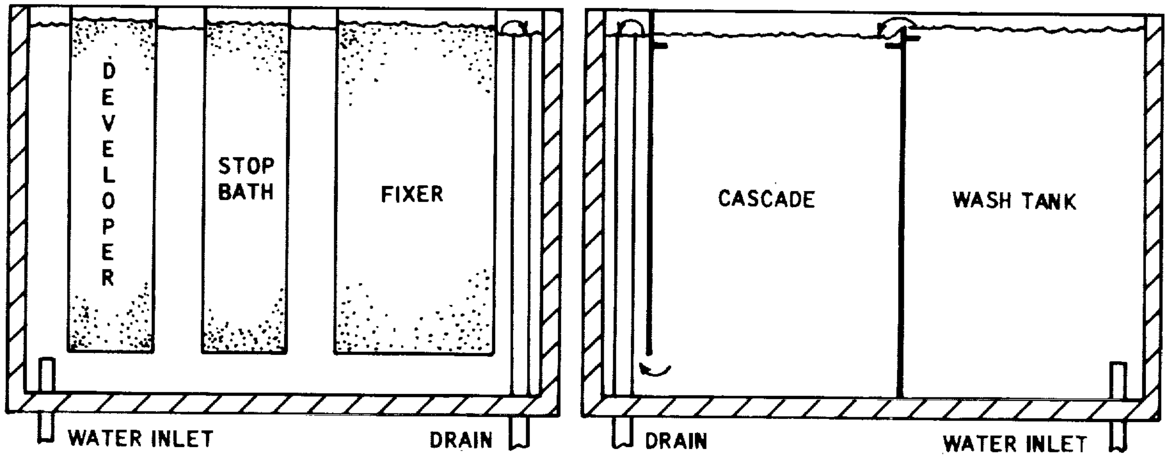


Figure 4-6. Typical Tank Processing Unit

processing holder the film is ready for processing. The advantages of tank processing are:

a. The solutions readily reach all portions of both sides of the film.

b. Temperature control of the water in which the processing tanks are immersed controls the temperature of the solutions.

c. Easy film handling is permitted during processing.

d. Time and space are saved.

4. TANK PROCESSING PROCEDURES

There are five separate steps in proper tank processing developing, stop bath, fixing, washing, and drying.

a. Developing. Developing is the chemical process of reducing silver bromide particles in the exposed portion of the film emulsion to metallic silver. This process commences when film is placed in the developer solution. The amount of silver bromide changed is a function of time and the chemical strength and temperature of the solution. Assuming that the chemical strength remains constant, the density of the radiographic image created through the developing process is proportional to the length of time the film remains in the solution, and inversely proportional to the solution temperature. To obtain consistent results, the temperature is kept within narrow limits and the development time is determined by the type film being processed. In practical applications the contrast and density desired in industrial radiographs is obtained with a solution temperature of 68°F

[redacted]

(20° C), and a development time between five and eight minutes.

(1) Manufacturers recommendations and time-temperature charts are consulted whenever doubt exists as to proper developing procedures. To avoid fogging, film is never left in the solution beyond recommended time limits. Solution temperature is checked before developing commences, since cold solutions result in underdevelopment (insufficient film density) due to retardation of the chemical reaction. Warm solutions cause overdevelopment, tending to fog the image, and can soften the emulsion so that it wrinkles or sloughs off.

(2) During the development process, the waste products of the chemical reaction at the surface of the film, having a higher specific gravity than the solution, flow downward, thus retarding the development of the film areas they pass. For this reason, to obtain uniform development the film is agitated. When first placed in the solution tank the film hanger is tapped to rid the emulsion of air bubbles. Each minute thereafter, until development is completed, the film is shaken vertically and horizontally, and moved from side to side for a few seconds.

(3) In use, the chemical strength of developer solution grows progressively weaker because of expenditure of the active chemicals in reaction with the silver bromide grains and the buildup of waste reaction products. The rate of this chemical depletion is proportional to the number and density of the films developed. At periodic intervals, determined by the rate of depletion, the activity (development ability) of the solution is tested. If below acceptable standards, the solution is replenished.

(4) Developer activity is tested by processing a film exposed to X-rays through a stepped wedge, and comparing the densities obtained with those of a standard film exposed in the same manner, and developed in a fresh solution. Similar density comparison results are obtained by cutting the standard film into strips after exposure, each strip containing exposures of all of the steps of the wedge. One strip is then developed in fresh solution and processed as the standard, and the remaining strips are used as solution activity test films. When the volume of work does not require more frequent testing of developer activity, it is good practice to test each day before commencing film processing.

(5) Developers are commercially available in both powder and liquid form. The solution is formed by combining the developer with water. Liquid developer, though more expensive, is much easier to prepare than powder, and is normally used. In preparing or replenishing developer

[redacted]

solution, the manufacturer's directions are followed in detail.

b. Stop Bath. When film is removed from the developing solution, a quantity of the solution remains within the emulsion, and the developing action will continue until the solution is removed. The stop bath, a solution of acetic acid and water, serves to remove this residual developer solution from the film, and prevents uneven development and film streaking. The stop bath also neutralizes the alkaline remnants of the developer, permitting the acid in the fixer solution to function in the desired manner.

(1) After development is complete the film is removed from the developer and allowed to drain for a second or two. The film is then doused in the stop bath which is maintained at the same temperature as the developer solution. The film is agitated in the bath for 30 to 60 seconds, and then removed for transfer to the fixer solution. If no stop bath is available, film after development is rinsed in uncontaminated running water for at least two minutes prior to placing in the fixer solution.

(2) Stop bath is mixed from commercially available 28% acetic acid or glacial acetic acid; most commonly from the former which is mixed with water, 16 ounces of acid to each gallon of solution. When glacial acid is used, the proportions are four-and-one-half ounces of acid to each gallon of solution. Manufacturers directions must be followed in mixing stop bath, particularly in the handling and preparation of a glacial acid solution. Glacial acetic acid is added slowly to water (never the water to the acid) while stirring constantly.

(3) Stop bath becomes spent after repeated use and is replaced to avoid poor quality radiographs. A fresh stop bath solution is yellow in color and when viewed under safelight, is almost clear. When the color changes to a blue purple, which appears dark under safelight illumination, the solution is replaced. Five gallons of stop bath will normally treat the equivalent of one hundred 14" by 17" films.

c. Fixing. If the unexposed silver bromide, remaining in the film emulsion after completion of the developer and stop bath processes, is not removed it will darken upon exposure to light, and ruin the radiograph. Fixer, a mildly acid solution, dissolves and removes the silver bromide from the unexposed portions of the film without affecting the exposed portion. It also hardens the emulsion gelatin permitting warm air drying. When first placed in the fixer solution, the film becomes clouded as a result of the dissolution of the silver bromide. In time, dependent upon the strength of the fixer solution, the film clears, but the dissolution and hardening processes are still going on. The total time required for fixing is twice the amount of

[redacted]

time necessary to clear the film. It should not exceed more than 15 minutes. Longer fixing time, indicative of a weak solution, can cause abnormal swelling of the film emulsion, improper hardening, overly long drying times, and loss of lesser film densities.

(1) Fixer solution is maintained at a temperature in the same range as that of the developer and stop bath, between 65° and 70° F. Particular care is taken to avoid high temperatures which cause the emulsion to wrinkle or slough off. When first placed in the solution, and at two minute intervals thereafter until fixing is completed, the film is agitated.

(2) Fixer solution becomes depleted through dilution by the stop bath or rinse water carried on the films, and by the accumulation of dissolved silver salts. The solution may be replenished by removing some of the solution and replacing it with undiluted fixer. There is, however, a limit to the effectiveness of replenishment, and after two or three replenishments the solution is discarded and replaced. The frequency of replenishment and replacement of fixer solution is determined by the acidity of the solution as evidenced by the length of time required for film fixation. It is directly proportional to the number of films processed.

(3) Fixers are commercially available in both powder and liquid form and the fixer solution is formed by combining the fixer with water. Liquid fixer is easier to handle and is most commonly used. In preparing or replenishing fixer solution, the manufacturer's directions are to be followed in detail.

d. Washing. After fixing, films undergo a washing process to remove the fixer from the emulsion. The film is thoroughly immersed in running water so that all of the emulsion surface is in contact with constantly changing water. The wash tank is large enough to handle the number of films going through the developing and fixing processes without crowding, and the hourly flow of water is between four and eight times the volume of the tank. Each film is washed for a period of time equal to twice the fixing time. When a number of films are proceeding through the processing cycle, each film is first placed in the drain end of the tank, and then progressively moved toward the intake. This procedure insures that the last wash any film receives is with fresh water.

(1) Temperature. The temperature of the water in the wash tank is an important factor of the wash efficiency. Best results are obtained with a water temperature between 65° and 70F since higher temperatures can cause the same damaging effects as those of high temperatures in the processing solutions. At low temperatures very little

washing action takes place.

(2) Wetting. When film is removed from the wash tank, small drops of water cling to the emulsion. If permitted to remain these drops will cause water marks or streaks on the finished film. To lessen the possibility of water mark damage, film is immersed in a wetting agent and then drained for one or two minutes before drying. Wetting agents, commercially available aerosol solutions, cause the water to drain evenly from the film.

e. Drying. The final step of film processing is drying, usually accomplished by hanging the film in a drying cabinet. Drying cabinets are designed to permit flow of heated and filtered air to reach both sides of the film. If no drying cabinet is available film may be air-dried by hanging in a position where air circulates freely. Figure 4-7 is a graphic representation of the manual film processing cycle.

5. AUTOMATIC FILM PROCESSING

Automatic film processing machines are a processing system built around film, chemicals, and mechanics. They are used wherever the volume of work makes them economical. The machines accomplish all required processing and the only manual operation necessary is loading and unloading the film. Though the processing steps used in an automatic unit are the same as those for tank processing, the entire processing cycle is completed in less than 15 minutes. This high speed processing is made possible by the use of special chemicals; continual agitation of the film; maintenance of all solutions at relatively high temperatures; and drying with jets of heated air. When properly maintained and operated, automatic film processing units consistently produce radiographs of much higher quality than those processed manually.

406 DARKROOM FACILITIES

1. GENERAL

Darkroom facilities may consist of a single room where all steps of film handling and processing are accomplished, or of a series of rooms each designed for a specific activity. The location, size, and design of the facilities are dependent upon the volume and type of work to be done. The location of equipment within the facility is designed to facilitate the logical flow of film through the processing cycle. Two requirements must be satisfied in the construction of a darkroom; it must be lighted with safelight of an intensity sufficient for processing operations without endangering film by exposure to light; and it must be protected against light from outside sources.

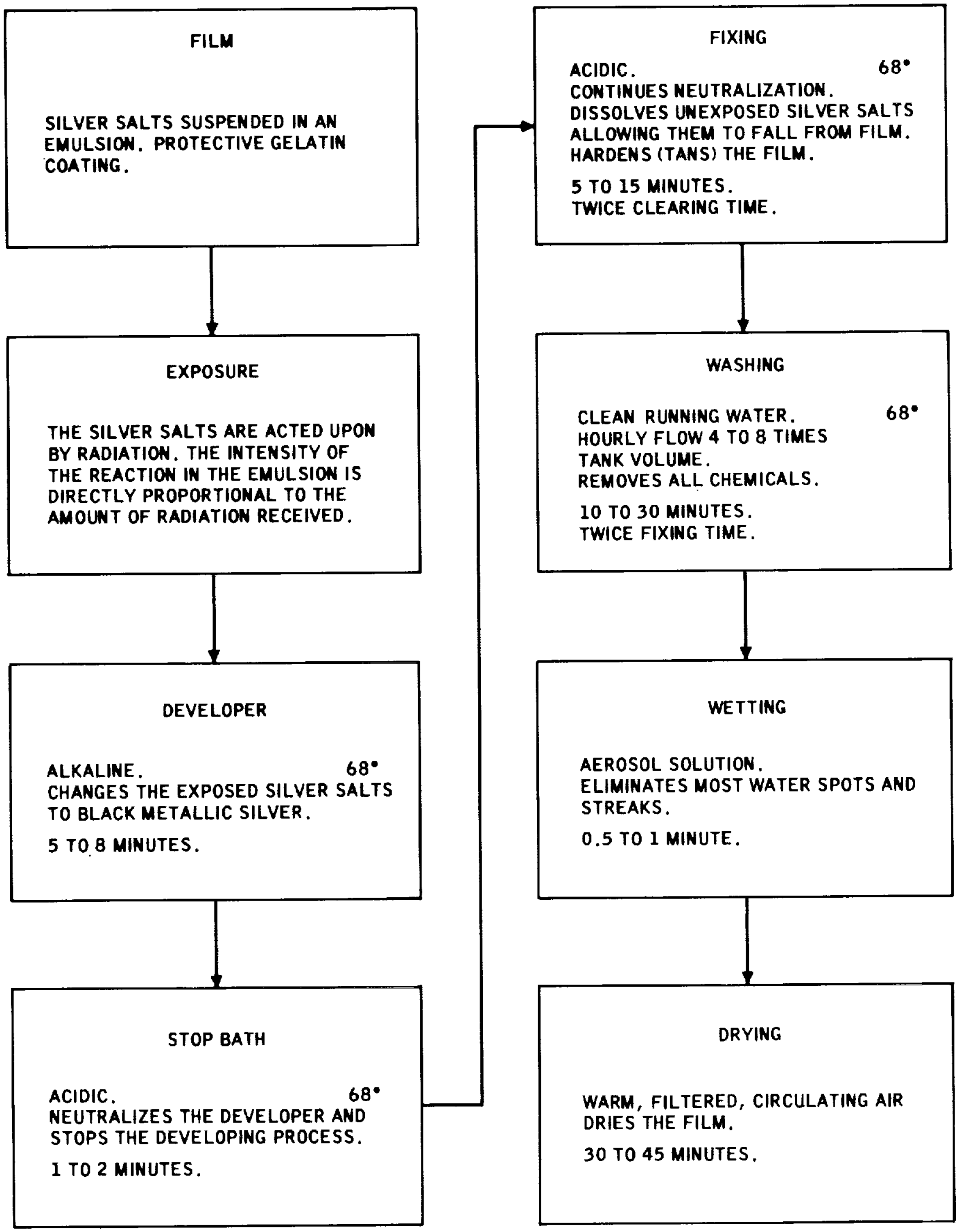


Figure 4-7. Manual Film Processing

[redacted]

2. SAFELIGHTS

The placement of safelights in the darkroom is determined by the need for maximum protection against light in the areas where unexposed film is handled (the loading bench); adequate but less protection in the developing and fixing areas; and normal safelight (white) in washing and drying areas. Safelights of correct wattage, properly filtered and at the correct distance from the film, can be used in all of these areas. Safelight installations can be determined as safe only by test. The simplest test for safelights is exposure of film to the light under time and distance conditions equivalent to those encountered during normal film handling. A portion of the test film is protected by opaque material during the exposure; after standard processing, if there is no density difference between the exposed and protected portions of the film, the light is safe.

3. PROTECTION AGAINST OUTSIDE LIGHT

Protection of darkroom spaces against outside light penetrating through entrances is a matter of proper safeguarding through the use of a door locked from the inside; a light lock made with double or revolving doors; or a labryinth (maze) entrance. Light-tight ventilators are used to prevent light entry through the darkroom ventilating system.

4. WALLS, CEILING AND FLOOR

The walls and ceiling of the darkroom are usually painted with semi-gloss paint of a pleasing light color that reflects a maximum amount of safelight. The walls in the areas where chemicals may splatter are protected with ceramic tile or glass. Darkroom floors are usually covered with a chemical-resistant, waterproof and slip-proof material.

5. AUTOMATIC PROCESSING DARKROOM

When automatic processing equipment is used, darkroom facilities are designed to accommodate the machine. Since all of the processing takes place within the machine, only the handling of unexposed film and film not yet processed, requires darkroom conditions. Usually the machine is installed through a wall so that the loading end is within a darkroom and the remainder in an open area.

407 DARKROOM EQUIPMENT

1. GENERAL

The loading bench, film storage cabinets and bins, processing tanks, and film driers are standard darkroom equipment. Handling of unprocessed film, loading and unloading of film holders and loading of processing hangers are all accomplished at the loading bench. The storage facilities for holders and hangers, and light-tight film storage bins are located in the loading bench area. This area, in which all "dry" activities of film handling take place, should be readily accessible to, but at some distance from, the processing tanks. The "dry" and "wet" areas of the darkroom are separated to prevent inadvertent water or chemical damage to film.

2. PROCESSING TANKS

The processing tanks used in the developing, stop bath, fixing, and washing processes are located in the "wet" area of the darkroom. The tanks are aligned in the order of processing. The relative sizes of the tanks fixes the amount of work that can be done. A five-gallon developer tank at normal development times can handle approximately 40 films per hour. Developer and stop bath tanks should be the same size, fixer tanks twice as large, and wash tanks at least four times as large.

3. DRYING CABINETS

Film drying cabinets should have a filtered air intake, film racks, exhaust fan, and a heating element. Since drying is the last processing step, the drier may be conveniently located for ease in film handling.

408 CLEANLINESS

Cleanliness is of great importance during the entire radiographic process. Film should be handled with care, and white gloves used during loading and unloading of film holders, and mounting of film in processing hangers. Film holders, film, and screens should be handled only in clean surroundings. Images of dirt, lead chips, scratched or nicked screens, handling crimps, scratches and nicks on the film result in a worthless radiograph. Similarly, chemical stains and streaks ruin a radiograph. The film processing area must be kept immaculately clean, and access limited to those who work in the area. Chemical contamination of the area can result in the ruin of film, so it is advisable to store chemicals in a separate area until they are used. Floors must be kept clean and preferably damp to hold down dust. High humidity assists in preventing static electricity and static marks on film. Nylon and other fabrics, which encourage static electricity, should be avoided by the radiographer.

CHAPTER 5: SAFETY
TABLE OF CONTENTS

TABLE OF CONTENTS (CONT)

CHAPTER 5: SAFETY

500 GENERAL

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

501 UNITS OF RADIATION DOSE MEASUREMENT

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

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

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

[redacted]

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

c. Rad. The rad (radiation absorbed dose) is the unit of measurement of radiation absorption by humans. It represents an absorption of 100 ergs of energy per gram of irradiated material, at the place of exposure. The roentgen applies only to X- and gamma rays; the rad applies to any type of radiation.

d. Rbe. The value assigned to various types of radiation, determined by the radiation's effect on the human body, is called rbe (relative biological effectiveness). Practically, the dose in rem is the product of the rad and rbe. Rbe values have been calculated by the National Committee on Radiation Protection as shown in Table 5-1.

Table 5-1. RBE Values

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

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

502 MAXIMUM PERMISSIBLE DOSE

1. GENERAL

It is impossible and impractical to safeguard radiographic personnel from some exposure to radiation. Permissible dose is defined by the National Bureau of Standards as, "...the dose of ionizing radiation that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime." Maximum permissible dose is the numerical value of the highest permissible dose, under prescribed conditions of exposure, stated in units of time. Currently accepted mpd, established through experience, is contained in USAEC regulations on Standards for Protection Against Radiation. Maximum radiation dose, in any period of one calendar quarter, to an individual in a restricted area, is normally limited to 1-1/4 rem. Maximum permissible dose per year must not average over 5 rem for each year past the age 18. An average weekly dose of 100 mrem is within tolerance dose levels. Under certain circumstances defined by cognizant government regulatory bodies, exposures up to 3 rem per calendar quarter may be permitted. Applicable radiation safety publications are issued by the National Bureau of Standards, the National Committee on Radiation Protection, the USAEC, and state authorities. The radiographer should be cognizant of the information in the "AEC Licensing Guide for Industrial Radiography", which is available from the U.S. Government Printing Office.

2. BANKING CONCEPT

The foregoing permissible radiation exposure rates are based on the banking concept of radiation exposure. This concept considers that an individual should not be subjected to radiation exposure prior to the age of 18. For each year of life after 18 the individual is given a credit of 5 rem. Exposure in any one year should not exceed 12 rem. Figure 5-1 illustrates the banking concept.

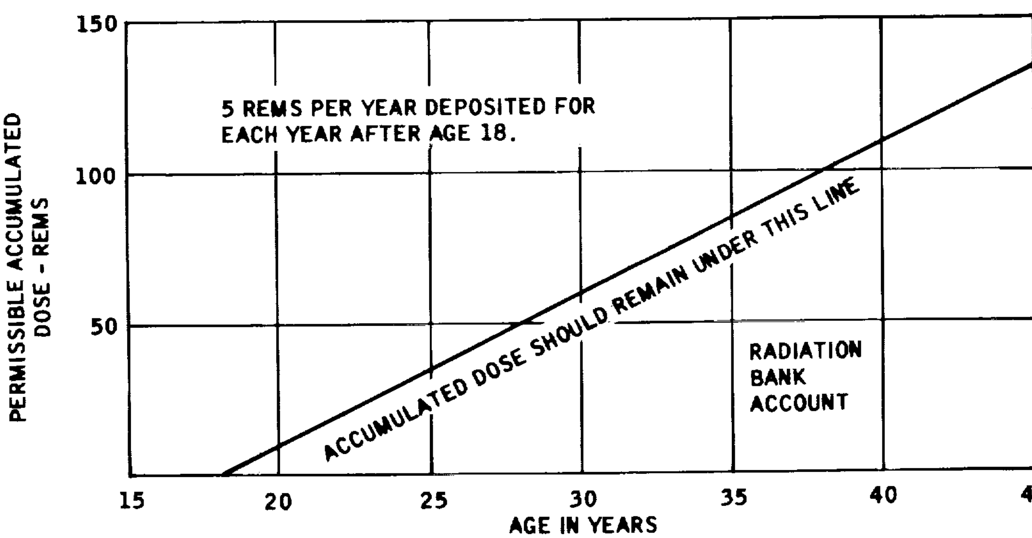


Figure 5-1. Banking Concept

503 PROTECTION AGAINST RADIATION

1. GENERAL

Three cardinal principles govern safety practices for controlling body exposure to radiation; time, distance, and shielding. Safe radiographic techniques and radiographic installations are designed by applying these principles.

2. ALLOWABLE WORKING TIME

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

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

3. WORKING DISTANCE

The greater the distance from a radiation source, the lower the exposure received. The inverse square law is used to calculate radiation intensities at various distances from a source. The inverse square law (Figure 2-8) is expressed as:

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

where I_1 and I are intensities at D_1 and D respectively. The following examples illustrate methods used to calculate radiation intensities in terms of dose rate. Table 5-2 lists dose rates of commonly used radioisotopes referred to in the examples.

Table 5-2. Radioisotope Dose Rates

RADIOISOTOPE	DOSE RATE R/HR/CURIE AT 1 FOOT EMISSIVITY
COBALT-60	14.5
IRIDIUM-192	5.9
CESIUM-137	4.2
THULIUM-170	0.03

[redacted]

Example 1: Given a 12 curie Cesium 137 source, what is the emission at 3 feet?

Step 1: From Table 5-2, the dose rate of Cesium 137 is 4.2 r/hr/c at one foot; thus, the dose rate of a 12 curie source at one foot is 12 x 4.2 or 50.4 r/hr.

Step 2: I = 50.4 r/hr

D = 1 foot

D_1 = 3 feet

Step 3: Substituting in the inverse square law equation

$$\frac{I_1}{50.4} = \frac{1^2}{3^2}$$

Step 4: Solving for I_1

$$I_1 = 50.4 \times \frac{1^2}{3^2} = 50.4 \times \frac{1}{9} = 5.6 \text{ r/hr}$$

Example 2: A 35 curie source of Iridium 192 is used at distance of 20 feet from a workman. What dose rate will he receive?

Step 1: From Table 5-1, the dose rate of Iridium 192 is 5.9 r/hr/c at one foot; thus, the dose rate of a 35 curie source at one foot is 35 x 5.9 or 206.5 r/hr.

Step 2: I = 206.5 r/hr

D = 1 foot

D_1 = 20 feet

Step 3: Substituting in the inverse square law equation

$$\frac{I_1}{206.5} = \frac{1^2}{20^2}$$

Step 4: Solving for I_1

$$I_1 = 206.5 \times \frac{1^2}{20^2} = 206.5 \times \frac{1}{400} = .51625 \text{ r/hr}$$

[redacted]

Example 3: In example 2, at what distance from the source should the workman be to receive only 3 mr/hr?

Step 1: I = 206.5 r/hr, or 206,500 mr/hr

I_1 = 3 mr/hr

D = 1 foot

Step 2: Substituting in the inverse square law equation

$$\frac{3}{206,500} = \frac{1^2}{D_1^2}$$

Step 3: Solving for D_1

$$D_1^2 = \frac{206,500 \times 1^2}{3} = 68,833$$

$$D_1 = \sqrt{68,833} = 262+ \text{ feet}$$

a. Tables such as Table 5-3, which list the dose rates at various distances from a source, are derived by application of the inverse square law.

Example: Given the dose rate of Cobalt 60 as 14.5 r/hr/c at one foot, what is the dose rate at 2, 4, 8, etc. feet?

Step 1: I = 14.5 r/hr/c

D = 1 foot

D_1 = 2 feet

Step 2: Substituting in the inverse square law equation

$$\frac{I_1}{14.5} = \frac{1^2}{2^2}$$

Step 3: Solving for I_1

$$I_1 = 14.5 \times \frac{1^2}{2^2} = 14.5 \times \frac{1}{4} = 3.6 \text{ r/hr/c}$$

Step 4: Solve for dose rates at other distances in similar fashion.

Table 5-3. Radioisotope Dose Rates vs Distance

DOSE RATE IN REMS PER HOUR PER CURIE				
DISTANCE	COBALT-60	IRIDIUM-192	CESIUM-137	THULIUM-170
1 FOOT	14.5	5.9	4.2	0.03
2 FEET	3.6	1.5	1.1	0.007
4 FEET	0.9	0.4	0.26	0.002
8 FEET	0.23	0.09	0.07	0.0004
10 FEET	0.145	0.059	0.042	0.00027

b. All of the foregoing examples are based on gamma radiation; however, the same principles for calculating dose rate or radiation intensity hold for X-radiation. In determining X-radiation intensities it is necessary to measure intensity at a known distance with predetermined ma and kv settings, and then apply the inverse square law. Any change in X-ray machine settings requires a new intensity measurement and recalculation.

c. Intensity and dose rate calculations based on the inverse square law should never be accepted as exact. Radiation intensity at any point is the sum of the primary radiation and the secondary (scatter) radiation at that point. Only under ideal conditions of no scatter, and in a complete vacuum, are calculated intensities exact.

4. SHIELDING

Lead, steel, iron, and concrete are materials commonly used as shielding to reduce personnel exposure. Since all of the energy of X- or gamma radiation cannot be stopped by shielding, it is practical to measure shielding efficiency in terms of half-value layers. The half-value layer is that amount of shielding which will stop half of the radiation of a given intensity. Similarly, shielding efficiency is often measured in tenth-value layers. A tenth-value layer is that amount of shielding which will stop nine-tenths of the radiation of a given intensity. See Tables 5-4 and 5-5. Half- and tenth-value layers are, in all cases, determined by experiment and actual measurement. The radiographer should rely only on actual measurement to determine the effectiveness of any shielding. The following examples illustrate the application of half-value layer information.

Example 1: A 200-kvp X-ray machine must be located so that the primary radiation is directed toward an adjacent occupied room. Without shielding, the dose rate in the adjacent room is 500 times the acceptable safe limit. How thick a concrete wall is required to reduce the dose rate in the adjacent room to a safe value?

Step 1: Since one half-value layer (HVL) reduces dose rate by a factor of $\frac{1}{2}$; two HVL by $\frac{1}{2} \times \frac{1}{2}$ or $\frac{1}{2^2}$; three HVL by $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$ or $\frac{1}{2^3}$;

etc., then 9 HVL will reduce dose rate by a factor of $\frac{1}{2^9}$ or $\frac{1}{512}$

and 9 HVL will reduce the dose rate to an acceptable safe limit.

Table 5-4. Approximate X-ray Half Value Layers

SHIELDING MATERIAL	HALF-VALUE LAYER FOR TUBE POTENTIAL OF							
	50 kvp	70 kvp	100 kvp	125 kvp	150 kvp	200 kvp	250 kvp	300 kvp
LEAD (mm)	0.05	0.18	0.24	0.27	0.3	0.5	0.8	1.5
CONCRETE (in.)	0.2	0.5	0.7	0.8	0.9	1.0	1.1	1.2

Table 5-5. Approximate Gamma Ray Half and Tenth Value Layers

SHIELDING MATERIAL IN INCHES	RADIOISOTOPE SOURCE					
	COBALT-60		IRIDIUM-192		CESIUM-137	
	1/10	1/2	1/10	1/2	1/10	1/2
LEAD	1.62	0.49	0.64	0.19	0.84	0.25
STEEL	2.90	0.87	2.0	0.61	2.25	0.68
CONCRETE OR ALUMINUM	8.6	2.6	6.2	1.9	7.1	2.1

Step 2: From Table 5-3 the concrete half-value layer for 200-kvp radiation is one inch. Thus, 9 inches of concrete shielding is required to reduce the dose rate to an acceptable safe value.

Example 2: In a previous example it was found that the dose rate for a workman 20 feet from a 35 curie Iridium 192 source was 516.25 mr/hr. If the workman must remain at his location, how much lead shielding is required to reduce the dose rate to 3 mr/hr?

Step 1: The desired dose rate is 3/mr/hr; therefore the original dose rate of 516.25 must be reduced $\frac{516.25}{3}$ or 172 times.

Step 2: Seven HVL reduces dose rate by a factor of $\frac{1}{2^7}$ or 128 times, but HVL reduces it by a factor of $\frac{1}{2^8}$ or 256^2 times. Thus, 7 HVL will not provide the required shielding but 8 HVL will.

Step 3: From Table 5-4, the lead half-value layer for Iridium 192 radiation is 0.19 inch. Therefore, 8 x 0.19 or 1.52 inches of lead shielding is required to reduce the dose rate to an acceptable safe value.

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

b. X-ray Tube Shielding. Theoretically, the lead housing around an X-ray tube effectively shields, to safe levels, all primary radiation except the useful

[redacted]

beam. Practically, this is not always the case, and the only way to assure the safeness of an X-ray tube is to measure leakage (unwanted) radiation about it. To limit the unwanted radiation, the area of primary radiation should be fixed by a cone or diaphragm at the tubehead.

c. Radiation Protective Construction. The most common material used to protect against radiation is lead. It is easily available and comparatively low in cost. Shielding protective measurements are usually expressed in terms of lead thickness. Particular care must be exercised to assure leakproof shielding. Adjacent sheets of lead must be overlapped, and nails or screws that pass through the lead, must also be covered with lead. Pipes, conduits, and air ducts passing through the walls of the shielded area must be completely shielded. Figure 5-2 illustrates good lead shielding construction practices.

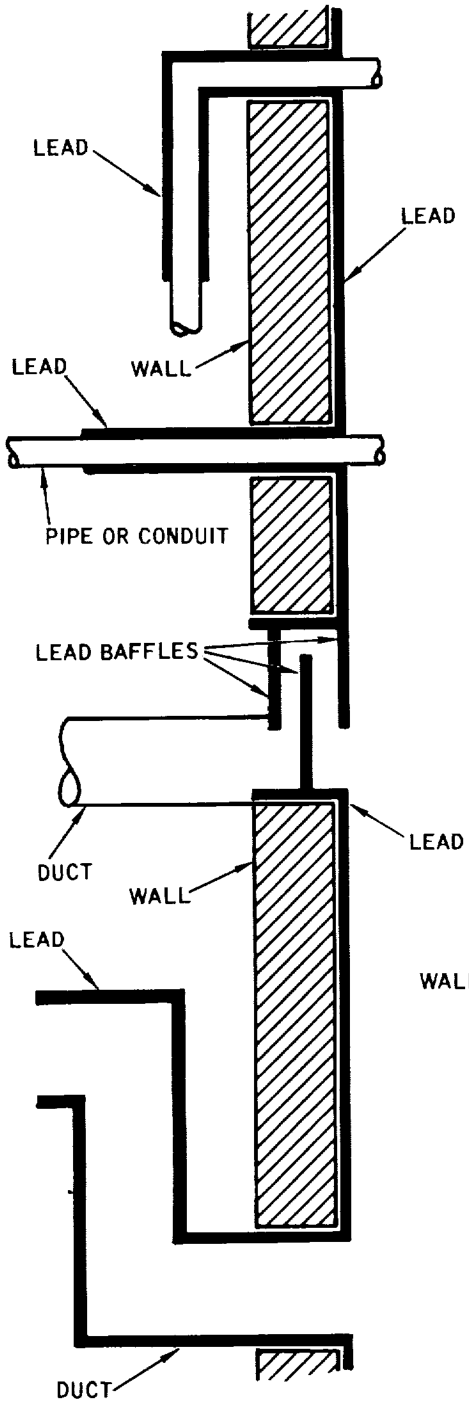
(1) The thickness of lead shield employed is dependent upon the energy of the radiation requiring shielding and the use (occupancy) of the surrounding areas. If the spaces, above, below, and about the exposure area are all occupied, then all of the exposure area — wall, ceiling and floor — must be shielded. If the room is on the top floor of the building it is not necessary to shield all of the ceiling, similarly if the room is on the bottom floor not all of the floor need be shielded. The methods of partial floor shielding shown in Figure 5-2 apply also to partial shielding of a ceiling. In either case, the partial shielding prevents radiation escaping above or below the wall and scattering into an adjacent area.

(2) Though lead is the most efficient of the easily available shielding materials, other structural materials such as concrete and brick are often used. At voltages greater than 400 kv, the thickness of lead shielding would be so great as to make it difficult to fasten the lead to the walls. At these higher potentials, concrete is used as shielding because of its relative effectiveness and its construction simplicity.

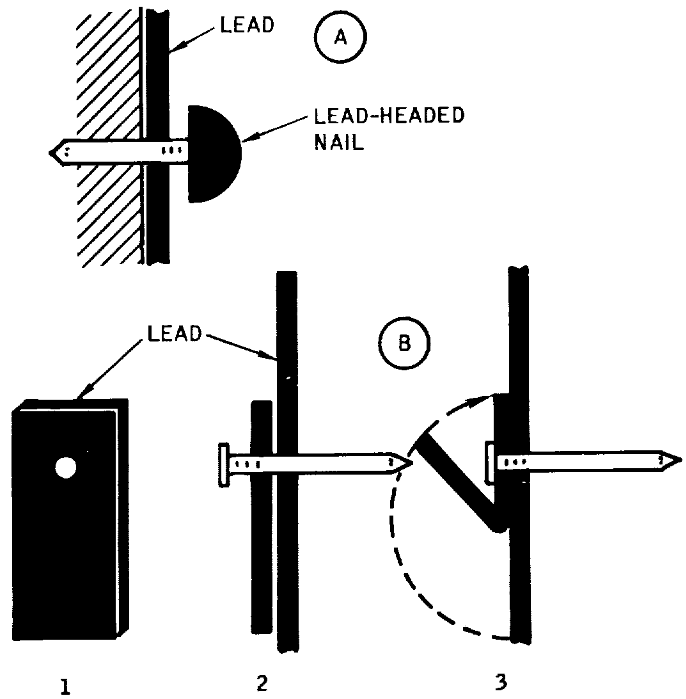
5. GAMMA RAY REQUIREMENTS

Special gamma radiation protection requirements are based on two factors: Gamma radiation is very penetrating, and the required protective shielding is excessively thick and heavy. (See Table 5-5.) Gamma radiation cannot be shut off, and protection must be provided at all times.

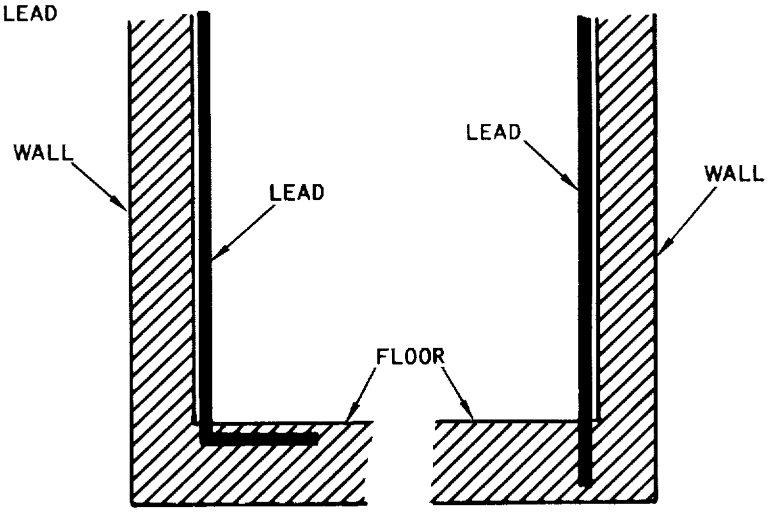
a. The penetrating capability of gamma radiation makes it impractical to rely on shielding for protection during gamma radiography; a combination of distance and shielding is usually employed. The radiation danger zone is roped off and clearly marked with conspicuous signs, and only those



METHODS OF SHIELDING WHEN PIPES, DUCTS, OR CONDUITS MUST PASS THROUGH WALLS OF AN X-RAY ROOM



METHODS OF SEALING NAIL OR SCREW HOLES IN LEAD PROTECTION
A - LEAD-HEADED NAIL
B - LEAD STRIP FOLDED OVER NAIL HEADS



METHODS OF HANDLING PROTECTION AT FLOOR LEVEL WHEN PROTECTION IS NOT NEEDED OVER ENTIRE FLOOR

Figure 5-2. Radiation Protection Constructions

[redacted]

persons making the radiograph are permitted in the zone. The extent of the danger zone is based on calculations of safe distance as determined by the source strength. In calculating the area of the danger zone, the possible effects of scatter radiation are considered and the calculations are confirmed by intensity measurements.

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

504 USAEC RULES AND REGULATIONS

1. GENERAL

The previously discussed safety precautions are non specific in nature. Handling, storage, and use of radioisotopes is regulated by the USAEC. The regulations are published in the Code of Federal Regulations, Title 10, Chapter I, parts 20, 30 and 31. These three parts of the Code are also published in the AEC Licensing Guide. The following regulations are subject to change and are presented for familiarization purposes.

2. EXPOSURE OF INDIVIDUALS TO RADIATION IN RESTRICTED AREAS

Limitations on individual dosage are specified in Table 5-6.

Table 5-6. Exposure Limits in Restricted Areas

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

[redacted]

a. Doses greater than specified in the table may be permitted provided: (1) during any calendar quarter the dose to the whole body does not exceed 3 rems; (2) the dose to the whole body, when added to the accumulated occupational dose to the whole body, does not exceed 5 (N-18) rems where "N" equals the individual's age in years at his last birthday; and (3) the individual's accumulated occupational dose has been recorded on Form AEC-4 (Figure 5-3) and the concerned individual has signed the form.

b. Form AEC-5, Current Occupational External Radiation Exposure, is shown in Figure 5-4. This form must be completed quarterly and is the source of the information recorded on Form AEC-4 (Figure 5-3).

3. EXPOSURE OF MINORS

Radiation damage becomes comparatively less severe as an individual ages. Minors are not allowed to work in restricted areas. Regulations to protect minors specify that no individual under 18 years of age is permitted to receive dosages exceeding 10% of the limits specified in Table 5-6.

4. PERMISSIBLE LEVELS OF RADIATION IN UNRESTRICTED AREAS

Under approved circumstances, a limited amount of radiation is permitted in unrestricted areas. Exposure limits in unrestricted areas are listed in Table 5-7. These dosage limits are based on an individual being continually present in the area and thus represent maximum radiation levels permitted.

Table 5-7. Exposure Limits in Unrestricted Areas

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

FORM AEC-4
(9-60)

Form Approved
Bureau of Budget No. 38 R119
Expiration Date: June 30, 1961

U.S. ATOMIC ENERGY COMMISSION

OCCUPATIONAL EXTERNAL RADIATION EXPOSURE HISTORY

See Instructions on the Back

IDENTIFICATION

1. NAME (PRINT—LAST, FIRST, AND MIDDLE)	2. SOCIAL SECURITY NO
3. DATE OF BIRTH (MONTH, DAY, YEAR)	4. AGE IN FULL YEARS (N)

OCCUPATIONAL EXPOSURE—PREVIOUS HISTORY

5. PREVIOUS EMPLOYMENTS INVOLVING RADIATION EXPOSURE—LIST NAME AND ADDRESS OF EMPLOYER	6. DATES OF EMPLOYMENT (FROM—TO)	7. PERIODS OF EXPOSURE	PREVIOUS DOSE HISTORY	
			8. WHOLE BODY (REM)	9. INSERT ONE RECORD OR CALCULATED
10. REMARKS		11. ACCUMULATED OCCUPATIONAL DOSE—TOTAL		

13. CALCULATIONS—PERMISSIBLE DOSE

WHOLE BODY

(A) PERMISSIBLE ACCUMULATED DOSE = 5(N-18) = ______ REM

(B) TOTAL EXPOSURE TO DATE (FROM ITEM 14) = ______ REM

(C) PERMISSIBLE DOSE = ______ REM

12. CERTIFICATION: I CERTIFY THAT THE EXPOSURE HISTORY LISTED IN COLUMNS 5, 6, AND 7 IS CORRECT AND COMPLETE TO THE BEST OF MY KNOWLEDGE AND BELIEF.

EMPLOYEE'S SIGNATURE ______ DATE ______

14. NAME OF LICENSEE

Figure 5-3. Occupational External Radiation Exposure History (Typical)

[redacted]

FORM AEC—5
(9-60)

Form approv
Bureau of Budget No. 38-R12
Expiration date June 30, 19

U.S. ATOMIC ENERGY COMMISSION

Current Occupational External Radiation Exposure

See Instructions on the Back

IDENTIFICATION

1. NAME (PRINT—Last, first, and middle)	2. SOCIAL SECURITY NO.
3. DATE OF BIRTH (Month, day, year)	4. AGE IN FULL YEARS (N)

OCCUPATIONAL EXPOSURE

5. DOSE RECORDED FOR (Specify: Whole body; skin of whole body; or hands and forearms, feet and ankles.)	6. PERMISSIBLE DOSE AT BEGINNING OF PERIOD COVERED BY THIS SHEET	7. METHOD OF MONITORING (e.g., Film Badge—FB; Pocket Chamber—PC, Calculations—Calc.

8. PERIOD OF EXPOSURE (From—to)	DOSE FOR THE PERIOD (rem)				13. RUNNING TOTAL FOR CALENDAR QUARTER (rem)
	9. GAMMA	10. BETA	11. NEUTRON	12. TOTAL	

LIFETIME ACCUMULATED DOSE

14. PREVIOUS TOTAL	15. TOTAL DOSE RECORDED ON THIS SHEET	16. TOTAL ACCUMULATED DOSE	17. PERM. ACC. DOSE	18. PERMISSIBLE DOSE
rem	rem	rem	5(N — 18) = rem	rem

19. NAME OF LICENSEE

Figure 5-4. Current Occupational External Radiation Exposure (Typical)

[redacted]

5. PERSONNEL MONITORING

a. Personnel monitoring equipment must be used by:

(1) Individuals entering restricted areas who receive, or may receive, dosage in any calendar quarter in excess of 25% of the applicable value specified in Table 5-6.

(2) Individuals under 18 years of age entering restricted areas who receive, or may receive, dosage in any calendar quarter in excess of 5% of the applicable value specified in Table 5-6.

(3) Individuals who enter high radiation areas.

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

6. CAUTION SIGNS, LABELS, AND SIGNALS

The radiation symbol is shown in Figure 5-5. Signs bearing this symbol must be placed in conspicuous places in all exposure areas, and on all containers in which radioactive materials are transported, stored, or used. On each sign the word "Caution," or the word "Danger," must appear. Other wording required is determined by specific sign use. Area signs bear the phrases, "Radiation Area," "High Radiation Area," or "Airborne Radioactivity Area," as appropriate. Containers of radioactive materials and areas housing such containers must be marked with signs or labels bearing the radiation symbol and the words "Radioactive Material(s)." Special tags bearing the radiation symbol and the phrase, "Danger-Radioactive Material-Do Not Handle. Notify Civil Authorities If Found," must be attached to sealed sources not fastened to, or contained in, an exposure device.

7. RADIOGRAPHIC EXPOSURE DEVICES AND STORAGE CONTAINERS

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

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

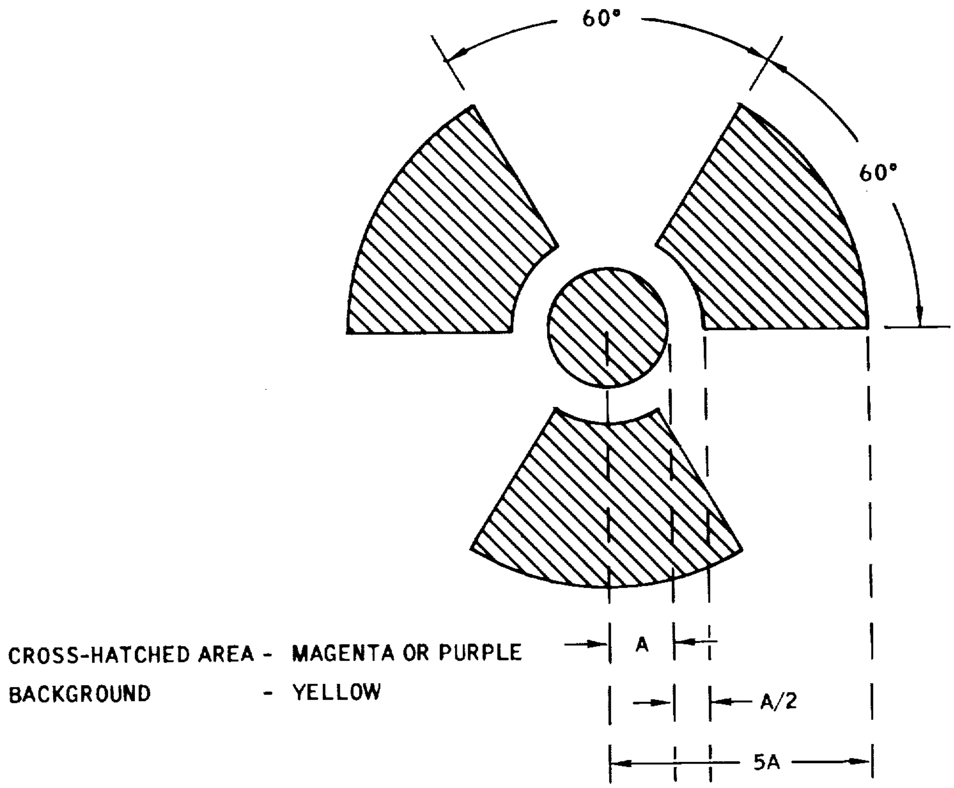


Figure 5-5. Radiation Symbol

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

8. RADIATION SURVEY INSTRUMENTATION REQUIREMENTS

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

9. RADIATION SURVEYS

Specific regulations for required surveys are as follows:

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

b. A physical radiation survey shall be made after each radiographic exposure

[redacted]

during operation to determine that the sealed source has been returned to its shielded condition.

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

505 RADIATION DETECTION AND MEASUREMENT INSTRUMENTS

1. GENERAL

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

2. POCKET DOSIMETERS AND POCKET CHAMBERS

The pocket dosimeter (Figure 5-6) is a small device approximately the size of a fountain pen. Its operation is based on two principles: (1) like or similar electrical charges repel each other; and (2) radiation causes ionization in a gas. The essential parts of the dosimeter are the metal cylinder, the metal-coated quartz fiber electrode consisting of a fixed section and a movable section, the transparent scale, and the lens. The electrode and the cylinder form an electroscope. When a potential (from an external source of voltage) is applied between the electrode and the cylinder, the electrode gains a positive charge and the cylinder a negative charge. Simultaneously, the movable portion of the eltrode moves away from the fixed portion since they are mutually repellent, each carrying a positive charge. The transparent scale and the lens are so placed that, when the scale is viewed through the lens, the movable portion of the electrode appears as the indicator on the scale. When the dosimeter is properly charged, the indicator will be at zero scale and the dosimeter is ready for use.

a. When a dosimeter is placed in an area of radiation, ionization takes place in the cylinder chamber. Negative ions are attracted to the electrode and positive ions to the cylinder. As the positive charge on the electrode becomes neutralized, the repellent force between the fixed and movable portions decreases. The movable portion moves toward the fixed portion

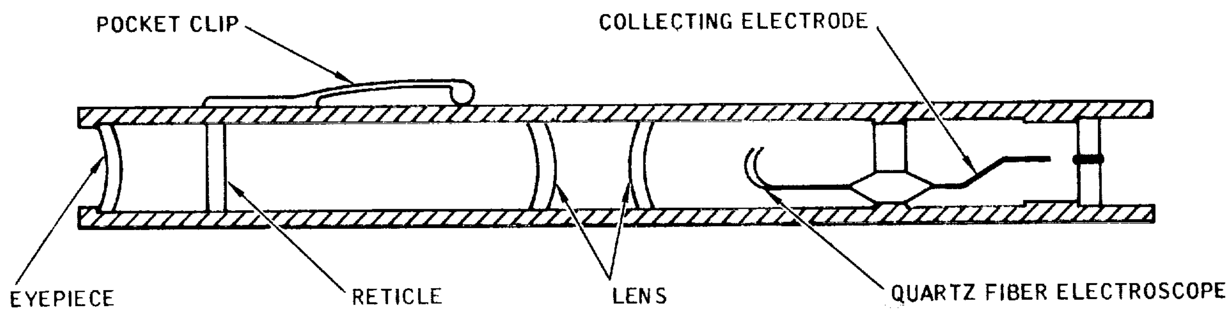


Figure 5-6. Pocket Dosimeter (Typical)

in an amount proportional to the ionization action. Since the quantity of ionization is determined by the quantity of radiation, the displacement of the movable portion of the electrode is a direct measure of radiation. Pocket dosimeters are designed with a sensitivity that permits them to be scaled in doses from 0 to 200 milliroentgens.

b. Dosimeters that are not direct reading (Figure 5-7) are called pocket chambers. Pocket chambers serve the same purpose as direct reading dosimeters but are more rugged. They are designed on the condenser principle, the central electrode and the chamber wall acting as the plates of a condenser. A charge is placed across the center electrode and the chamber wall by a separate charging device. The charger contains a power supply, a calibrated scale, a lens system, a means of varying the charge applied to the chamber, and a movable fiber. Prior to use, the chamber is charged until the movable fiber has moved across the calibrated scale to the zero position. When the chamber is exposed to radiation, ionization in the chamber decreases the charge between the center electrode and the chamber wall in direct proportion to the degree of ionization. After exposure, the chamber is inserted in the charger and the movable fiber (operating on the same electrostat principle as the electrode of a dosimeter) moves across the scale to a position determined by the charge remaining between the center electrode and the chamber wall, thus directly indicating the quantity of radiation causing ionization in the chamber. To avoid error, the chamber must always be read on the same charger used to charge the chamber.

[redacted]

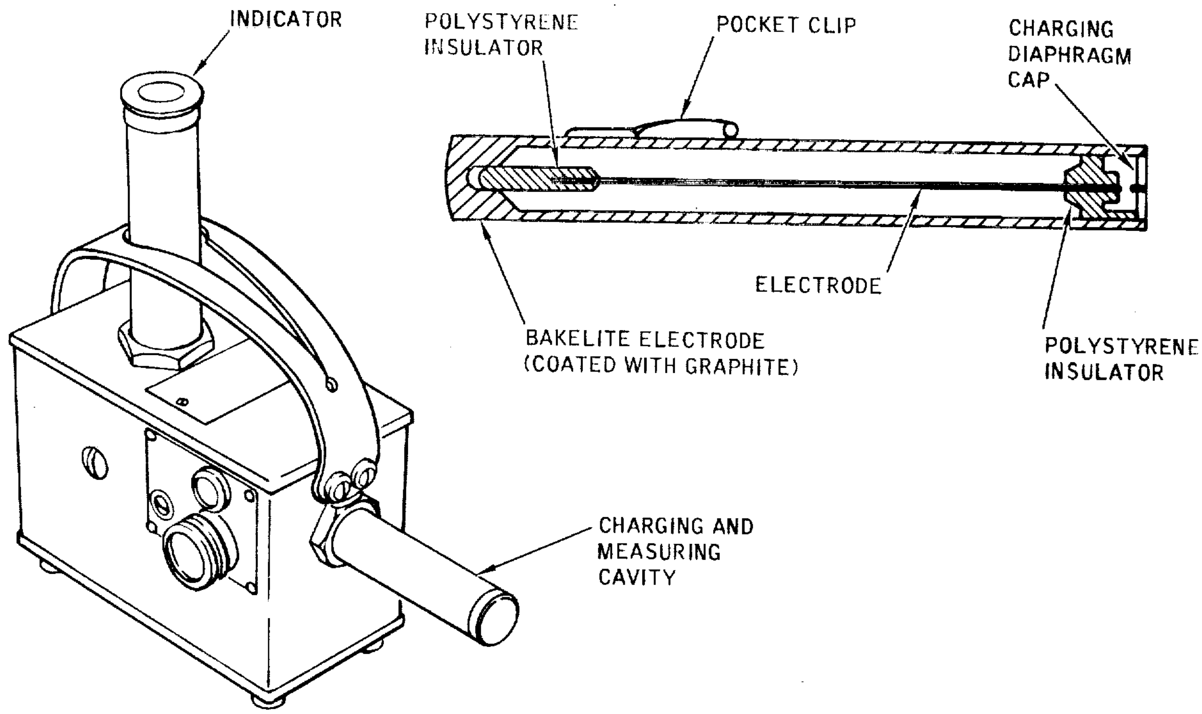


Figure 5-7. Pocket Chamber and Charger (Typical)

3. FILM BADGES

The film badge (Figure 5-8) consists of a small film holder equipped with thin lead or cadium filters, in which is inserted special X-ray film. The badge is designed to be worn by an individual when in radiation areas, and is not to be otherwise exposed. After a period of time, usually two weeks, the film is removed and developed by standard techniques. The density of the processed film is proportional to the radiation received. By use of a densitometer the density of the film is compared to that of a set of control films. Through this comparison, an estimate of the amount of radiation received by the individual, who wore the badge, is made. Film badges and dosimeters each record total radiation received and serve as a check on each other.

4. SURVEY METERS

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

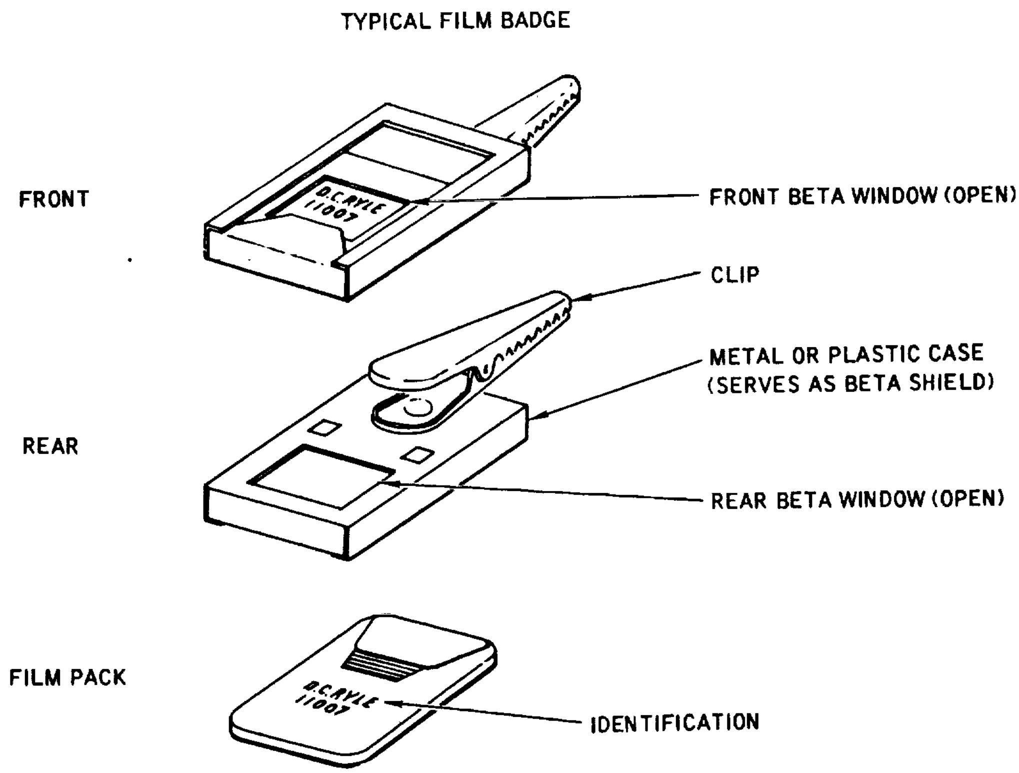


Figure 5-8. Film Badge (Typical)

5. IONIZATION CHAMBER INSTRUMENTS

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

6. GEIGER COUNTERS

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

7. AREA ALARM SYSTEMS

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

506 ELECTRICAL SAFETY

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

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

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

b. Insure that grounding instructions are complied with.

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

d. Avoid handling power cables when power is ON.

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

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

2. If common sense precautions are observed there is little electrical hazard in the use of X-ray equipment.

[redacted]

CHAPTER 6: SPECIALIZED APPLICATIONS
TABLE OF CONTENTS

[redacted]

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

CHAPTER 6: SPECIALIZED APPLICATIONS

600 GENERAL

A quality radiograph will have minimum distortion, sharp definition, high contrast, and adequate density where exposure is controlled. These four requirements influence all of the techniques of radiography. Any technique that fulfills one or more of them, without compromising any other, is a good application. The radiographer need only follow procedures that meet these requirements to produce quality radiographs.

1. Most of the large number of variables in radiography have been discussed in previous chapters. Many of the variables can be treated as constants by application of the information contained in charts and graphs. Others can be related to the charts, or to the known constants of specific equipment. This chapter presents information of proven shop and laboratory exposure techniques that assure reasonable control of the variables for the majority of radiographic tasks. The radiographer with a basic knowledge and understanding of the radiographic process, and the ability to use the charts and graphs available to him, can readily devise effective procedures for the radiography of different specimens.

2. Proper film processing as described in Chapter 4 is an essential part of good radiographic practice. An ideal exposure technique can result in a worthless radiograph if the film is improperly processed. The exposure techniques that follow are all based on correct handling of the film during processing.

601 SELECTION OF EQUIPMENT

1. Selection of equipment for a particular test consists of the following related decisions.

   a. Selection of radiography as a test method.

   b. Selection of X- or gamma radiography.

   c. Selection of specific X- or gamma ray equipment.

2. As previously stated, radiography is but one of the nondestructive test methods in common use. Before selecting radiographic equipment for a task it must first be determined that radiography will produce the desired test results. This determination cannot be made until the task has been thoroughly analyzed.

3. Ideally, there is a best equipment selection for any radiographic test. Practically, most radiography is accomplished by using the equipment available. The equipment lends itself to numerous adaptations and, by knowledgeable choice of film and exposure, any particular equipment can be used for a variety of tasks. For this reason the capabilities of individual X-ray machines and isotope cameras overlap in

[redacted]

many areas of test. Except in large production installations, or in a test laboratory, it is impractical to have multiple radiographic equipment. Therefore, it is the responsibility of radiographic test and quality assurance personnel to insure that the equipment and techniques selected are capable of performing the required task.

4. Because of its flexibility, ease of operation, and fewer radiation hazards, X-radiography is preferred to gamma radiography. Gamma radiography is usually selected for industrial applications that involve:

a. High radiation energy requirements.

b. Low testing rates.

c. Simultaneous exposure of many specimens.

d. Confined areas where X-ray cannot be used.

e. Field inspections in areas where electrical power is difficult to obtain.

f. Tasks where time is not a consideration.

5. Prior to the selection of specific radiographic equipment for a test, the radiographer must consider all aspects of the job. Available equipment, the time allocated for the test, and the number or frequency of similar specimen tests are major considerations influencing equipment selection. Since each task is different, the selection among available equipment is the responsibility of the radiographer.

602 ACCESSORY EQUIPMENT

1. GENERAL

To create a radiograph, only a radiation source, a specimen, and film are needed. To create a useful radiograph of quality, additional equipment is required. This equipment, the working tools of a radiographer, includes:

a. Diaphragms, collimators and cones.

b. Filters.

c. Screens

d. Masking material.

e. Penetrameters.

f. Shim stock.

g. Step wedges.

h. Film holders and cassettes.

i. Linear and angular measuring devices.

j. Positioning devices.

k. Identification and orientation markers.

l. Shielding material.

m. Densitometer.

n. X-ray exposure charts.

o. Gamma ray exposure charts.

p. Dated decay curves.

q. Film characteristic (H & D) curves.

r. Table of radiographic equivalence factors.

2. DIAPHRAGMS, COLLIMATORS, AND CONES

Diaphragms, collimators, and cones are thicknesses of lead, fitted to the tubehead of X-ray equipment, or built to contain a gamma ray source, and designed to limit the area of radiation. (See Figure 6-1.) They decrease the amount of scatter radiation by limiting the beam to the desired specimen area. Many X-ray machines have built-in adjustable diaphragms designed so that the beam at a fixed distance covers a standard film size area.

3. FILTERS

Filters are sheets of high atomic number metal, usually brass, copper, steel, or lead, placed in the X-ray beam at the tubehead. (See Figure 6-2.) By absorbing the "soft" radiation of the beam, filters accomplish two purposes: they reduce subject contrast permitting a wide range of specimen thicknesses to be recorded with one exposure; and they eliminate scatter caused by soft radiation. Filters are particularly useful in radiography of specimens with adjacent thick and thin sections.

a. The material and thickness of the specimen, and its range of thicknesses determine the filter action required. No tables of filter thicknesses are available; however, in radiographing steel, good results have been obtained by using lead filters, 3% of the maximum specimen thickness; or copper filters, 20% of the maximum specimen thickness. Particular care must be exercised in the use of lead filters since defects in the filter may be mistakenly interpreted as specimen defects.

4. SCREENS

When an X- or gamma ray beam comes in contact with film, less than one percent of the radiation energy available is absorbed by the film in producing an image through

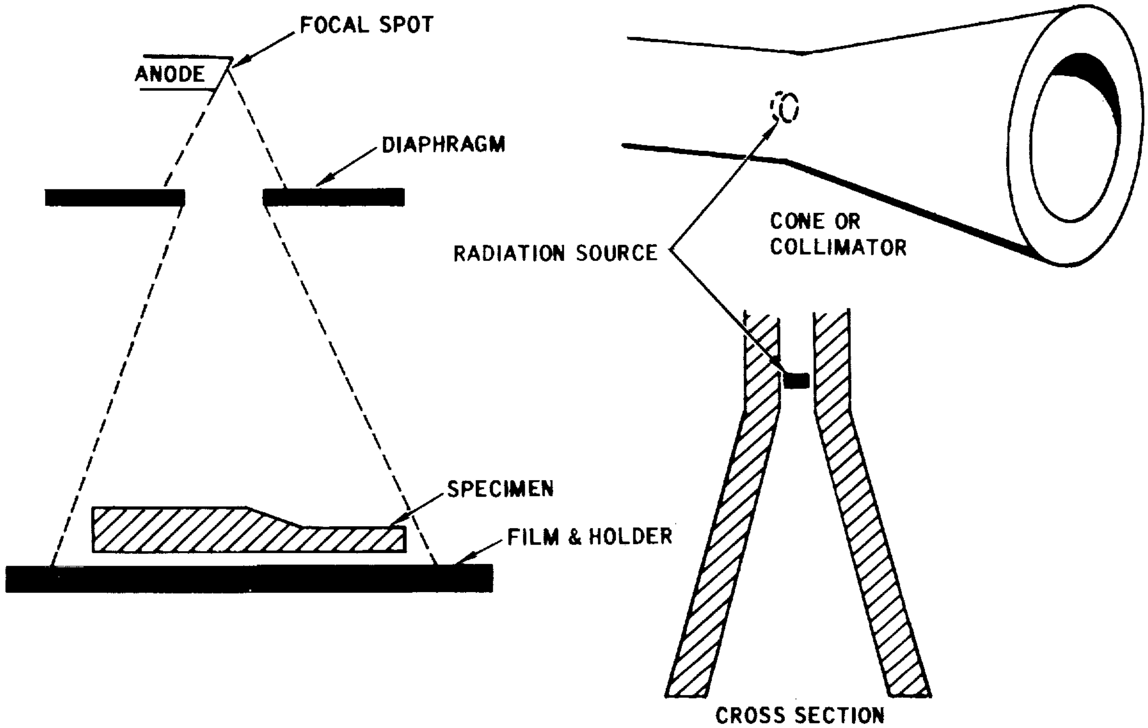


Figure 6-1. Diaphragm, Collimator and Cone

photographic effect. To convert the unused energy into a form that can be absorbed by film, two types of radiographic screens are used: fluorescent and lead.

a. Fluorescent Screens. Fluorescent screens consist of powdered fluorescent material, usually calcium tungstate, bonded to a plastic or cardboard base.

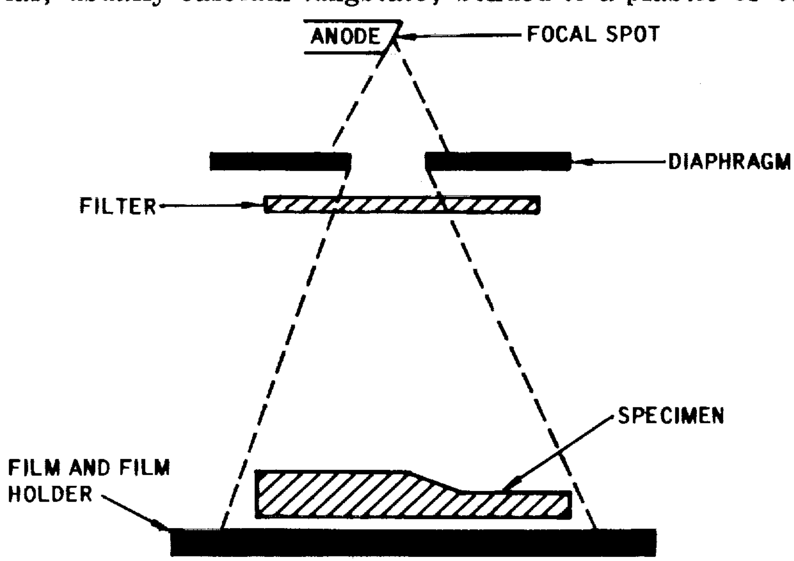


Figure 6-2. Filter

[redacted]

When activated by radiation, the fluorescent material emits light in proportion to the amount of radiation available for absorption. The screens are used in pairs with the film placed between them in a clamp type film holder. During exposure, the photographic effect on the film is the additive result of the radiation, and the light emitted by the screens, impinging on the film. Since the emitted light is diffused, image definition is less sharp when the screens are used. Close contact between the screens and the film must be maintained or the diffused light will cause a blurred, worthless, radiograph.

(1) The ratio of an exposure without screens to an exposure with screens, which results in films of similar density, is called the intensification factor. Fluorescent screens have a high intensification factor permitting reductions in exposure of the magnitude of 95%. This, however, is the only advantage of using fluorescent screens. Because of their inherent poor image definition characteristic, fluorescent screens are used only in special applications. Practically, their use is limited to those occasions when a short exposure is required, and the specimen conformation permits extensive masking to reduce scattered radiation. Fluorescent screens cause excessive film graininess when exposed to high energy radiation, thus their use is restricted to low energy radiation applications.

(2) To prevent misleading shadows in the radiograph caused by blocking of emitted light during exposure, dirt and dust must be prevented from collecting between the screen and film surfaces. The screens must also be kept free from stain. Their sensitive surfaces must be touched only when absolutely necessary and, if cleaning is required, it must be accomplished strictly in accordance with the manufacturer's directions.

b. Lead Screens. Lead screens are usually constructed of an antimony and and lead alloy that is stiffer, harder, and more wear resistant than pure lead. The screens are used in pairs, on each side of, and in close contact with, the film. Depending upon the specimen and the energy of radiation, the screens may be of varying thicknesses. The front screen in most applications is thinner than the back screen. Front screens 0.005 inch thick and back screens 0.010 inch thick are commonly used. Lead screens are particularly efficient because of their ability to absorb scattered radiation (soft radiation) in addition to increasing the photographic effect on the film. The increased photographic effect is a result of the release of electrons from the lead atoms when acted upon by high energy radiation. Energy from the released electrons is readily absorbed by the film emulsion, and intensifies film response.

(1) The intensification factor of lead screens is much lower than that of fluorescent screens. Under exposure to low energy radiation it is

possible for the front screen absorption effect to be of such magnitude that required exposure is greater than that without screens. However, due to their capability for reducing the effects of scattered radiation and the resultant better contrast and definition of the radiographic image, lead screens are used wherever practicable. They are used in almost all gamma ray applications.

(2) To insure the intensification action of lead screens they must be kept free from dirt, grease, and lint since these materials have high electron absorption qualities and can absorb the "intensifying" electrons emitted by the screens. The screens may be cleaned with carbon tetrachloride and, if a more thorough cleaning is desired, fine steel wool may be used. The fine abrasion marks caused by gently rubbing with steel wool will have no harmful effects. Deep scratches, gouges, wrinkles, or depressions that affect the flatness of the screen surface will cause poor radiographic results.

5. MASKING MATERIAL

Masking is the practice of covering, or surrounding, portions of the specimen with highly absorbent material during exposure. Masking reduces the specimen exposure in the masked areas, eliminating much scatter. Commonly used masking materials are lead, (Figure 6-3), barium clay, and metallic shot (Figure 6-4). When barium clay is used as a mask material, it should be thick enough so that radiation absorption of the clay is appreciably greater than that of the specimen; otherwise, the clay will generate noticeable scatter. In any circumstance, the sole purpose of masking is to limit scattered radiation by reducing the area of, or about, the specimen exposed to the primary beam.

6. PENETRAMETERS

The penetrameter is a device whose image on a radiograph is used to determine radiographic quality level (sensitivity). It is not intended for use in judging the size, or in establishing acceptance limits, of discontinuities. The standard penetrameter is a rectangle of metal with three drilled holes of set diameter. It is composed of material identical, or radiographically similar, to the material being radiographed. Each penetrameter is identified by a lead number (ID No.) which gives the maximum thickness of material for which the penetrameter is normally used. (See Figure 6-5.)

a. The thickness (T) of the standard penetrameter is 2% of the thickness denoted by the ID No., and the hole diameters are 1 x T (1T), 2 x T (2T), and 4 x T (4T). The standard 1.0 inch penetrameter has a 1.0 ID No. and hole diameters as shown in Figure 6-5. Standard penetrameter sizes are listed in Table 6-1.

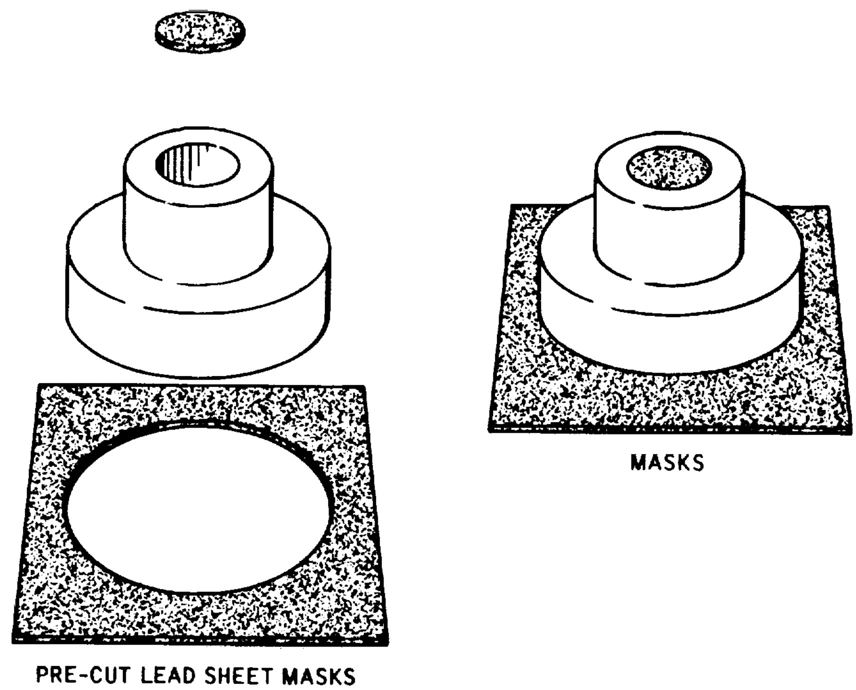


Figure 6-3. Lead Masking Technique

b. The penetrameter is normally placed source side on top of the specimen being radiographed. Thus, it is a built-in defect of known thickness (usually 2% of T_m) and known hole diameters. The penetrameter measures the ability of the technique used to show contrast (the thickness of the penetrameter) and definition (the hole images).

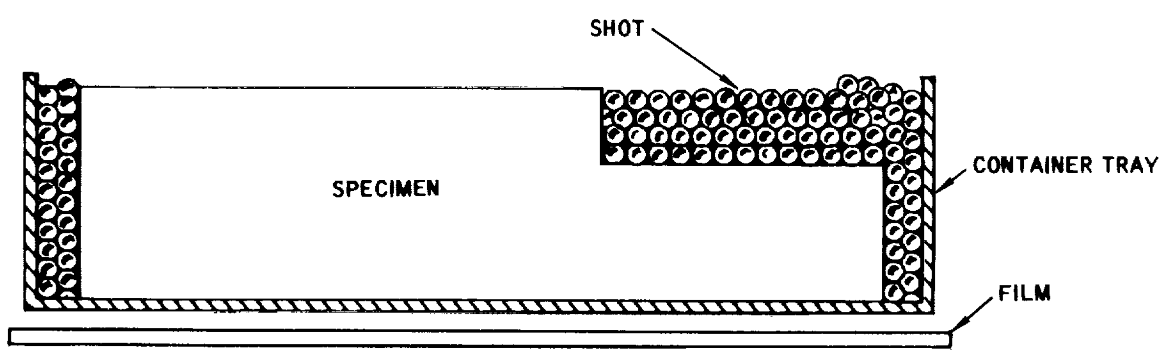


Figure 6-4. Masking with Metallic Shot

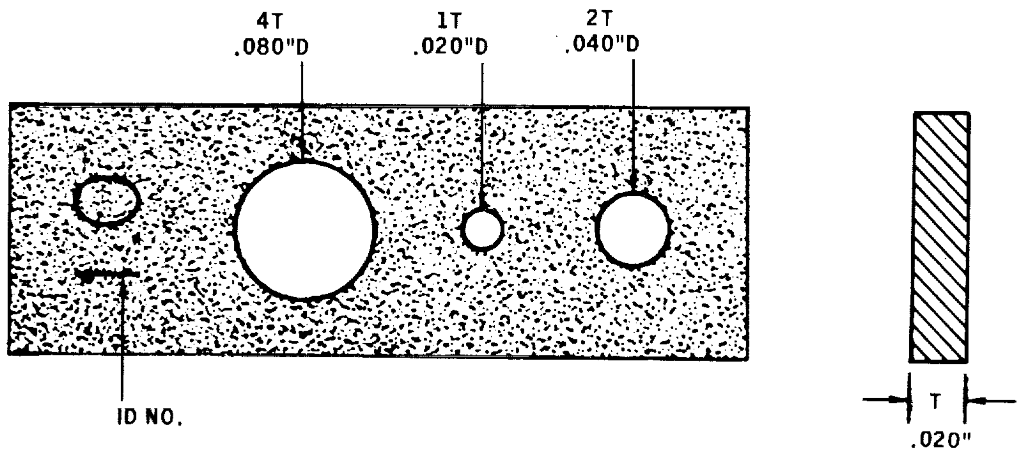


Figure 6-5. Standard Penetrameter for 1" Material

Table 6-1. Standard Penetrameter Sizes

APPLIES TO DESIGN MATERIAL THICKNESS** (T_m) UP TO AND INCLUDING (INCHES)		ID NO.	"T"	1T HOLE DIA.	2T HOLE DIA.	4T HOLE DIA.
1/4"	0.25"	25	.005"	.010*	.020*	.040*
3/8	0.375	37	.008	.010*	.020*	.040*
1/2	0.5	50	.010	.010	.020	.040
5/8	0.625	62	.013	.013	.025	.050
3/4	0.75	75	.015	.015	.030	.060
7/8	0.875	87	.018	.018	.035	.070
1	1.0	1.0	.020	.020	.040	.080
1-1/8	1.125	1.1	.023	.023	.045	.090
1-1/4	1.25	1.2	.025	.025	.050	.100
1-1/2	1.5	1.5	.030	.030	.060	.120
AND SO ON FOR EACH 1/4 INCH UP TO 2-1/2" AND THEN IN 1/2* INCREMENTS UP TO 8", AND THEN IN 1" INCREMENTS.						

* MINIMUM HOLE SIZES REQUIRED BY THE STANDARD, DO NOT BEAR CORRECT RELATIONSHIP TO ID NO. OR THICKNESS OF THE PENETRAMETER.

** DEFINED AS THE THICKNESS OF THE MATERIAL (T_m) UPON WHICH THE THICKNESS OF THE PENETRAMETER IS BASED. FOR WELDS, THE MATERIAL THICKNESS SHALL BE THE THICKNESS OF THE STRENGTH MEMBER.

c. Standard 2% sensitivity requires the technique to image the penetrameter whose thickness is 2% of T_m, and the 2T hole of the penetrameter (penny). Other sensitivities (quality levels) are shown in Table 6-2. For specimen

[redacted]

Table 6-2. Quality Levels

SENSITIVITY	QUALITY LEVEL	PENNY "T" AS % OF T_m	PERCEPTIBLE HOLE DIA.
.7%	1-1T	1%	1T
1.0%	1-2T	1%	2T
1.4%	2-1T	2%	1T
2.0%	2-2T	2%	2T
2.8%	2-4T	2%	4T
4.0%	4-2T	4%	2T

thicknesses that are between penny sizes the smaller penny must always be used.

d. Penetrameters of different types have been devised for special uses, such as the wire penetrameters used in the radiography of small electronic components. In all cases, however, the penny is designed to determine the radiographic quality level, usually referred to as sensitivity.

7. SHIM STOCK

Shim stock is defined as thin pieces of material identical to specimen material. They are used in radiography of specimens, such as welds, wherein the area of interest radiographically is thicker than the specimen thickness. Shims are selected so that the thickness of the shim(s) equals the thickness added to the specimen (by the weld) in the area of interest (Figure 6-6). The shim(s) is placed underneath the penetrameter (between the penetrameter and the specimen). In this way the image of the penny is projected through a thickness of material equal to the thickness in the area of interest. In use, the length and width of the shim(s) should always be greater than the similar dimensions of the penny.

8. FILM HOLDERS AND CASSETTES

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

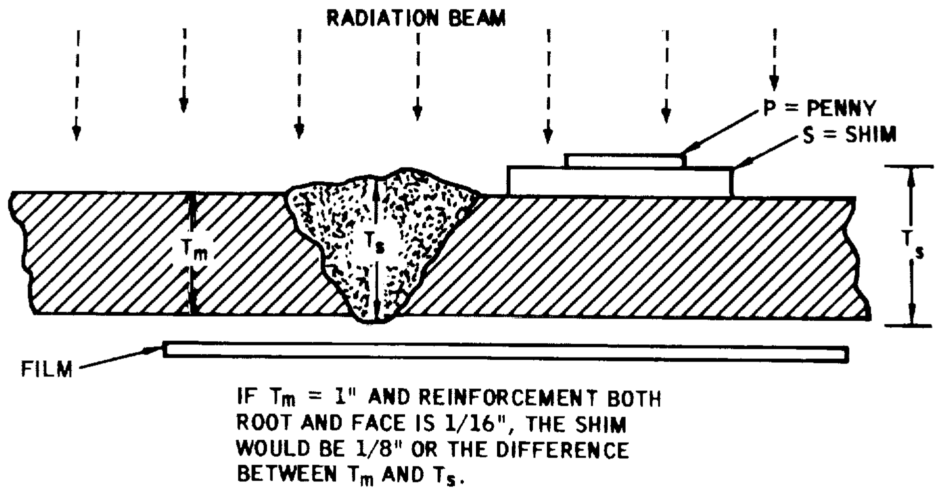


Figure 6-6. Use of Shim Stock

9. LINEAR AND ANGULAR MEASURING DEVICES

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

10. POSITIONING DEVICES

For quality radiography, the position of the source (either X-ray or gamma ray), the specimen, and the film should remain fixed during exposure. With X-ray equipment, the floor, a table, or any stable surface, may suffice to support the specimen. With gamma ray equipment, support of the specimen is identical with that of X-ray, and specially designed holders (usually tripods) are used to position the cable containing the source. Any positioning arrangement, complying with safety considerations, that does not cause excess scatter radiation is acceptable.

11. IDENTIFICATION AND ORIENTATION MARKERS

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

[redacted]

12. AREA SHIELDING EQUIPMENT

The control of scatter radiation is effected only by proper use of shielding techniques. Areas in which radiography takes place must be adequately protected against both side and back scatter (Figures 2-14 and 2-15). In permanent installations, this is accomplished by use of lead shielded rooms or compartments. When permanent installations are not available, the radiographer uses lead screens and places them so that areas reached by the primary radiation are shielded. The area immediately beneath, or behind, the film should always be covered with lead.

13. DENSITOMETER

The densitometer is an instrument that measures density. Two types of densitometers, visual and electronic, are commerically available. Accuracy is a desirable densitometer characteristic but more important is consistency. A good densitometer, under similar conditions, will give similar readings each time used.

14. X-RAY EXPOSURE CHARTS

X-ray exposure charts (Figure 6-7) show the relationship between material thickness, kilovoltage, and exposure. Each chart applies only to a specific set of conditions: a certain X-ray machine; a certain target-to-film distance; a certain type of film; certain processing conditions; and the density upon which the chart is based.

a. Exposure charts are adequate to determine exposures of specimens of uniform thickness, but should be used only as a guide when radiographing a specimen of wide thickness variations. Charts furnished by manufacturers are accurate, but only within ± 10% since no two X-ray machines are identical. For quality radiography, X-ray exposure charts, based on the material most often radiographed; the film most commonly used; and an arbitrarily chosen target-to-film distance are prepared for each X-ray machine in use.

b. To prepare an exposure chart, a series of radiographs are taken of a step wedge of the selected specimen material. The wedge is radiographed at several different exposures (milliampere-minutes) at each of a selected number of kilovoltages. The resultant film is processed in accordance with routine work procedures. Each radiograph will image the wedge as a series of different densities corresponding to the intensity of the X-rays transmitted through the wedge thicknesses. Choosing the desired density (density required in routine work radiographs) the radiographer uses a densitometer to locate that density on each radiograph. At each point the desired density appears, a corresponding value of kilovoltage, exposure, and wedge thickness exists. When the desired density does not appear on a radiography, the correct material thickness for that density is determined by interpola-

[redacted]

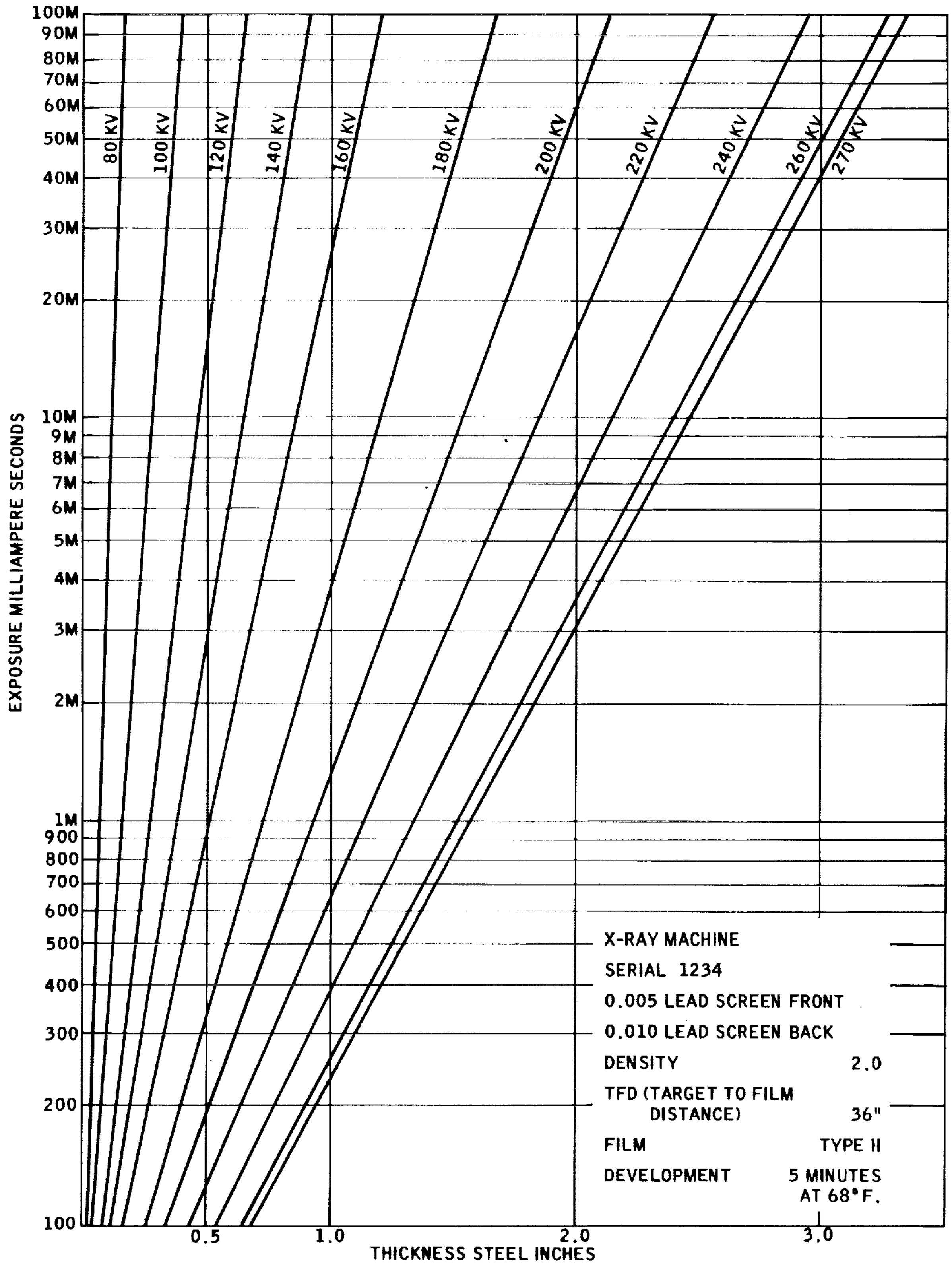


Figure 6-7. X-ray Exposure Chart

[redacted]

tion. The kilovoltage, exposure, and material thickness for each of the density points are then plotted on semilog paper. To compress an otherwise overly long scale, the exposure (milliampere-minutes) is laid off on the logarithmic scale. Material thickness is laid off on the linear scale. The resultant chart will be similar to Figure 6-7, and will be accurate for the particular X-ray machine used.

c. A second method of preparing an exposure chart requires more arithmetical calculations but requires fewer exposures. At each selected kilovoltage one step wedge exposure is made. The densities of each of the wedge thicknesses is measured on each radiograph. Then, an exposure is determined, which would have given the desired density under each wedge step, by use of the film characteristic curve. The resultant values of exposure, thickness, and kilovoltage are plotted as in the previous method. Use of the film characteristic curve in the preparation of an X-ray exposure chart is shown in the following example.

Example: At 240 kv, a 300 milliampere-second exposure of a steel step wedge produced a density of 1.6 under the 1" thick section of the wedge. At 240 kv, what should the exposure be for a 2.0 density under the 1" thick section of the wedge, when the film characteristic curve indicates a log relative exposure of 1.80 for a density of 1.6 and 1.91 for a density of 2?

Step 1: The difference between the log relative exposures is .11. The antilog of .11 is 1.28. Thus, 300 (the exposure for 1.6 density) multiplied by 1.28 will give the exposure for 2.0 density, or 300 x 1.28 = 384 milliampere-seconds.

d. Exposure charts can also be prepared to show film latitude, which is defined as the variation in material thickness which can be radiographed with one exposure, while maintaining film density within acceptable limits. These limits are fixed by the lowest and highest densities that are acceptable in the finished radiograph. To prepare such an exposure chart, either of the procedures described are followed, except that both the lowest and the highest acceptable densities are plotted. The result is two curves for each kilovoltage, one representing the lowest, and the other the highest, acceptable density. For any given exposure and kilovoltage, the range of material thickness capable of being satisfactorily radiographed in a single exposure is shown on the chart as the horizontal difference between the two curves.

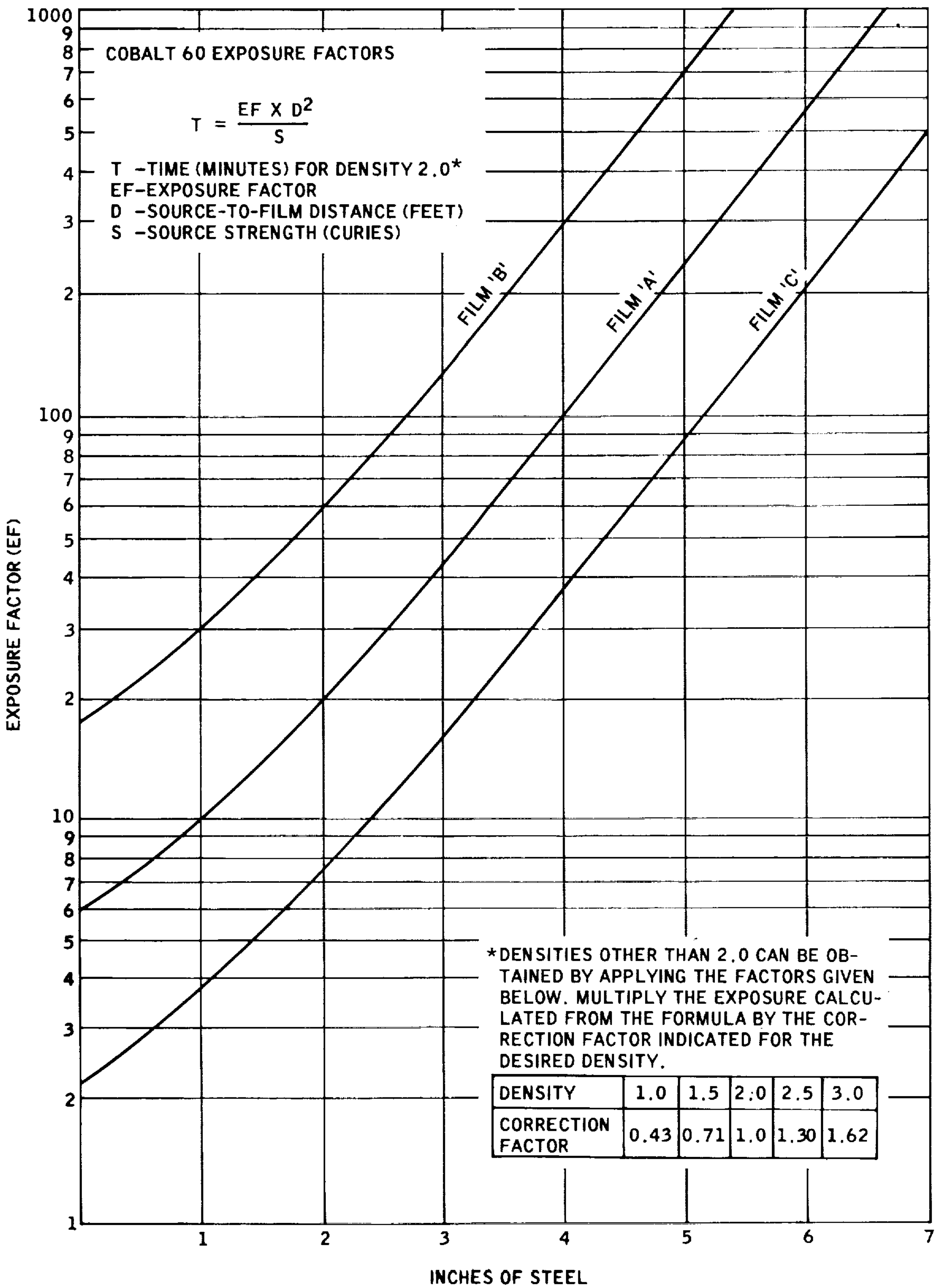
15. GAMMA RAY EXPOSURE CHARTS

A typical gamma ray exposure chart is shown in Figure 6-8. The variables in gamma radiography are the source strength, and the source-to-film distance. These are related on the chart to each of three different speed films. By selecting a film, the radiographer can determine exposure time for desired image density. Similar to X-ray exposure charts, gamma ray exposure charts are adequate to determine exposures of specimens of uniform thickness, but should be used only as a guide when radiographing a specimen of wide thickness variation. Charts similar to that shown are available from film manufacturers and are accurate when used with film processed in compliance with the manufacturer's recommendations. The exposure factor shown in the figure is a logarithmic scale layout of the set of values derived by dividing the product of source strength (gamma ray intensity) and time, by the square of the source-to-film distance (inverse square law). The density correction factors listed were obtained from the film characteristic curves.

a. Gamma ray exposure charts are easily modified to show latitude. To modify a given chart to reflect highest acceptable density, a curve parallel to the existing curve is drawn. The new curve is displaced vertically above the original by a distance equal to that obtained by applying the density correction factor to the exposure factor at the left edge of the chart. The curve for the lowest acceptable density is drawn in the same manner, but below the original. An example of this procedure is shown in Figure 6-9, in which the 2.0 density curve for "A" film is used to develop the 1.5 and 2.5 density curves. The given curve for 2.0 density enters the left edge of the chart at an exposure factor of 6. The correction factor for a density of 1.5 is .71. The new curve for 1.5 density enters the left edge at 6 x .71 or 4.26 exposure factor, and continues below and parallel to the 2.0 density curve. Similarly, the curve for 2.5 density enters at 6 x 1.3 or 7.8 and continues above and parallel to the 2.0 density curve. The range of material thickness that can be radiographed in one exposure and result in densities between 1.5 and 2.5 is shown in Figure 6-9 as the horizontal difference between the 1.5 and the 2.5 density curves.

16. DATED DECAY CURVES

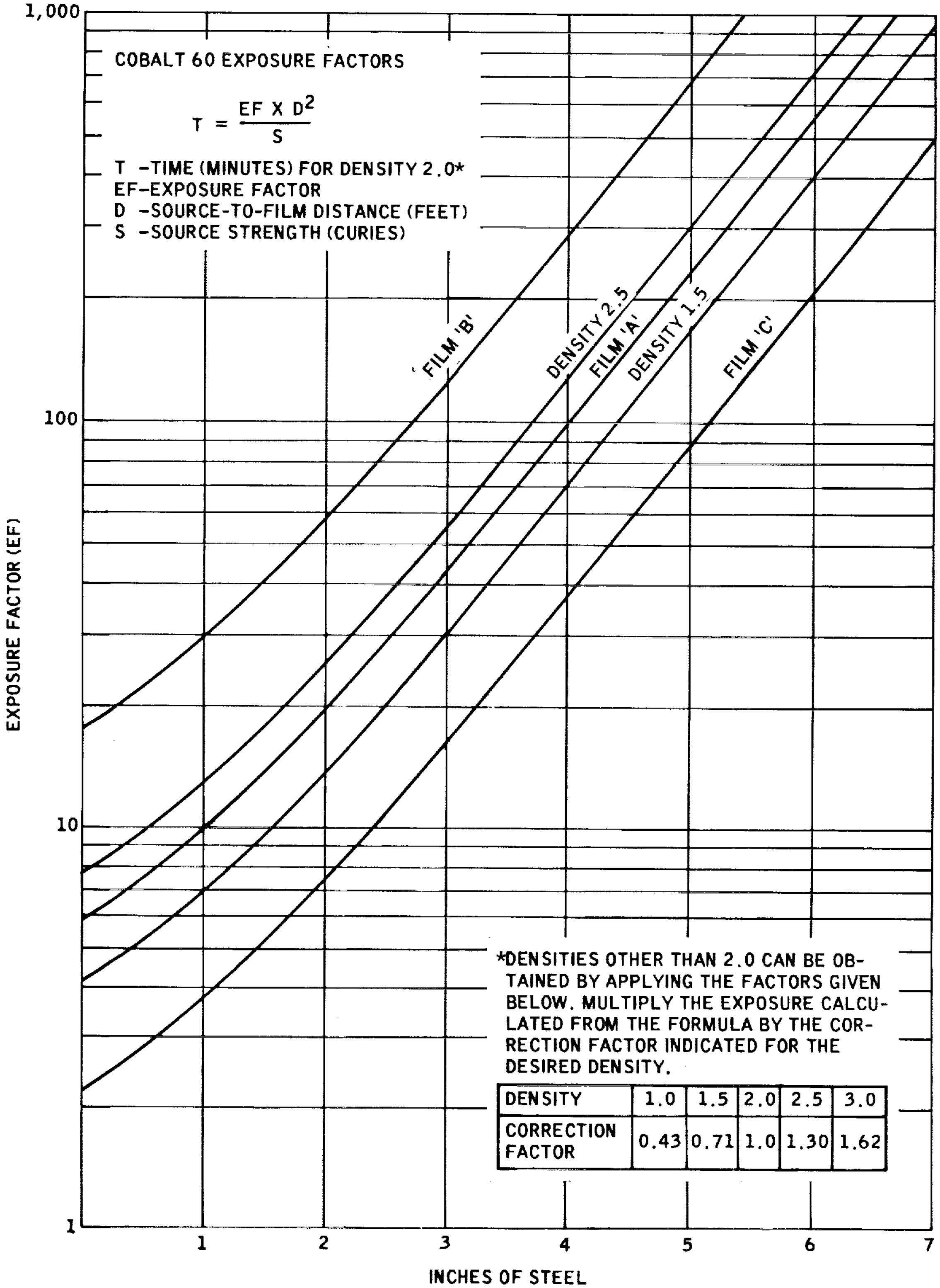
Dated decay curves (Figure 6-10) are supplied with radioisotopes. By use of the curve, the source strength may be determined at any time. Since the source strength must be known before exposure calculations can be made, the decay curve eliminates the necessity of source strength measurement, or calculation, prior to source use. When source strength is known, decay curves similar to the one shown are readily prepared by using half-life values (Table 3-2) and plotting the resultant curve on semi-logarithmic paper.



DENSITY	1.0	1.5	2.0	2.5	3.0
CORRECTION FACTOR	0.43	0.71	1.0	1.30	1.62

Figure 6-8. Gamma Ray Exposure Chart

[redacted]



DENSITY	1.0	1.5	2.0	2.5	3.0
CORRECTION FACTOR	0.43	0.71	1.0	1.30	1.62

Figure 6-9. Gamma Ray Exposure Chart (Modified)

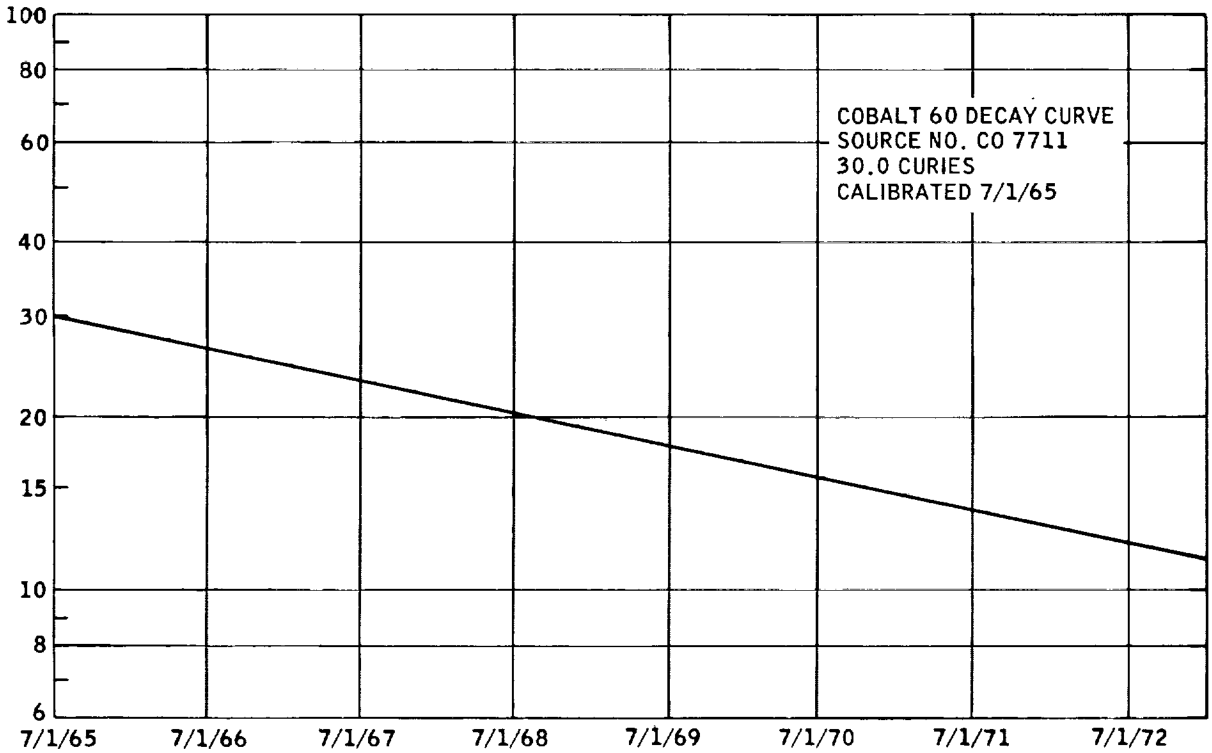


Figure 6-10. Dated Decay Curve

17. FILM CHARACTERISTIC CURVES

Film curves were discussed in Chapter 4 and will be further discussed in later portions of this chapter. The curves furnished by manufacturers are accurate, describe the film, and can be used without change.

18. RADIOGRAPHIC EQUIVALENCE FACTORS

Most applications of radiation sources are expressed in terms of aluminum or steel thicknesses as shown in Table 6-3. Radiographic equivalence factors for other commonly used metals are shown in Table 6-4. The values shown are approximate. In radiographic equivalence tables, aluminum is usually used as the standard metal at 100 kv and below, and steel at the higher voltages, and with gamma rays. The thickness of the specimen is multiplied by the factor shown to obtain an approximate equivalent standard metal thickness.

Table 6-3. Applications of Industrial Radiation

X-RAY KV OR ISOTOPE	SCREENS	APPROXIMATE PRACTICAL THICKNESS LIMITS
50	NONE *	WOODS, PLASTICS, THIN LIGHT METAL SECTIONS
100	NONE *	2-INCH ALUMINUM
150	LEAD FOIL	1-INCH STEEL, 4-1/2-INCH ALUMINUM
250	LEAD FOIL	2-INCH STEEL OR EQUIVALENT
400	LEAD FOIL	3-INCH STEEL OR EQUIVALENT
1000	LEAD FOIL	5-INCH STEEL OR EQUIVALENT
2000	LEAD FOIL	9-INCH STEEL OR EQUIVALENT
THULIUM-170	NONE *	WOODS, PLASTICS, LIGHT ALLOYS, 1/2-INCH STEEL OR EQUIVALENT
IRIDIUM-192	LEAD FOIL	2-1/2-INCH STEEL OR EQUIVALENT
CESIUM-137	LEAD FOIL	3-1/2-INCH STEEL OR EQUIVALENT
COBALT-60	LEAD FOIL	7-1/2-INCH STEEL OR EQUIVALENT

* BACKUP SCREENS ARE RECOMMENDED IN ALL APPLICATIONS. LEAD FOIL SCREENS AS THIN AS 0.001 INCH ARE AVAILABLE WITH SPECIAL VACUUM PACK ARRANGEMENTS THAT PERMIT SCREEN USE WITH LOW ENERGY RADIATION.

Table 6-4. Radiographic Equivalence Factors

	X-RAYS KV							GAMMA RAYS		
	50	100	150	220	400	1000	2000	Ir 192	CE-137	CO-60
MAGNESIUM	0.6	0.6	0.05	0.08				0.22	0.22	0.22
ALUMINUM	1.0	1.0	0.12	0.18				0.34	0.34	0.34
TITANIUM		8.0	0.63	0.71	0.71	0.9	0.9	0.9	0.9	0.9
STEEL		12.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
COPPER		18.0	1.6	1.4	1.4	1.1	1.1	1.1	1.1	1.1
ZINC			1.4	1.3	1.3	1.1	1.0	1.1	1.0	1.0
BRASS			1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0
LEAD			14.0	12.0		5.0	2.5	4.0	3.2	2.3

603 EXPOSURE VARIABLES

1. GENERAL

Table 6-5 is a listing of exposure variables and their effect on the four requirements of a quality radiograph. The following paragraphs review and discuss each of the variables as they affect practical radiography techniques.

Table 6-5. Effect of Radiographic Variables on Desired Radiograph Quality

RADIOGRAPHIC VARIABLE	DESIRED RADIOGRAPH QUALITY			
	MINIMUM DISTORTION	SHARP DEFINITION	HIGH CONTRAST	ADEQUATE DENSITY
MOVEMENT		MOVEMENT OF EITHER SOURCE, SPECIMEN, OR FILM DURING EXPOSURE BLURS AND DISTORTS FILM IMAGE.		
SOURCE SIZE, SOURCE-TO-FILM DISTANCE (SFD), SPECIMEN-TO-FILM DISTANCE		SEE FIGURES 2-3 AND 2-4. FOR OPTIMUM SHARPNESS, SOURCE-TO-FILM DISTANCE GREAT AND SPECIMEN-TO-FILM DISTANCE MINIMUM.	SFD IS AN EXPOSURE FACTOR (INVERSE SQUARE LAW). SEE MA AND SOURCE STRENGTH.	SFD IS AN EXPOSURE FACTOR (INVERSE SQUARE LAW). SEE MA AND SOURCE STRENGTH.
SOURCE POSITION, SPECIMEN POSITION, FILM POSITION	SEE FIGURE 2-5. RELATIVE POSITIONS OF SOURCE, SPECIMEN, AND FILM DETERMINE DISTORTION. DISTORTION IS NOT ACCEPTABLE IF IT INTERFERES WITH FILM INTERPRETATION.			
FILM CONTRAST			BY REGULATING EXPOSURE, THE SAME DEGREE OF CONTRAST CAN BE ATTAINED WITH MOST FILM REGARDLESS OF FILM SPEED. SEE FIGURE 4-3.	
FILM SPEED				FILM SPEED AND EXPOSURE DETERMINE DENSITY. WITH FAST FILM LESS EXPOSURE IS REQUIRED.
FILM GRAININESS		FAST FILM IS COARSE GRAINED, SLOW FILM IS FINE GRAINED. THE QUALITY DESIRED IN THE RADIOGRAPH DETERMINES THE ACCEPTABLE GRAININESS. THE FINER THE GRAIN THE BETTER THE DEFINITION.		
LEAD SCREENS		LESSEN SCATTER EFFECT IMPROVING DEFINITION.		USED WITH LOW ENERGY RADIATION, FRONT SCREEN MAY CAUSE DECREASE IN DENSITY. WITH HIGHER ENERGY RADIATION, INTENSIFICATION CAUSES INCREASE IN DENSITY.
CALCIUM TUNGSTATE SCREENS		DIFFUSED LIGHT REDUCES SHARPNESS. CANNOT BE USED WITH HIGH ENERGY RADIATION RADIATION.		ITENSIFICATION FACTOR IS HIGH. GREAT INCREASE IN DENSITY WHEN USED WITH LOW ENERGY RADIATION.
FILTERS		ABSORB SOFT RADIATION, DECREASE SCATTER.	ABSORB SOFT RADIATION, DECREASE SCATTER.	

Table 6-5. Effect of Radiographic Variables on Desired Radiograph Quality (Cont)

RADIOGRAPHIC VARIABLE	DESIRED RADIOGRAPH QUALITY			
	MINIMUM DISTORTION	SHARP DEFINITION	HIGH CONTRAST	ADEQUATE DENSITY
COLLIMATORS, CONES, AND DIAPHRAGMS		LIMIT AREA EXPOSED TO RADIATION, DECREASE SCATTER.	LIMIT AREA EXPOSED TO RADIATION, DECREASE SCATTER.	
MASKS		LIMIT AREA OF SPECIMEN EXPOSED, DECREASE SCATTER.	LIMIT AREA OF SPECIMEN EXPOSED, DECREASE SCATTER.	
AREA SHIELDS		ABSORB UNWANTED RADIATION, DECREASE SCATTER.	ABSORB UNWANTED RADIATION, DECREASE SCATTER.	
KVP (X-RAY ONLY)		ALL OTHER FACTORS REMAINING CONSTANT, AS KV IS INCREASED, DEFINITION IMPROVES BECAUSE OF DECREASED SCATTER.	ALL OTHER FACTORS REMAINING CONSTANT, AS KV IS DECREASED, CONTRAST INCREASES. KV SELECTION IS DEPENDENT UPON SPECIMEN AND DESIRED SENSITIVITY.	ALL OTHER FACTORS REMAINING CONSTANT, AS KV IS INCREASED, DENSITY INCREASES. KV SELECTION IS DEPENDENT UPON SPECIMEN AND DESIRED SENSITIVITY.
MA (X-RAY ONLY)			AT A GIVEN SFD WITH A GIVEN KV, THE PRODUCT OF MA AND TIME IS EXPOSURE. SEE FILM CONTRAST.	AT A GIVEN SFD WITH A GIVEN KV, THE PRODUCT OF MA AND TIME IS EXPOSURE. SEE FILM SPEED.
TIME			SEE MA AND SOURCE STRENGTH.	SEE MA AND SOURCE STRENGTH.
SOURCE STRENGTH (GAMMA ONLY)			AT A GIVEN SFD, THE PRODUCT OF SOURCE STRENGTH AND TIME IS EXPOSURE. SEE FILM CONTRAST.	AT A GIVEN SFD, THE PRODUCT OF SOURCE STRENGTH AND TIME IS EXPOSURE. SEE FILM SPEED.
SOURCE ENERGY (GAMMA ONLY)		ALL OTHER FACTORS REMAINING CONSTANT, AS SOURCE ENERGY IS INCREASED, DEFINITION IMPROVES BECAUSE OF DECREASED SCATTER.	ALL OTHER FACTORS REMAINING CONSTANT, AS SOURCE ENERGY IS DECREASED, CONTRAST INCREASES. SOURCE ENERGY SELECTION IS DEPENDENT UPON SPECIMEN AND DESIRED SENSITIVITY.	ALL OTHER FACTORS REMAINING CONSTANT, AS SOURCE ENERGY IS INCREASED, DENSITY INCREASES. SOURCE ENERGY SELECTION IS DEPENDENT UPON SPECIMEN AND DESIRED DENSITY.
SPECIMEN ABSORPTION				DETERMINES EXPOSURE AND EITHER KV OR SOURCE ENERGY SELECTION.
SPECIMEN CONTRAST			DETERMINES EXPOSURE AND EITHER KV OR SOURCE ENERGY SELECTION.	

2. MOVEMENT

Movement of source, specimen, or film during exposure is not usually a problem. In X-radiography, permanently installed equipment is designed to remain in the chosen set position, and portable equipment is easily placed so that it does not move. In gamma radiography, the source switch assembly (source holder) is firmly positioned with clamps, tape, wire, etc. The specimen, in either case, is positioned according to its weight, shape, and the desired angle of exposure, and the film is taped to the specimen when it is not held in position by the weight of the specimen. Any means of holding source, specimen, and film firmly in place is acceptable as long as it does not create scatter radiation problems.

3. SOURCE SIZE

Source size is a factor in every radiograph and is a primary consideration in purchasing either X-ray equipment or gamma ray sources. X-ray focal spots vary from 8 mm square down to fractions of a millimeter, and after consideration of the overall requirements, the X-ray equipment best meeting all of the requirements is purchased. The same requirements, and the half-life of the radioisotopes under consideration, determine the purchase of a gamma ray source. Generally the radiographer has available X-ray and gamma ray equipment capable of most radiographic applications, and the problem is how to make an acceptable radiograph with the equipment available. Selection of correct source-to-film distance permits good radiography with available equipment, since source (focal spot) size is usually within acceptable dimensions.

4. SOURCE-TO-FILM DISTANCE

Source-to-film distance (SFD) is usually used with reference to gamma ray equipment, and target-to-film distance (TFD) with X-ray equipment. In the following discussion the two terms are considered synonymous. In selecting an SFD, three factors must be considered: source size, specimen thickness, and specimen-to-film distance. When any point on the film is at an appreciably greater distance from the source than any other point on the film, the resultant radiograph will have a large penumbral effect (unsharpness). The image densities on the radiograph will also not be in agreement with the specimen thickness. The penumbral effect is caused by the rays from different points of the source penetrating the specimen at different angles. The erroneous densities are caused by the difference in radiation intensity at different points on the specimen, due to the difference in distance (inverse square law effect) from the source. Since optimum geometrical sharpness of the image is obtained when the radiation source is small, the distance from the source to the specimen is relatively great, and the distance from the specimen to the film is small; it follows then, that the SFD selected must not be below acceptable limits.

a. The maximum unsharpness (penumbral effect) that cannot be recognized by the human eye is approximately 0.02 inch. Based on this capability of the eye, the following equation is used to determine a minimum acceptable source-to-film distance.

$$D = \frac{t \times d}{0.020} + t$$

where D = Source-to-film distance.

t = Distance from upper surface of the specimen to the film (specimen thickness when the film is immediately adjacent to the specimen).

d = Diameter of the source (focal spot) in inches.

b. A second means of determining minimum SFD is stated in the commonly used rule of thumb, "The source-to-film distance should not be less than eight to ten times the specimen thickness." Either of these methods of determining minimum SFD are acceptable for most radiography, but are of little use when thin specimens are radiographed. Usually, an SFD is selected that is long enough for all anticipated specimen exposures, and exposure charts are constructed on the basis of that distance. Commonly used distances are 36" (one yard) and 40" (approximately one meter).

5. PHYSICAL ARRANGEMENT

The physical arrangement (setup) of the source, specimen, and film during exposure, affects the useful quality of the finished radiograph. In making an exposure setup, the following considerations govern:

a. Best radiographic contrast in specimen area of suspected discontinuities.

b. Best radiographic contrast in specimen area that is under stress during operation.

c. Shortest exposure time compatible with quality radiography.

d. Need for more than one exposure, or for double film technique.

e. Need for beam, panoramic, or other special exposure technique. (Various exposure arrangements are discussed in subsequent paragraphs.)

6. FILM CONTRAST, SPEED, AND GRAININESS

Film characteristics were detailed in Chapter 4. With most industrially used films the same degree of contrast is obtainable regardless of the speed of the film selected, since the characteristic curves of the different speed films are similar in shape. Thus, the degree of resolution (sharpness) required in the radiograph fixes the speed of film that is acceptable. The time-saved, economic, consideration of fast film is secondary to the desired resolution. Fast film is seldom used.

[redacted]

7. SCREENS

Lead screens are universally used because of their scatter absorption capability. They are available in a wide range of thicknesses, and extremely thin lead screens in special vacuum pack film holders are successfully used in radiography of thin specimens. Exposure charts should be based on the use of lead screens. Because of the loss of sharpness that accompanies their use, calcium tungstate screens should be employed only in special low-energy radiation applications.

8. SCATTER RADIATION

Scatter radiation can never be eliminated but its effects can be lessened by limiting the amount of scatter created, and by further limiting the scatter reaching the film. Filters placed between the source and the specimen absorb many of the scatter-producing "soft" rays of the beam, and are usually used with X-ray equipment. They are not required in gamma radiography because of the high energy of gamma ray emissions. Lead screens absorb both internal scatter (front screen) and back scatter (back screen); collimators, cones, and diaphragms reduce side and back scatter by limiting the beam to the area of interest. Scatter, generated by the specimen (internal scatter), is reduced by limiting the area of the specimen exposed to the beam. Masks of lead, barium clay, metallic shot, or other absorbent material are used to shield portions of the specimen, or areas surrounding the specimen. The principle of masking is the same as that of filtering, except that filters are designed to absorb only "soft" rays, whereas masks absorb the soft rays and many of the higher energy rays. Shields serve to limit scatter radiation by absorbing rays that might otherwise strike walls, floors, or objects that would generate scatter. Shields usually consist of lead sheets, in some convenient handling form, placed in positions of most scatter reduction benefit. It is particularly important that areas immediately below, or behind, the film be shielded to absorb back scatter. Permanent radiography installations usually include lead-lined rooms, but in all other applications, control of scatter by area shielding is required.

9. KILOVOLTAGE, MILLIAMPERAGE, AND TIME

Kilovoltage, milliamperage, and time are exposure factors in X-radiography. X-ray exposure charts (Figure 6-7) describe the correct value of each for certain applications. A combination of the information contained in an exposure chart and the information contained in a table of radiographic equivalents (Table 6-4) results in determination of proper exposure values for X-ray of material other than that shown on the chart. Application of the inverse square law to exposure chart information results in correct exposure values for different source-to-film distances. Combining exposure chart information with information obtained from film characteristic curves results in correct exposure values for various speed films. Since milliamperage and

[redacted]

time are reciprocal functions and milliamperage is limited by equipment capability, required exposure time is usually determined by the equipment used.

10. SOURCE ENERGY, SOURCE STRENGTH, AND TIME

Source energy, source strength, and time are exposure factors in gamma radiography. Gamma ray exposure charts (Figure 6-8) describe the proper value of each under certain conditions. Source energy (wavelength of the emitted waves) is a function of the radioisotope source and remains constant. Source strength is a time-decay function of the radioisotope and must be known at the time of exposure. Since source strength and time are reciprocal functions, the length of exposure time required is determined by the source strength. Gamma ray exposure chart information combined with a table of radiographic equivalents (Table 6-4) results in determination of correct exposure values for material not shown on the chart. The exposure formula accompanying most gamma ray exposure charts allows for application of the inverse square law, and the remainder of the information on the chart permits selection of a source-to-film distance most suited for the immediate task.

11. SPECIMEN ABSORPTION AND SPECIMEN CONTRAST

Specimen absorption and specimen contrast are the only variables of the radiographic process that cannot be changed or controlled by the radiographer. They determine the radiographers control, or setting, of the other variables encountered in the making of a radiograph.

604 EXPOSURE CALCULATIONS

1. GENERAL

The following examples of exposure calculations illustrate the use of equipment and film information available to the radiographer. The referenced figures are located together for ease in following the examples. The equipment used in the examples consists of a portable X-ray machine whose characteristics are shown in Figure 6-11, a permanently installed X-ray machine whose characteristics are shown in Figure 6-12, and an isotope camera containing an iridium 192 source whose decay curve is shown in Figure 6-13. The film used in the examples is of six different types: types I, II and III typical of one manufacturer and types A, B, and C typical of another. Characteristic curves for types I, II, and III film are shown in Figure 6-14; characteristic curves for types A, B, and C film, when used with gamma radiation, are shown in Figure 6-15. An iridium 192 exposure chart for types A, B, and C film is shown in Figure 6-16. Figure 6-17 details the maximum permissible voltage for specified material thicknesses that will obtain 2% sensitivity in the finished radiograph. It also details the permissible thickness range of material for gamma radiography that will obtain 2% sensitivity.

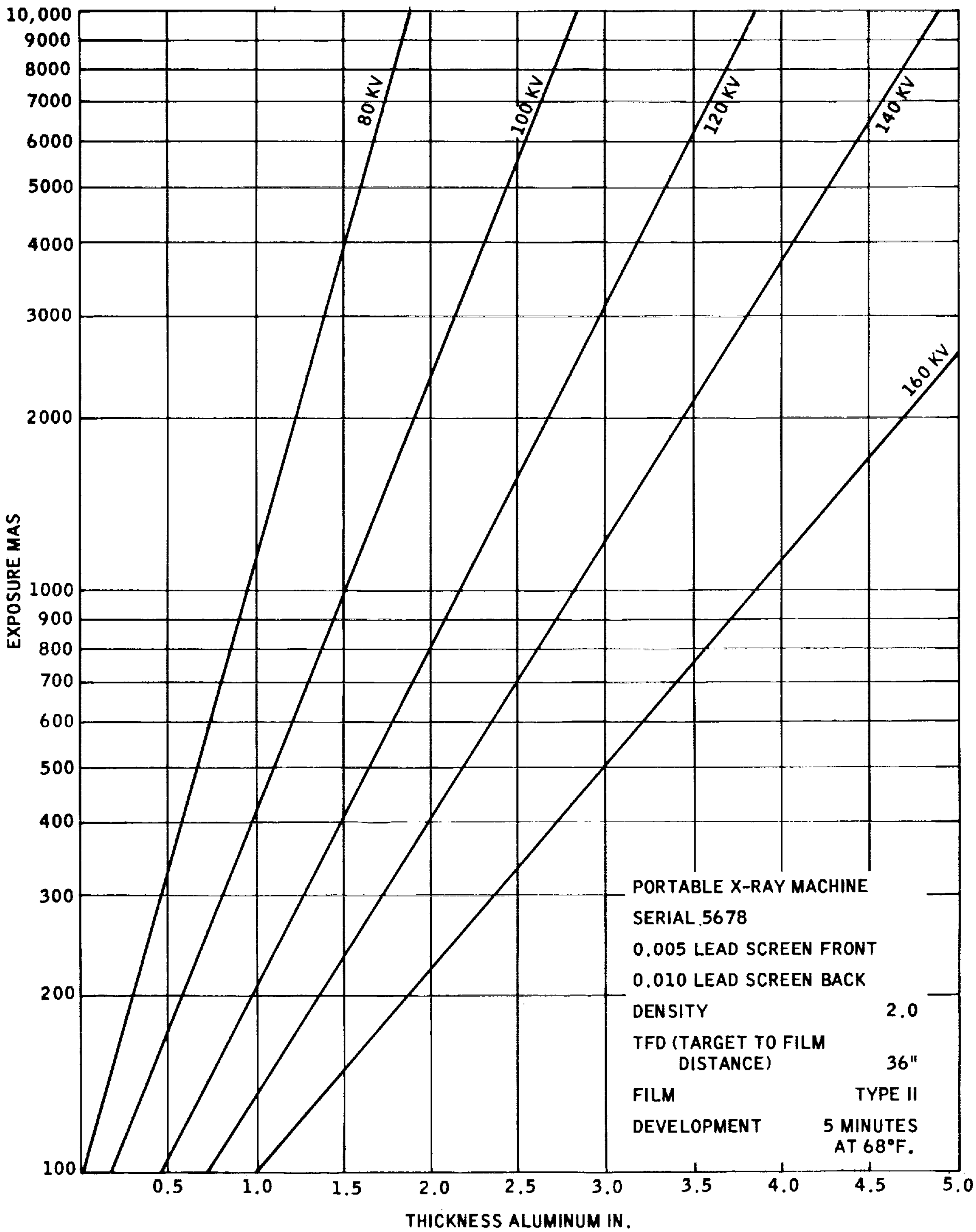


Figure 6-11. X-ray Exposure Chart (Portable Equipment)

[redacted]

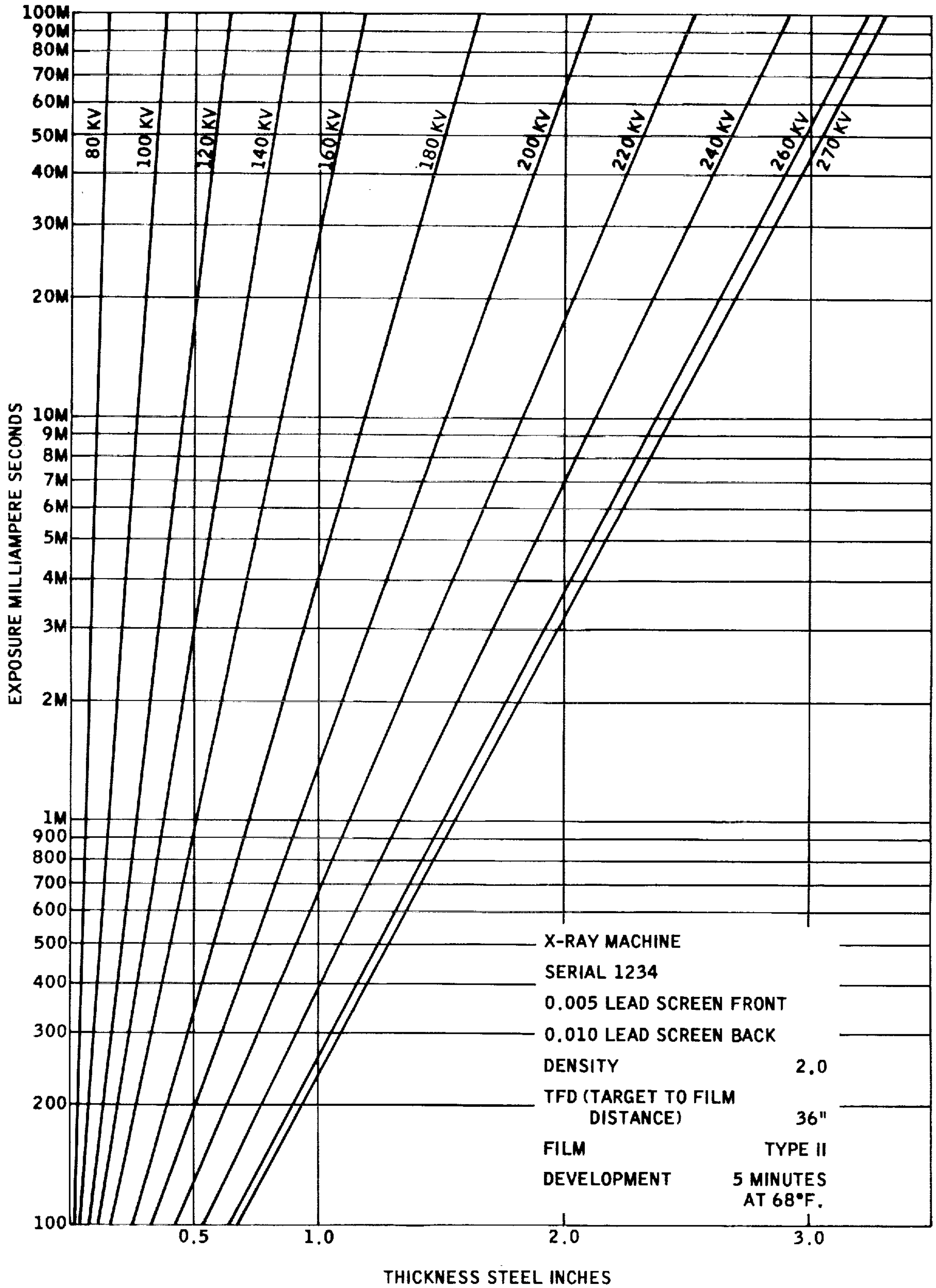


Figure 6-12. X-ray Exposure Chart (Permanently Installed Equipment)

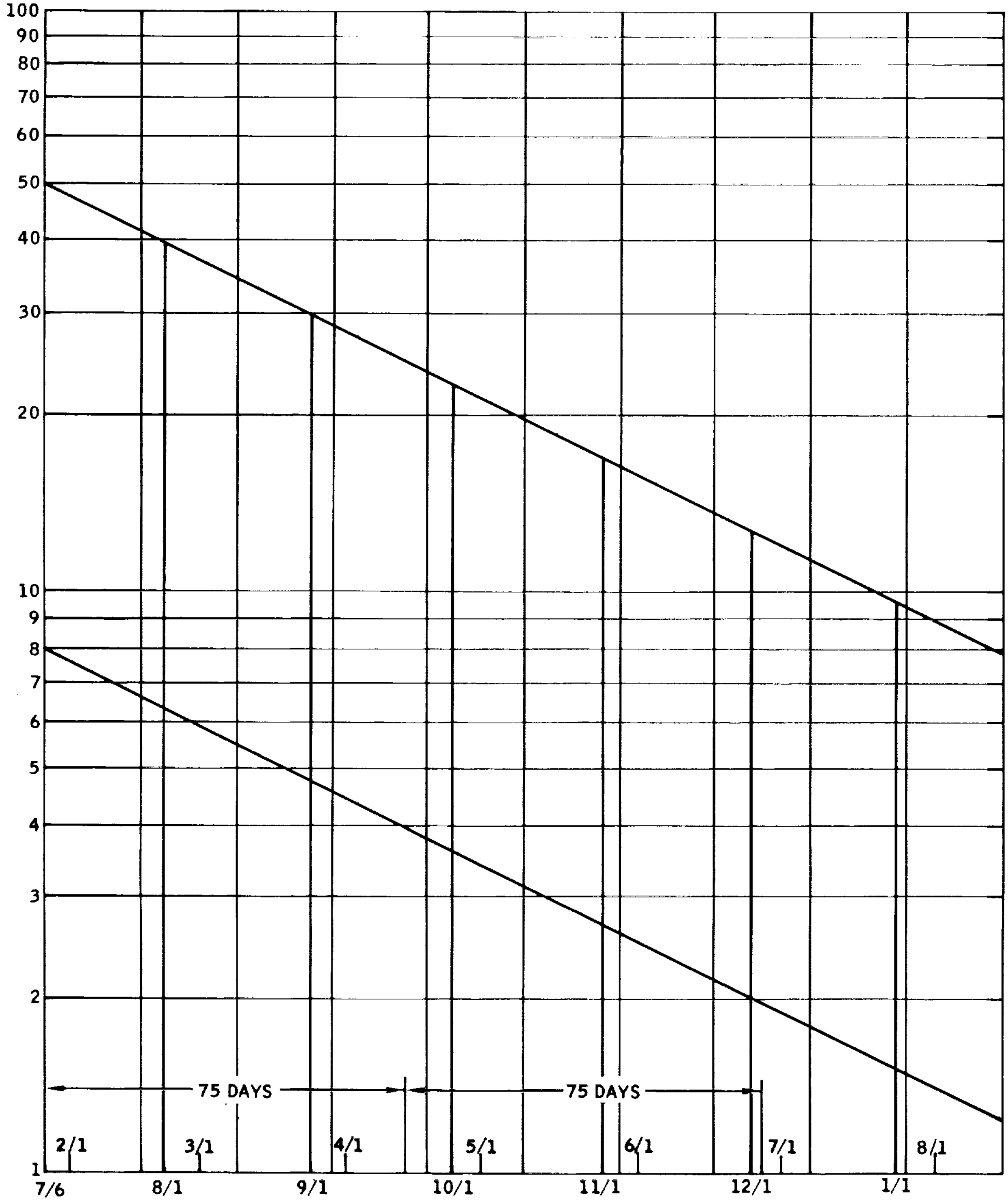


Figure 6-13. Iridium 192 Decay Curve

[redacted]

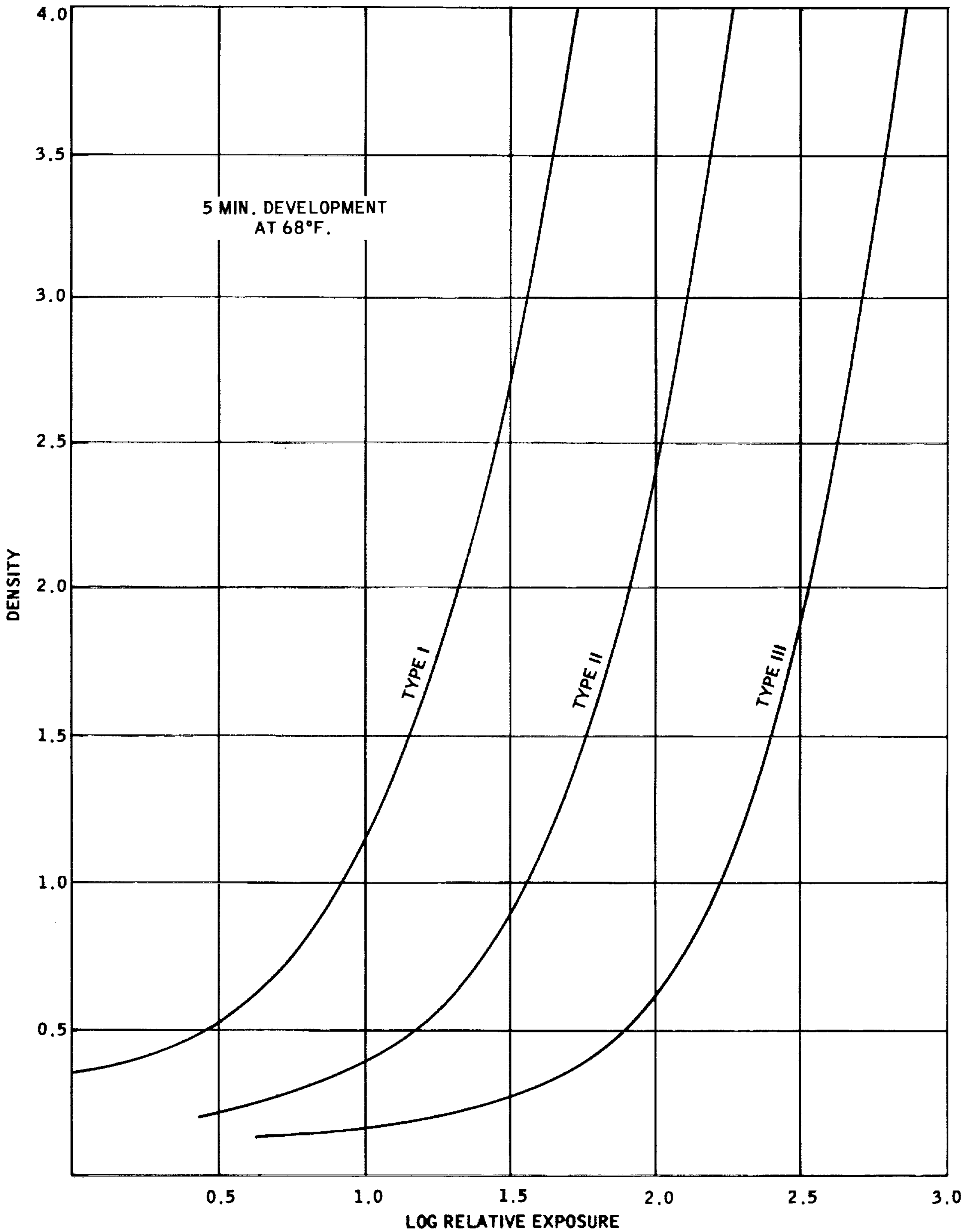


Figure 6-14. Film Characteristic Curves (Types I, II and III)

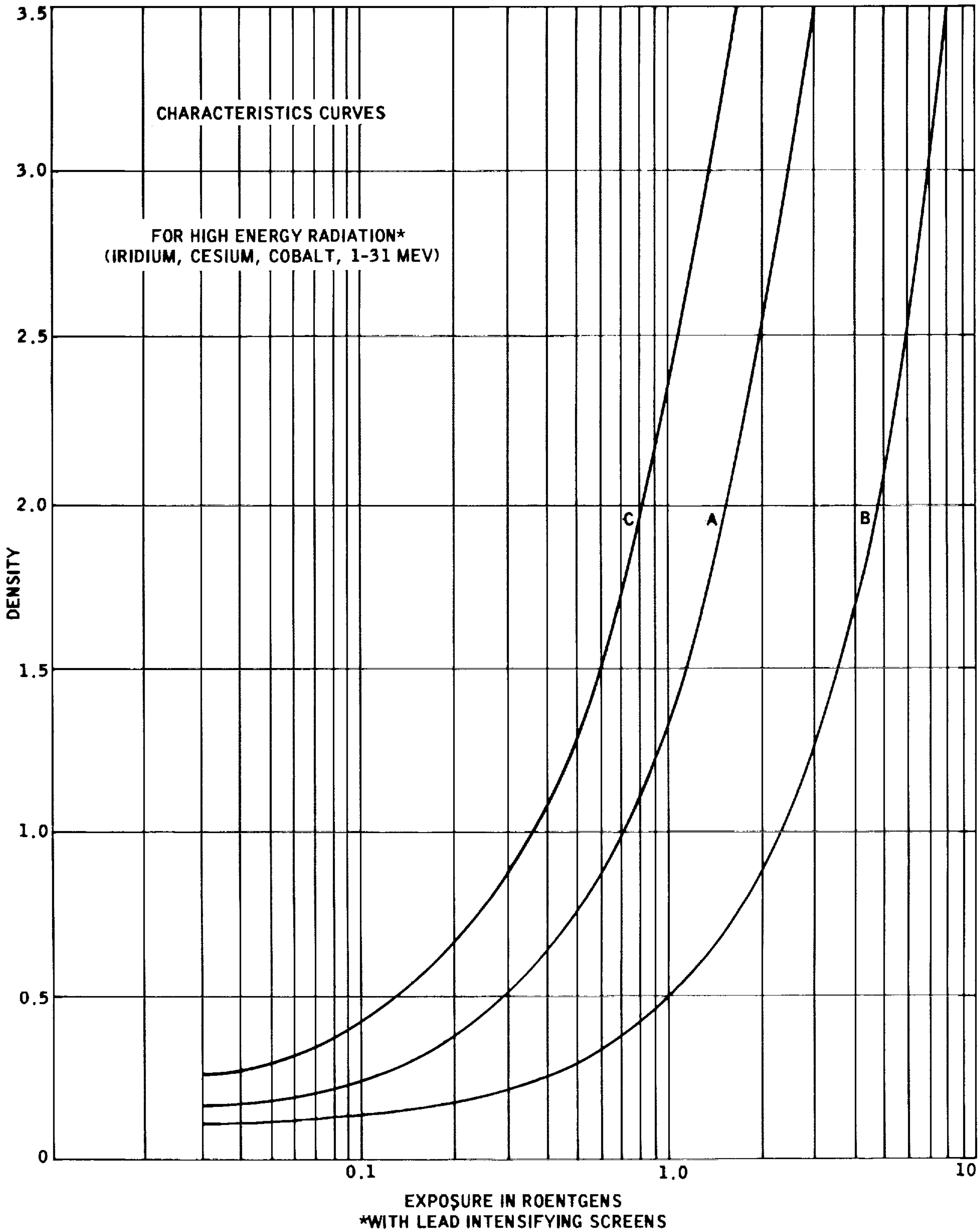
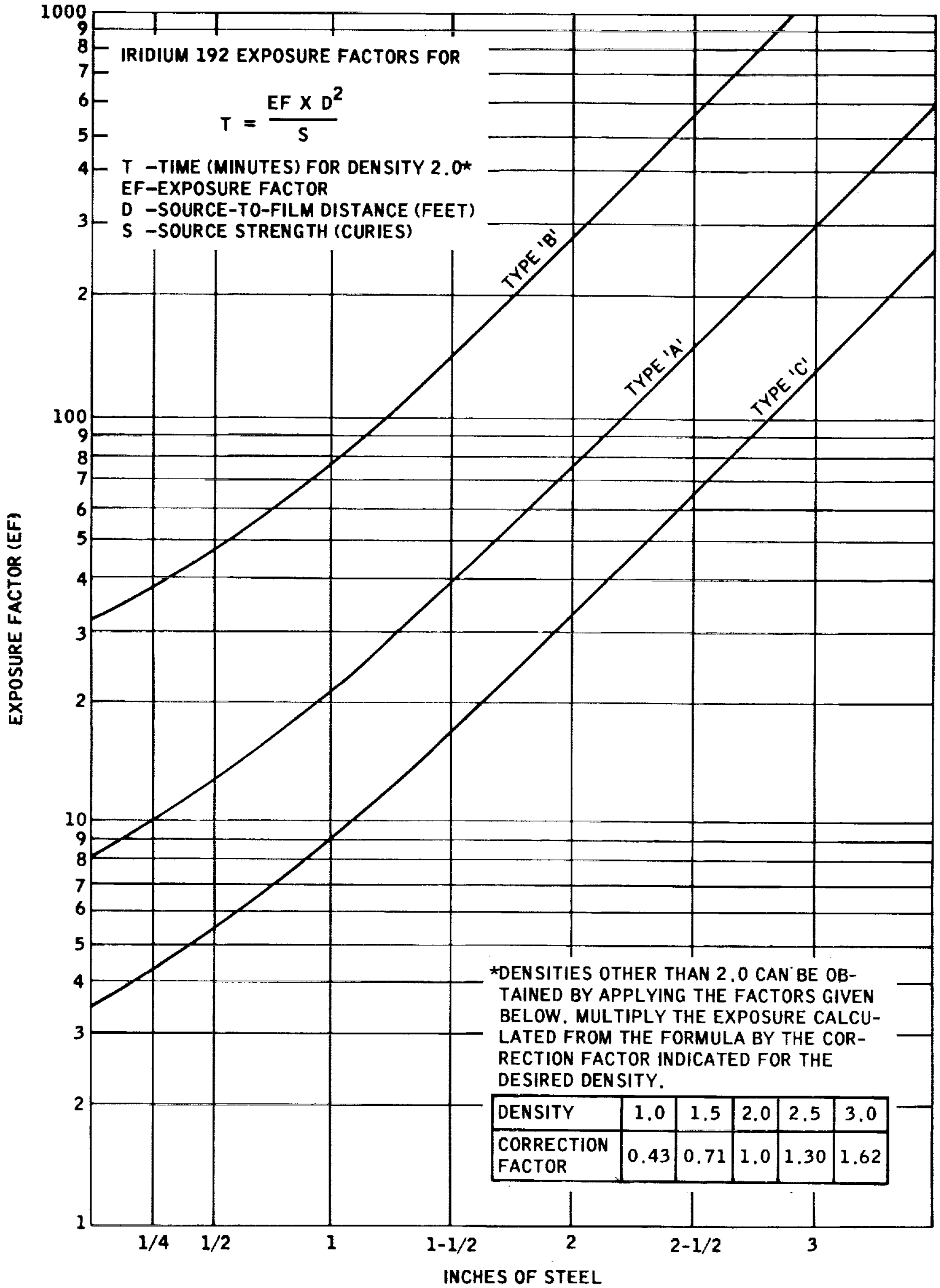


Figure 6-15. Film Characteristic Curves (Types A, B and C)



DENSITY	1.0	1.5	2.0	2.5	3.0
CORRECTION FACTOR	0.43	0.71	1.0	1.30	1.62

Figure 6-16. Iridium 192 Exposure Chart

[redacted]

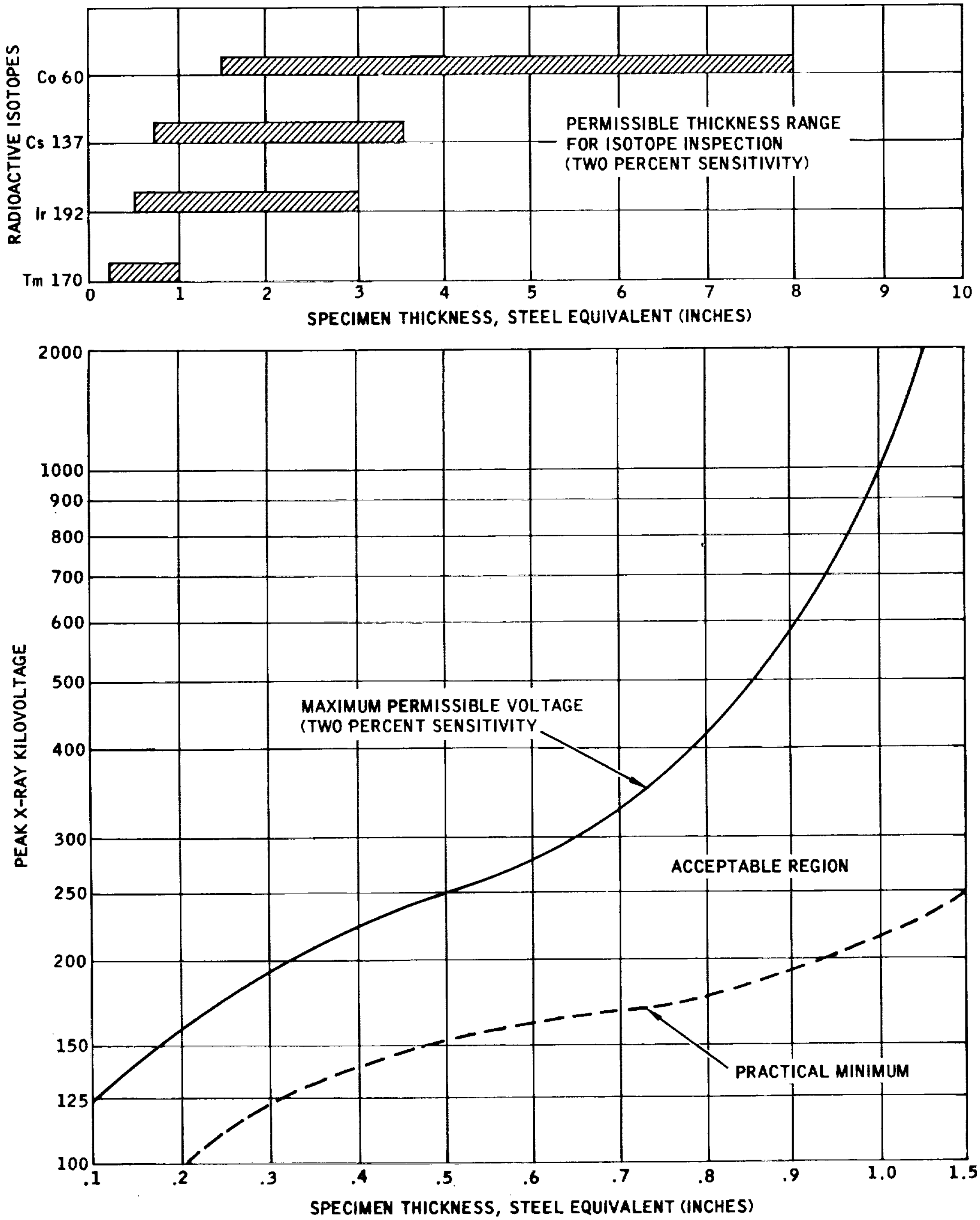


Figure 6-17. Energy vs. Thickness Ranges

[redacted]

Example 1: A two-inch-thick specimen of aluminum is to be X-rayed. Using the portable X-ray equipment (Figure 6-11) determine the exposure for a sensitivity of 2% and a density of 3. 3, with type II film.

Step 1: From Figure 6-11. Two inches of aluminum may be X-rayed with type II film at a target-to-film distance of 36" for a density of 2. 0 as follows:

At 100 kv - 2300 mas (milliampere-seconds)
120 kv - 800 mas
140 kv - 400 mas
160 kv - 225 mas

Step 2: From Table 6-4. The radiographic equivalence factor for aluminum at 150 kv is 0. 12. Thus at 150 kv, two inches of aluminum is equivalent to 0. 24 inch of steel (2 x 0. 12).

Step 3: From Figure 6-17. The maximum permissible voltage for 2% sensitivity with 0. 24 inch of steel is 170 kv. Since this is the maximum, consult Figure 6-11 and select 140 kv for the exposure. This selection is a compromise between the economic consideration of less exposure time at 160 kv and the greater sensitivity available at lower kv.

Step 4: From Figure 6-14. The log relative exposure with type II film for a 2. 0 density is 1. 91, and for 3. 3 density 2. 18. The difference between the log relative exposures is 0. 27. The antilogarithm of 0. 27 is 1. 83. Therefore, to obtain the exposure for 3. 3 density, the exposure for 2. 0 density is multiplied by 1. 83.

Step 5: From Step 1. The exposure for 2. 0 density at 140 kv is 400 mas. Thus at 140 kv an exposure of 732 mas (400 x 1. 83) will result in a radiograph of 2% sensitivity and 3. 3 density.

Example 2: In Example 1 determine the exposure required with type III film.

Step 1: From Figure 6-14. The log relative exposure for 3. 3 density with type II film is 2. 18, and with type III film 2. 76. The difference between the log relative exposures is 0. 68. The antilog of 0. 68 is 4. 78. Therefore, to obtain the exposure with type III film the exposure for type II film is multiplied by 4. 78.

Step 2: From Example 1. The exposure for type II film is 732 mas. Thus an exposure of 3500 mas (732 x 4. 78) will result in a radiograph of 2% sensitivity and 3. 3 density with type III film.

Example 3: In Examples 1 and 2, the exposure was based on a target-to-film distance of 36". The rule of thumb previously given states that the target-to-film distance should not be less than 8 to 10 times the thickness of the specimen. Based on this rule, a 20" target-to-film distance is selected because of the possible saving in time. Determine the exposure for 2% sensitivity and 3.3 density at this target-to-film distance (TFD) for types II and III film.

Step 1: The inverse square law states that the intensity varies inversely with the square of the distance. Thus, the exposure at a 20" TFD for 2% sensitivity and 3.3 density is $20^2/36^2$ of the exposure at a 36" TFD for 2% sensitivity and 3.3 density.

Step 2: From Example 1. The exposure for type II film at a 36" TFD is 732 mas.

Step 3: Thus, an exposure of 226 mas ($732 \times 20^2/36^2$) will result in a radiograph of 2% sensitivity and 3.3 density with type II film at a TFD of 20".

Step 4: From Example 2. The exposure for type III film at a 36" TFD is 3500 mas.

Step 5: Thus, an exposure of 1080 mas ($3500 \times 20^2/36^2$) will result in a radiograph of 2% sensitivity and 3.3 density with type III film at a TFD of 20".

NOTE: The procedures of Examples 1 through 3 may be followed to X-ray the specimen using the equipment described in Figure 6-12, and the radiographic equivalence factors listed in Table 6-4.

Example 4: The specimen of Example 1 must be radiographed with Iridium 192. Fifty-five days have passed since the source shown in Figure 6-13 was calibrated at 50 curies. Using this source, determine the exposure with type A film to obtain 2% sensitivity and 3.3 density.

Step 1: From Figure 6-13. The 50 curie source after 55 days will have decayed to 30 curies.

Step 2: As in Example 3, select a source-to-film distance of 20" (1.67 feet).

Step 3: From Table 6-4. The radiographic equivalence factor for aluminum, when using Iridium 192, is 0.34. Thus, with Iridium 192, two inches of aluminum are equivalent to 0.68 inch of steel (2 x 0.34).

Step 4: From Figure 6-17. The lower level of the permissible thickness range for Iridium 192, testing with 2% sensitivity, is 0.5 inch of steel. Therefore, two inches of aluminum (0.68 inch of steel) can be radiographed with Iridium 192 with 2% sensitivity.

Step 5: Using the equation from Figure 6-16, calculate T in minutes.

$$T = \frac{EF \times D^2}{S} = \frac{15 \times 1.67^2}{30} = 1.4 \text{ minutes}$$

Thus, an exposure time of 1.4 minutes will result in a radiograph of 2% sensitivity and 2.0 density.

Step 6: Figure 6-16 does not give the correction factor for 3.3 density. From Figure 6-15 the exposure with type A film for 2.0 density is 1.5, and for 3.3 density is 2.8. Therefore, to obtain a density of 3.3 the exposure for 2.0 density must be increased by the ratio of 2.8 to 1.5.

Step 7: From Step 5 the exposure time for 2.0 density is 1.4 minutes. Thus, an exposure time of 2.6 minutes (1.4 x 2.8/1.5) will result in a radiograph of 2% sensitivity and 3.3 density.

NOTE: In Examples 1 and 2, the film characteristic curves were plotted on a log relative scale and it was necessary to determine the antilog of the log relative exposure difference between any two exposures to calculate required exposure change. In this example the film characteristic curve is plotted on a logarithmic scale in actual values, and calculation of required exposure changes is a matter of applying the ratio between any two exposures. Illustrations of both methods of plotting film characteristic curves are shown, since film manufacturers use either.

Example 5: The steel specimen shown in Figure 6-18A is to be X-rayed. Required sensitivity is 2%, maximum acceptable density is 3.3, minimum is 2.0. Using the X-ray equipment described in Figure 6-12, determine if a radiograph of acceptable sensitivity and densities can be made with a single exposure of type II film.

Step 1: From Figure 6-17. The maximum permissible voltage for 2% sensitivity with 0.25 inch of steel is 170 kv, and the practical minimum voltage for 0.375 inch of steel is 135 kv. Therefore, only the 140- and 160-kv curves of Figure 6-12 are considered.

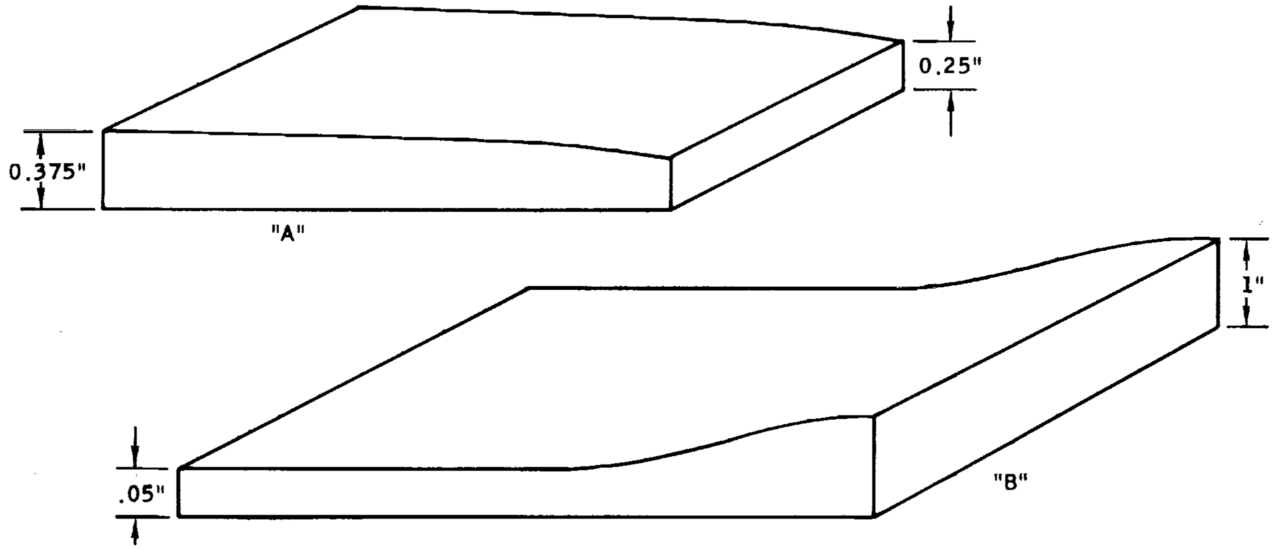


Figure 6-18. Steel Specimens

Step 2: From Figure 6-12. With type II film at a target-to-film distance of 36", 0.25 and 0.375 inch of steel may be X-rayed for a density of 2.0 as follows:

	140 KV	160 KV
Exposure 0.25" steel	330 mas	170 mas
Exposure 0.375" steel	1000 mas	400 mas

Step 3: From Figure 6-14. The log relative exposure with type II film for a 2.0 density is 1.91, and for 3.3 density is 2.18. The difference between the log relative exposures is 0.27. The antilog of 0.27 is 1.83. Therefore, to obtain the exposure for 3.3 density, the exposure for 2.0 density is multiplied by 1.83.

Step 4: From Step 2. The exposure of 0.25 inch of steel for 2.0 density at 140 kv is 330 mas, and at 160 kv is 170 mas. Thus, an exposure of 604 mas (330 x 1.83) at 140 kv, and 311 mas (170 x 1.83) at 160 kv will result in radiographs of 3.3 density.

Step 5: Therefore, exposures within the acceptable density range are

	140 KV	160 KV
Exposure 0.25" steel, 3.3 density	604 mas	311 mas
Exposure 0.375" steel, 2.0 density	1000 mas	400 mas

Since with 140 kv, any exposure more than 604 mas will result in a density greater than 3.3 at the thin portion of the specimen, and any exposure less than 1000 mas will result in a density of less than 2.0

[redacted]

at the thick portion of the specimen, and the same relative conditions hold true with 160 kv, it is impossible to obtain a radiograph of acceptable sensitivity and densities with a single exposure of type II film.

Example 6: The steel specimen shown in Figure 6-18B must be radiographed with Iridium 192. The available source measures 30 curies. Required sensitivity is 2%, maximum acceptable density is 3.3 and minimum is 2.0. Determine if a radiograph of acceptable sensitivity and densities can be made with a single exposure of type A film.

Step 1: From Figure 6-17. The lower level of the permissible thickness range for Iridium 192, testing with 2% sensitivity, is 0.5 inch of steel. Therefore, the specimen can be radiographed with Iridium 192 with 2% sensitivity.

Step 2: From Figure 6-16. The EF (exposure factor) for 0.5 inch steel for 2.0 density with type A film is 12.5, and of 1 inch of steel is 21.

Step 3: Figure 6-16 does not give the correction factor for 3.3 density. From Figure 6-15 the exposure with type A film for 2.0 density is 1.5, and for 3.3 density 2.8. Therefore, to obtain a density of 3.3, the exposure for 2.0 density must be increased by the ratio of 2.8 to 1.5.

Step 4: From Step 2, the EF of 0.5 inch of steel for 2.0 density with type A film is 12.5. Thus an EF of 23.4 (12.5 x 1.87) will result in a radiograph of 3.3 density.

Step 5: Since an EF of 21 will result in 2.0 density through the thicker (1") portion of the specimen, and an EF of 23.4 will result in 3.3 density through the thinner portion of the specimen, any EF between 21 and 23.4 will result in a radiograph of acceptable sensitivity and density with a single exposure of type A film.

2. DOUBLE FILM EXPOSURES

The specimen of Example 5, which could not be X-rayed satisfactorily with a single exposure on one film, may be X-rayed by using two exposures, one for the thicker portion of the specimen and one for the thinner portion. However, the specimen also may be X-rayed with a single exposure using two films of different speeds, with consequent savings in time. In this double film technique, the two films are placed in the same holder, and exposed simultaneously. This is practicable because the absorption of radiation by film is so slight that the effect of the radiation on either of the two films is, for practical purposes, identical to that of a single film exposure.

a. The exposure ratio between the films employed in the double film technique determines the range of specimen thickness that can be radiographed with acceptable density. The ratio of exposure between fine (medium speed) and extra-fine (slow speed) film ranges from 1 to 3, to more than 1 to 4, dependent upon the particular film characteristics as set by the manufacturer. Because of this high ratio, calculations for double film technique are based on an exposure for maximum acceptable density through the thicker portions of the specimen, recorded on the faster of the two films; and an acceptable density through the thinner portions of the specimen, recorded on the slower film. (Fast, coarse grain, film is not considered here since it is seldom used.)

Example 7: The steel specimen shown in Figure 6-18A is to be X-rayed. Required sensitivity is 2%, maximum acceptable density is 3.3, minimum is 2.0. Using the X-ray equipment described in Figure 6-12, determine if radiographs of acceptable density can be made with types II and III film and the double film technique.

Step 1: From Figure 6-17. The maximum permissible voltage for 2% sensitivity with 0.25 inch of steel is 170 kv, and the practical minimum voltage for 0.375 inch of steel is 135 kv. Therefore, only the 140- and 160-kv curves of Figure 6-12 are considered.

Step 2: From Figure 6-12. With type II film at a target-to-film distance of 36", 0.25 and 0.375 inch of steel may be X-rayed for a density of 2.0 as follows.

	140 KV	160 KV
Exposure 0.25" steel	330 mas	170 mas
Exposure 0.375" steel	1000 mas	400 mas

Step 3: From Figure 6-14. The log relative exposure with type II film for 2.0 density is 1.91, and for 3.3 density 2.18. The difference between the log relative exposures is 0.27. The antilog of 0.27 is 1.83. Therefore, to obtain the exposure for 3.3 density, the exposure for 2.0 density is multiplied by 1.83. And, the log relative exposure with type III film for 2.0 density is 2.53. The difference between the log relative exposures for 2.0 density with types II and III film is 0.62. The antilog of 0.62 is 4.17. Therefore, to obtain the exposure for 2.0 density with type III film, the exposure for type II film is multiplied by 4.17.

Step 4: From Step 2. The exposure with type II film of 0.25 inch of steel for 2.0 density at 140 kv is 330 mas, and at 160 kv is 170 mas. Thus, an exposure of 1376 mas (330 x 4.17) at 140 kv, and 709 mas

(170 x 4.17) at 160 kv will result in radiographs of 2.0 density with type III film.

Step 5: From Step 2. The exposure of 0.375 inch steel for 2.0 density at 140 kv is 1000 mas, and at 160 kv is 400 mas. Thus an exposure of 1830 mas (1000 x 1.83) at 140 kv, and 732 mas (400 x 1.83) at 160 kv will result in radiographs of 3.3 density with type II film.

Step 6: Therefore exposures within the acceptable density range are

	140 KV	160 KV
Exposure 0.25" steel, 2.0 density, type III film	1376 mas	709 mas
Exposure 0.375" steel, 3.3 density, type II film	1830 mas	732 mas

Since with 140 kv any exposure more than 1376 and less than 1830 mas will result in radiographs with a density greater than 2.0 at the thin portion of the specimen on type III film, and a density less than 3.3 at the thick portion of the film on type II film, radiographs of acceptable density can be made with one exposure at 140 kv. The 709 mas exposure for the thin portion of the specimen and the 732 mas exposure for the thick portion of the specimen at 160 kv are approximately equal. Exposing the specimen to 160 kv at an exposure between 709 and 732 mas will result in radiographs of acceptable density.

NOTE: The calculations in the foregoing examples and in most radiography are close approximations and not exact values. Minor variances in film, in equipment performance, and in measurement capabilities (time, distance, density, etc.) do not permit exact calculations.

3. RADIOGRAPHIC SLIDE RULES

The principles of exposure calculation illustrated in the foregoing examples may be applied to almost any exposure. Slide rules, rapid calculators, and similar devices designed to assist the radiographer in calculating exposures are simply handy arrangements of the information contained in film characteristic curves, exposure charts, and radiographic equivalence tables, and application of the inverse square law. These devices are reasonably accurate, and the information obtained from them may be relied upon, providing the user understands the principles illustrated in the examples.

[redacted]

605 RADIOGRAPHIC APPLICATIONS

1. GENERAL

The exposure arrangements discussed in the following paragraphs and illustrated in Figures 6-19 through 6-42 are commonly used, and application of the principles illustrated permits radiography of most specimens. Except where otherwise specified, any of the arrangements may be used with either X-ray or gamma ray equipment. The basic principles of film density and contrast as related to source-to-film distance, source energy, and exposure apply to each of the arrangements. In the interest of applying radiation to the highest degree, special attention should be given the following:

a. Tube Angulation. Prior to setup and exposure of any weldment configuration, the radiographer must know the joint preparation, penetration standard, and fusion lines in order to set the tube angulations and the resultant incident beam propagation path.

b. Focal Spot Location. The focal spot location is relative to the film position and distance and is commonly called the FFD (focal film distance). The focal spot is shown on illustrations by the symbol ⊕.

c. Incident Beam Alignment. The incident beam is the central beam of the radiation field. It is the effective focal spot size, projected in straight lines, to the center of the area of interest, and parallel with a prepared joint fusion line. As an example, if a fillet weld calls for 100% corner penetration, instead of 100% joint penetration, the incident beam should intersect the corner of the junction of the two legs instead of at the unfused area where fusion is not required. (See Figures 6-21 through 6-23.)

d. Discontinuity Location. Sometimes it is essential to precisely locate discontinuities especially in exceptionally thick specimens where the depth of the discontinuity must be known in order to remove a minimum amount of material from the nearest side. Correctly locating and removing the discontinuity will reduce built in stresses and additional discontinuities, save manufacturing and testing time, and conserve both manufacturing and radiographic materials.

e. Critical and Non-critical Criteria. The radiographer must know the stress criteria of every specimen before any function is performed in the radiographic process. To illustrate, he must decide which film will give the least and/or highest sensitivity, he must determine the distance and angle to give the least amount of distortion, and he must determine the number of exposures necessary to give full part coverage with respect to heat affected zones and designed configuration. Typical radiographic standard requirements are:

[redacted]

(1) Extent and distribution of radiographic testing for initial and subsequent weldments.

(2) Specific welds to be examined for individual weldments.

(3) Numerical sequence of weldments to be examined.

(4) Radiographic standards to apply to each weld.

2. RELATED FACTORS

a. Improper Interpretation of Discontinuities. In order to properly interpret discontinuities, all factors of the radiographic process must be correctly applied, noted, and known by all personnel involved in overall and final evaluation. Figures 6-19 through 6-42 illustrate some typical weldment configurations and correct and incorrect interpretations. These weldments are discussed under paragraph 3, Typical Applications.

b. Elimination of Distortion. Observing the proper geometry of application will minimize distortion by showing the image in the proper perspective.

c. Proper Identification and Penetrameters Placement.

(1) Penetrameters are added to a specimen to show a known discontinuity. They can also serve other purposes, such as image orientation and identification of the minimum thickness to be interpreted, although the proper penetrameter indicates the total of the overall thickness penetrated.

(2) Identification Plate. The identification plate is used to identify each and every individual exposure. Information such as article number, X-ray control number, weld number, area number, date of exposure, or any other pertinent information is provided. The identification plate can also serve the purpose of orientation. The identification plate should normally face the propagated radiation. In the case of a circular article, if the area of interest numbers show a reversed position in relation to the identification plate and the article has been rotated to place the area of interest adjacent to the film (under the article), the interpreter knows the proper technique has been used and that the geometric principles have been followed.

3. RADIOGRAPHIC APPLICATIONS ON WELDED FLAT PLATES

Figures 6-19 and 6-20 illustrate flat weld areas. This type of weld is easily radiographed since its critical area is clearly defined in length, width, and thickness. Subject contrast is small and exposure calculations are relatively simple.

a. Figure 6-19 is a common buttweld. An exposure angle of 90° will be sufficient for this particular joint.

b. Figure 6-20 is an example of a 45° V-groove buttweld. In this instance, the incident beam alignment should be parallel along the fusion line, as well as 90° to the horizontal plane. To insure the correct degree of sensitivity, the radiographer must select the proper penetrameter and sufficient shim stock so that the image of the penetrameter is a true representation of sensitivity for the thickness of the specimen at the weld area.

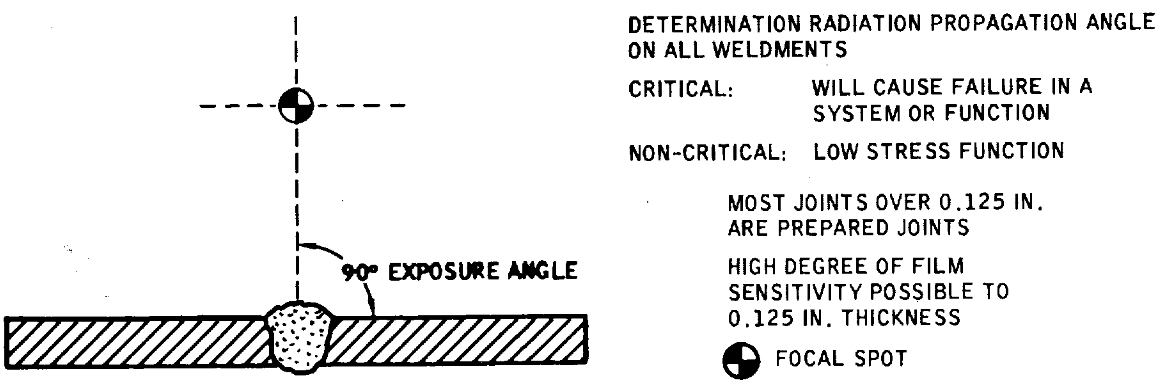


Figure 6-19. Common Buttweld

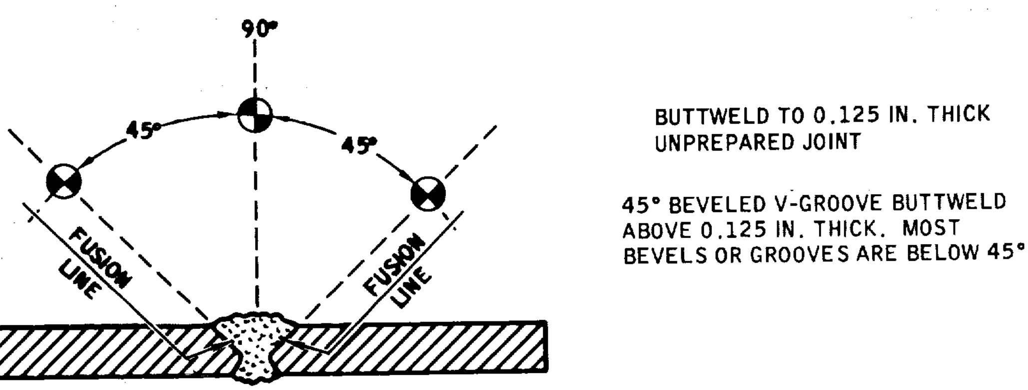


Figure 6-20. V-Groove Buttweld

4. RADIOGRAPHIC APPLICATION ON WELDED T-JOINTS

Welded T-joints illustrated in Figure 6-21 present a more difficult problem. The root of the weld is most apt to contain discontinuities and there is no place to locate the film so that good resolution of the weld root image will be obtained.

a. Figures 6-21, 6-22, and 6-23 are examples of the correct and incorrect incident beam alignment of a T-weldment. The usual tendency is to position the tube or focal spot midway between the two right angles or at 45°. This tendency may or may not be correct, as will be shown.

b. Figure 6-21 illustrates the correct angulation of 15° for a 100% corner penetration. As only the corner penetration is required, an angle of 15° or less

[redacted]

will be sufficient as long as the standing leg is not superimposed over the corner.

c. Figure 6-22 shows that if the beam should be angled too much, it will pass under the standing leg and be misinterpreted as incomplete corner penetration. Assuming the specimen had 100% corner penetration, it would have been accepted by the technique shown in Figure 6-21 and rejected by the technique shown in Figure 6-22 resulting in unnecessary rework or scrap.

d. Figure 6-23 illustrates a correct technique and should be exposed with the tube angle at 45°. Since 100% joint penetration was required, the joint must have full penetration by X-ray as well as welding.

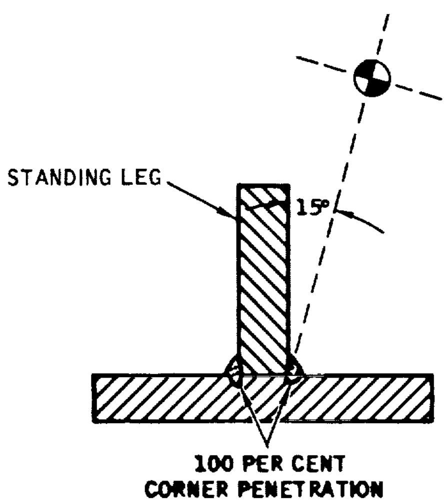


Figure 6-21. Correct Angle for T-Joint (100% Corner Penetration)

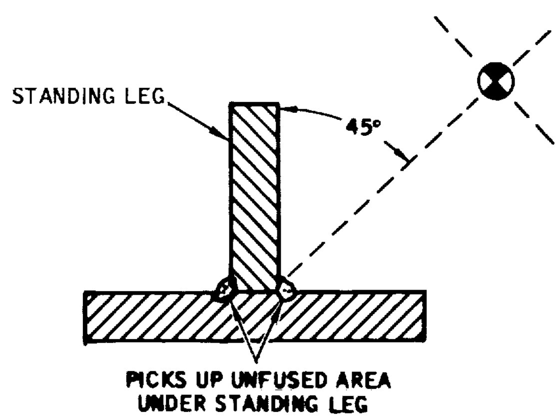


Figure 6-22. Incorrect Angle for T-Joint (100% Corner Penetration)

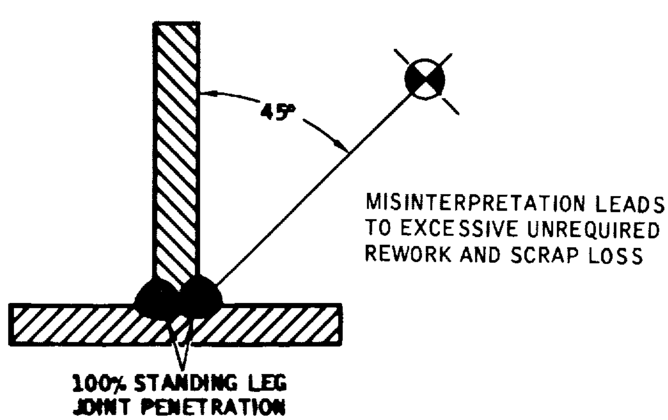


Figure 6-23. Correct Angle for T-Joint (100% Standing Leg Penetration)

[redacted]

5. RADIOGRAPHIC APPLICATION ON WELDED CORNER JOINTS

a. Figures 6-24 and 6-25 are illustrative of correct and incorrect X-ray and/ or detail placement of a corner joint. Proper criteria should cover all weldment configurations to show them to the best advantage on the film. The deciding factors are welding standards, joint configuration, and design stress. Since the technician concentrates on the focal spot, weld, and article alignment, he often forgets joint alignment or the recorded result on the film.

b. Figure 6-24 shows correct tube angulation, article placement, and joint alignment.

c. Figure 6-25 shows correct tube angulation, but tube or detail have been placed in such a position that the unfused area will appear on the film resulting in an incorrect interpretation.

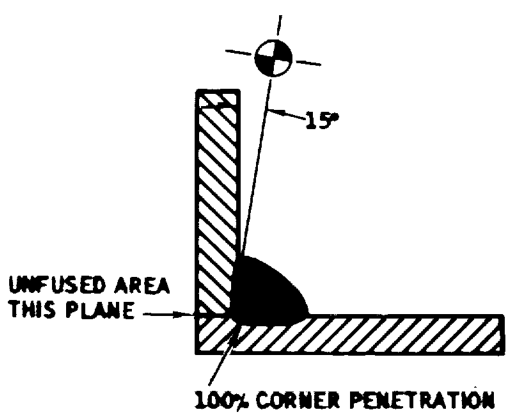


Figure 6-24. Correct Angle for Corner Joint and Correct Detail Placement

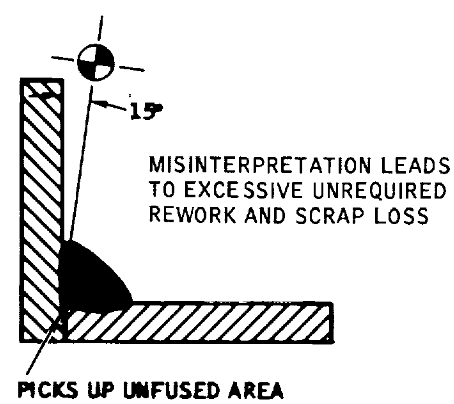


Figure 6-25. Correct Angle for Corner Joint but Incorrect Detail Placement

d. Figure 6-26 illustrates 100% joint penetration. The X-ray tube angulation of 45° is correct. The film and joint must be placed parallel with the tube aperture.

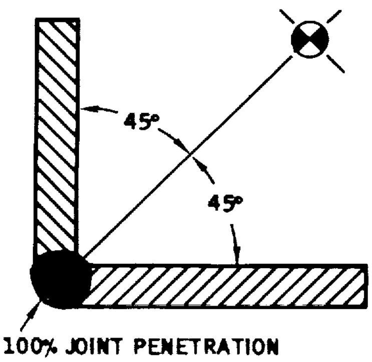
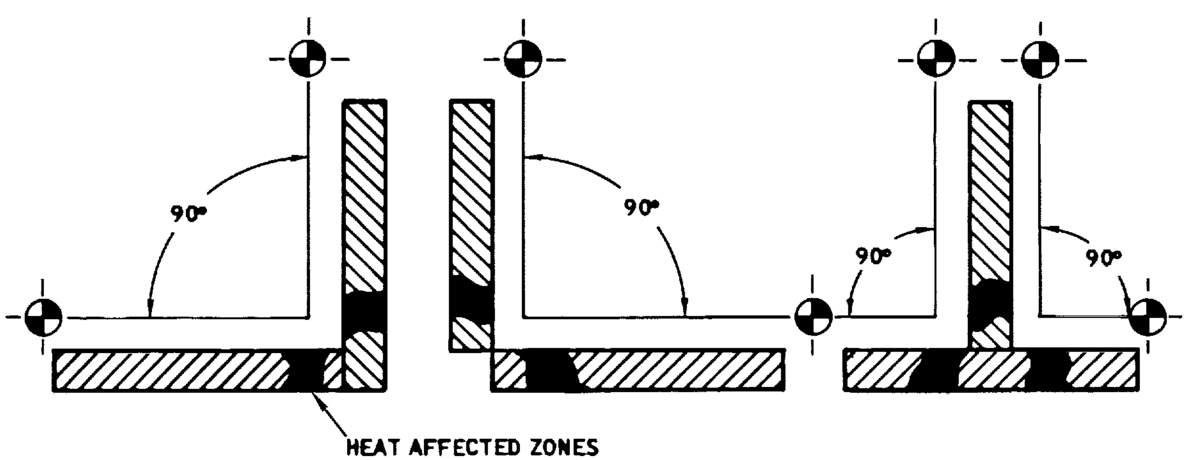


Figure 6-26. Correct Angle for Corner Joint and Correct Detail Placement (100% Penetration)

6. RADIOGRAPHIC APPLICATION ON HEAT AFFECTED ZONES

a. The three diagrams in Figure 6-27 show the heat affected zones of weldments. Additional X-rays should be obtained at 90° to the heat affected zones of critical weldments in view of the effects of expansion and contraction, the rapid cooling due to relative thinness of zone, and the possible rearrangement of molecular structure. It should be noted that routine X-rays of the weldment will not produce the sensitivity required to detect flaws at heat affected zones.



WELDMENTS CLASSIFIED AS CRITICAL
NOTE: ALL WELDMENTS WHICH COULD CAUSE A FAILURE IN A SYSTEM OR FUNCTION SHOULD HAVE ADDITIONAL RADIOGRAPHIC EXPOSURES AT 90° TO THE HEAT AFFECTED ZONES. REGARDLESS OF JOINT CONFIGURATION, WELD PENETRATION, AND FUSION SPECIFICATIONS.

Figure 6-27. Heat Affected Zones of Weldments

b. The two focal spots shown in Figure 6-27 represents a single source at two positions, with the central (incident) beam at 90° to the heat affected zones on each leg of the weldments.

c. Since the shots of the welds were taken at an angle to the legs of the weldment, and the beams pass through the legs at an angle, a 2% sensitivity in the heat affected zones would not produce good resolution.

d. Particular attention should be given to the toe of the weld where it joins the parent metal to detect cracks which follow the configuration of the weld metal.

e. In welding, the elongated crystals or dendrites of the solidifying metal grow from the walls of the melt toward the center of the weld. This results in a coarsened structure that is highly segregated and weakened by eutectic, which is the last to solidify. The final eutectic zone of solidification is the area where cracking usually begins.

7. RADIOGRAPHIC APPLICATION ON SINGLE WALL TUBING

Figure 6-28 shows an example of the single wall application, which should always be used when possible. This is true of flat objects as well as circular objects. Factors relating to all single wall applications are:

a. All circular articles should be numbered in a clockwise direction facing the propagated beam. Lead numbers should be placed on the side opposite the weld, away from the beam, and at least 1/8 inch from the heat affected zone. By placing the lead numbers away from the beam, they will not superimpose in the weld area of interest. Numbering the circular article in a clockwise direction is for future reference. A good method to retain identification is to electrolytically etch the numbers or to utilize metal impression stamps if the specifications permit. Lead numbers, when used, should be taped or otherwise temporarily affixed to the article.

b. In laying out a circumferential weld for the least amount of geometrical distortion the following methods can be used:

   (1) Calculate on both sides of each area the points at which the greatest visual circumferential changes take place.

   (2) Deduct approximately 10% from both sides to allow for distortion.

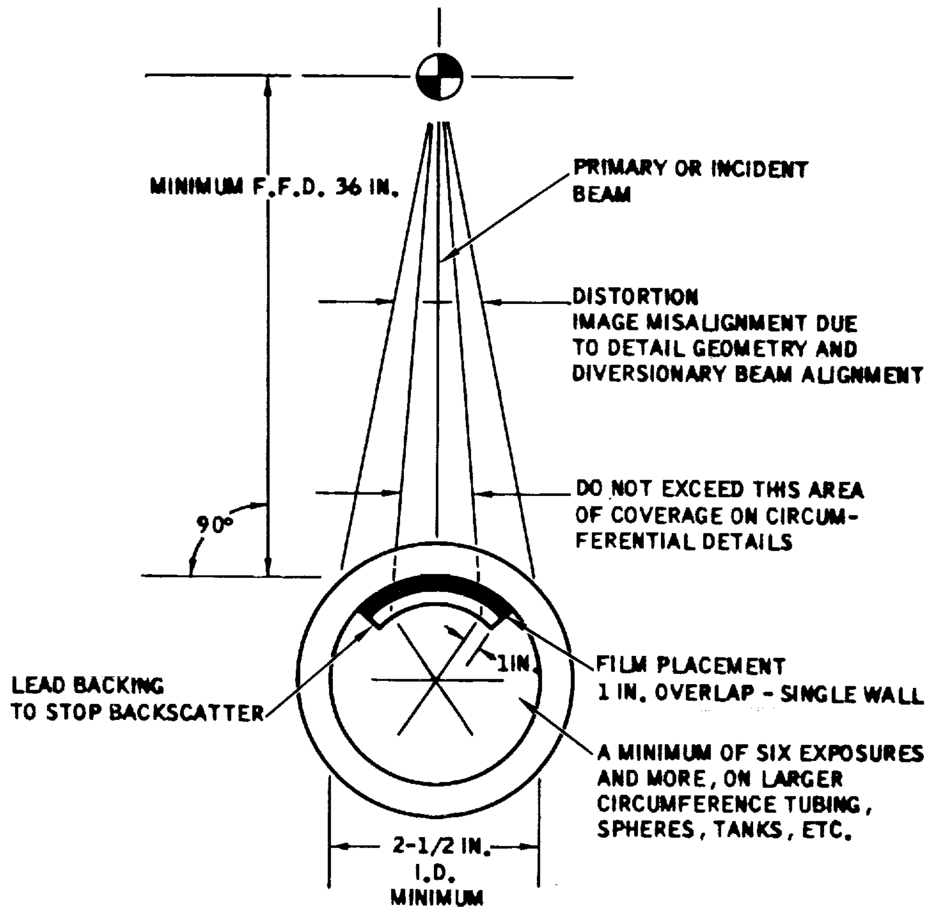


Figure 6-28. Circumferential Single Wall Application

c. Another good method for discontinuity location and area orientation, is to place lead arrows with adhesive backs in the center and at the ends of each area. These arrows must remain on the article until the film has been interpreted, and then removed, as any subsequent welding will be contaminated should the lead arrows melt and run into the weld. The lead arrows will also blow holes into or through a metal article on subsequent heat treating operations if they are not removed.

d. All lead tables and secondary radiation backing should be covered to protect the specimen against contamination.

8. RADIOGRAPHIC APPLICATION ON DOUBLE WALL TUBING

Figures 6-29 and 6-30 illustrate geometric principles, minimum distortion, and orientation as related to double wall applications.

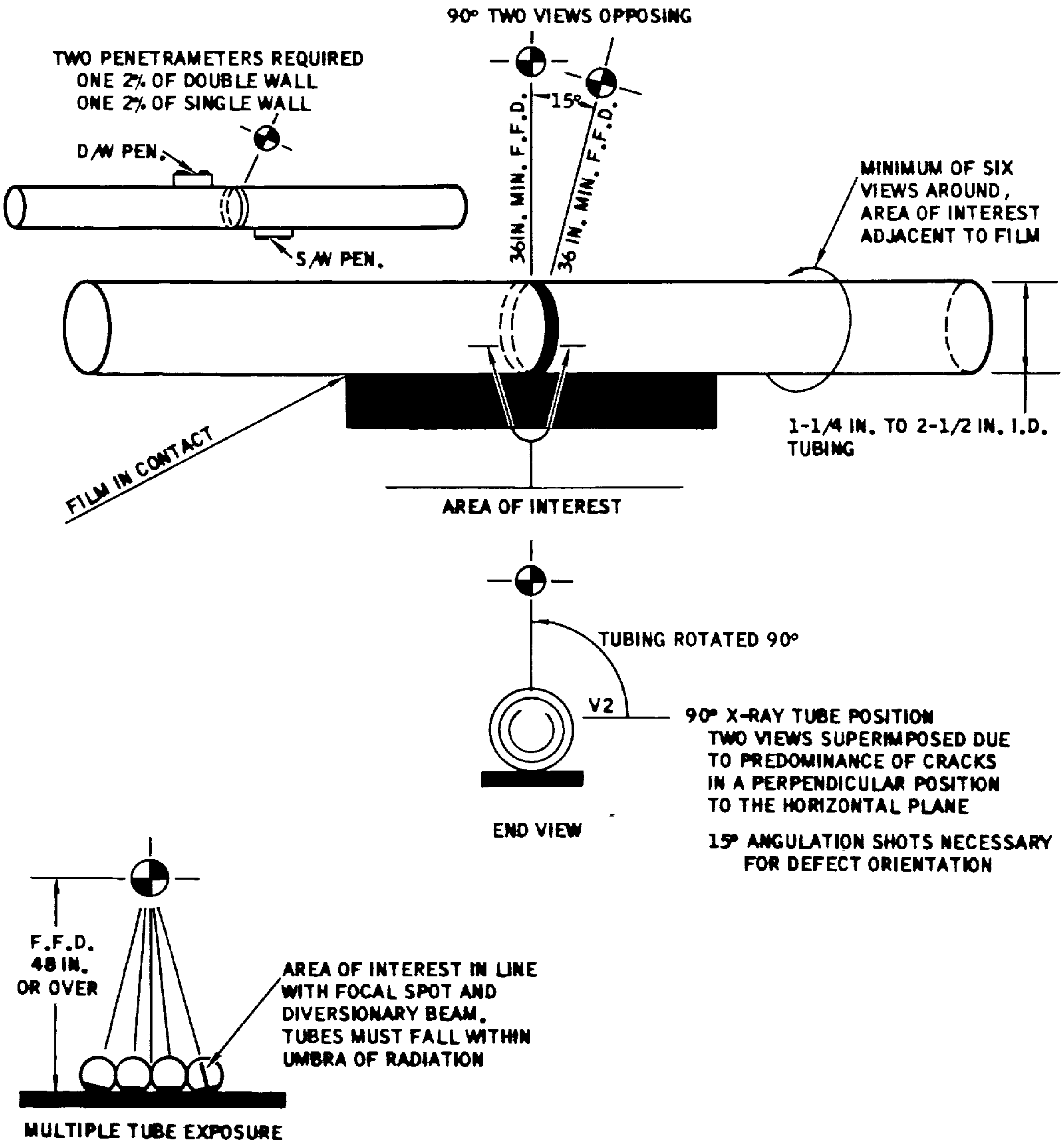


Figure 6-29. Double Wall Application with Tube Size Over 1 1/4 Inch Inside Diameter

[redacted]

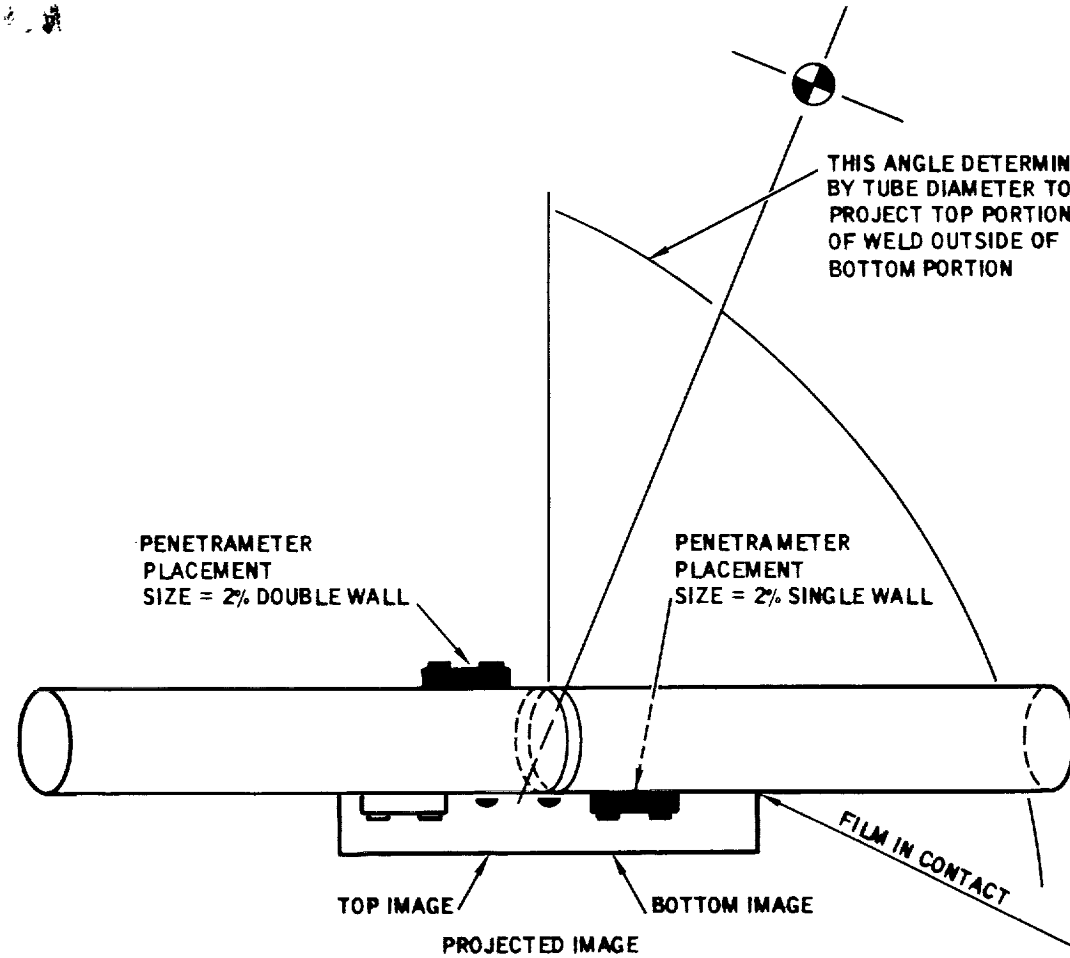


Figure 6-30. Double Wall Application with Tube Size Less Than 1-1/4 Inch Inside Diameter

a. Tubing Size 1-1/4 to 2-1/2 Inch Inside Diameter. (See Figure 6-29.)

(1) Two penetrameters are shown, but only one is required by standard. The top penetrameter is equal to 2% of the total material the beams of radiation pass through. The bottom penetrameter is not required per standard, but it is useful to the film interpreter to show the single wall thickness and the side of the radiation angle as both top and bottom of the circular welds will appear side by side on the film. In addition, lead area numbers and the top penetrameter should be on the side away from the angled beam so they will not superimpose in the weld area.

[redacted]

(2) Two 90° vertical and 90° opposing shots, superimposed, should be taken to show the joint fusion and cracks in the perpendicular position. The angle shots are required for area and defect orientation. There should be a minimum of six views around the tube.

(3) Film should be in contact per geometrical principles so that discontinuities acceptable to standard requirements will not be expanded oversize and rejected.

(4) The lower left of Figure 6-29 illustrates a method for exposing more than one tube assembly on a single exposure. Note that the areas of interest are adjacent to the film and angled to align with the focal spot. To minimize distortion it is best to use a focal film distance of 48 inches or more. The "Umbra" referred to pertains to the central 80% of the cone of radiation diameter. The outer 20% of the cone of radiation diameter is known as the "Penumbra", or the "Halo".

b. Tube Size Less Than 1-1/4 Inch Inside Diameter.

(1) The double wall exposure application for tubing 1-1/4 inch or less, is shown in Figure 6-30. Since the diameter is small, defects present will not be expanded to any appreciable degree. The amount of expansion can be calculated by measuring the top penetrameter and deducting that amount from the discontinuity, provided the discontinuity image has been projected from the top of the tube to the film.

(2) Three ellipsed exposures will give sufficient coverage for these tubing diameters.

(3) The placement of the bottom penetrameter and the lead numbers are very important to this operation in order to provide absolute orientation.

9. RADIOGRAPHIC APPLICATION ON CLOSED SPHERES

The radiographic applications for a closed sphere are shown in Figure 6-31. The applications are similar to those for double wall tubing. The penetrameters must be placed on a block of similar material to show total thickness of the double wall. In this case the area numbers may be face up with the identification plate if desired, since the area can be more easily oriented.

[redacted]

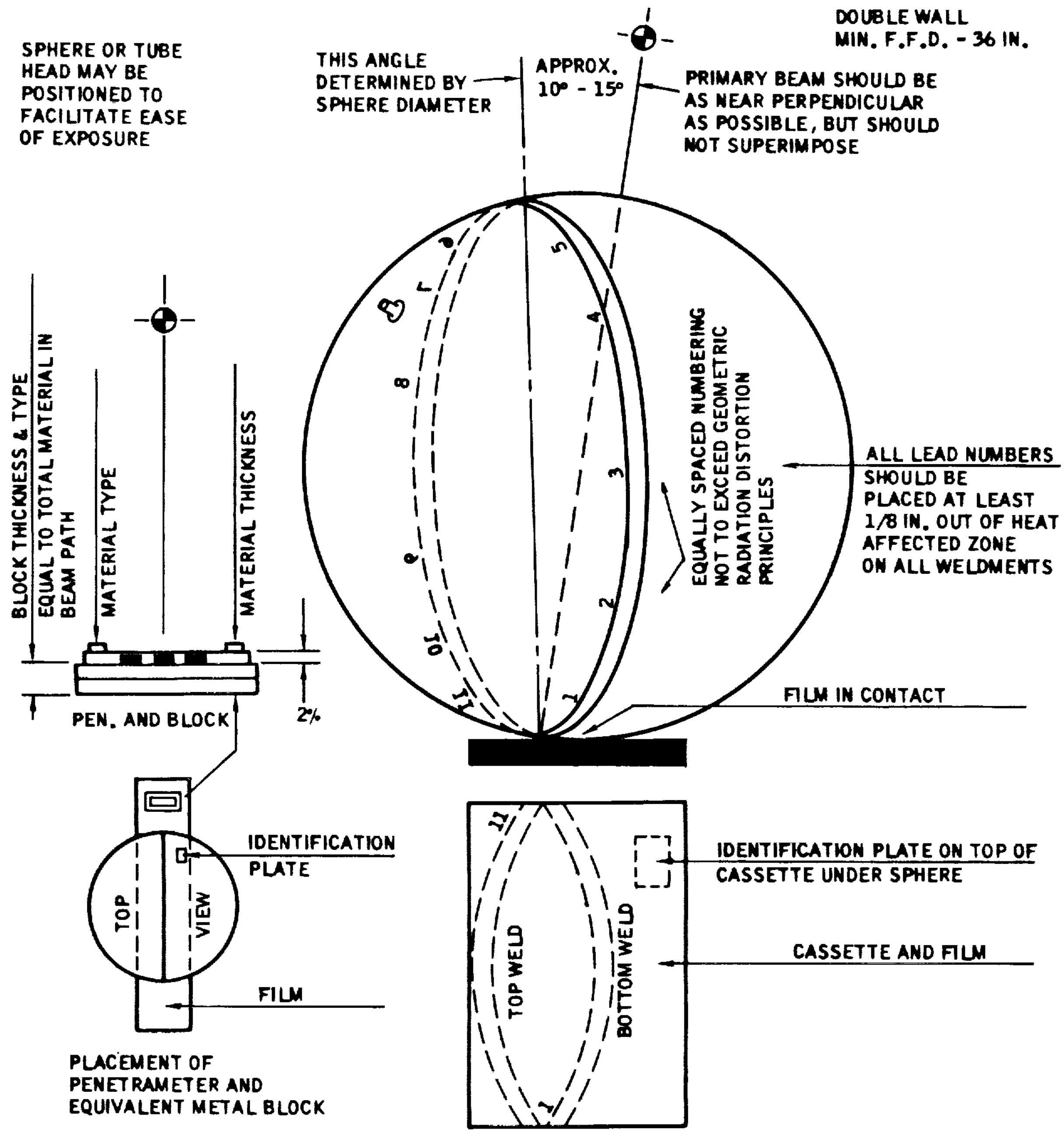


Figure 6-31. Sphere Weldment Application

[redacted]

10. RADIOGRAPHICAL APPLICATION ON CLOSED TANKS

Figure 6-32 shows some of the procedures of radiographing a closed tank when the X-ray tube or film cannot be placed inside. The multiple source represents a single source at various positions. The source position at one end of the tank illustrates that the other end of the tank can be covered with film and exposed with a single exposure. If the circumferential weld at the tank end should be on a cross sectional plane in relation to the source positioned at the tank end, additional exposures must be taken through the horizontal plane, as represented by the source position at the upper left. Geometric principles and minimum distortion distance must be maintained.

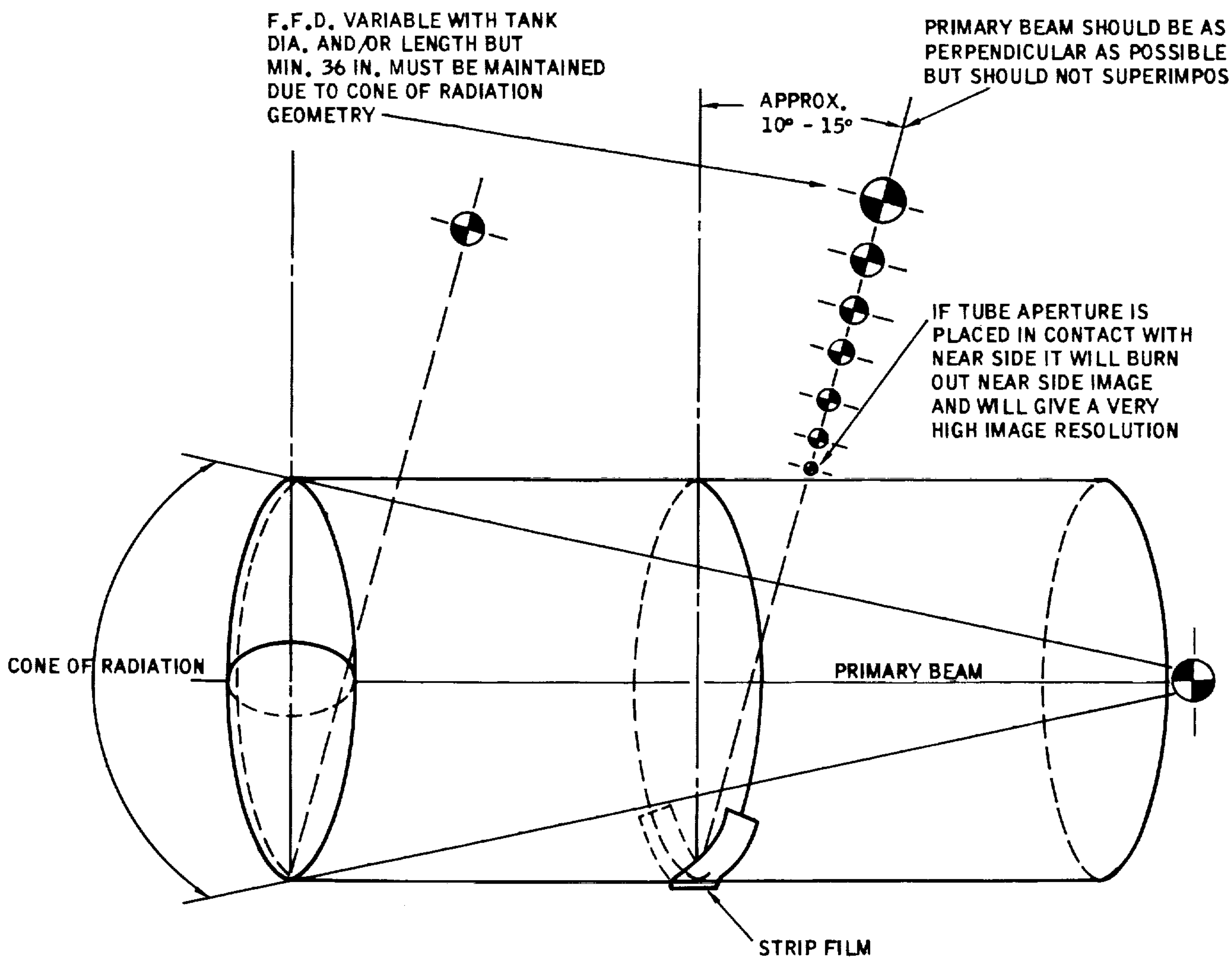
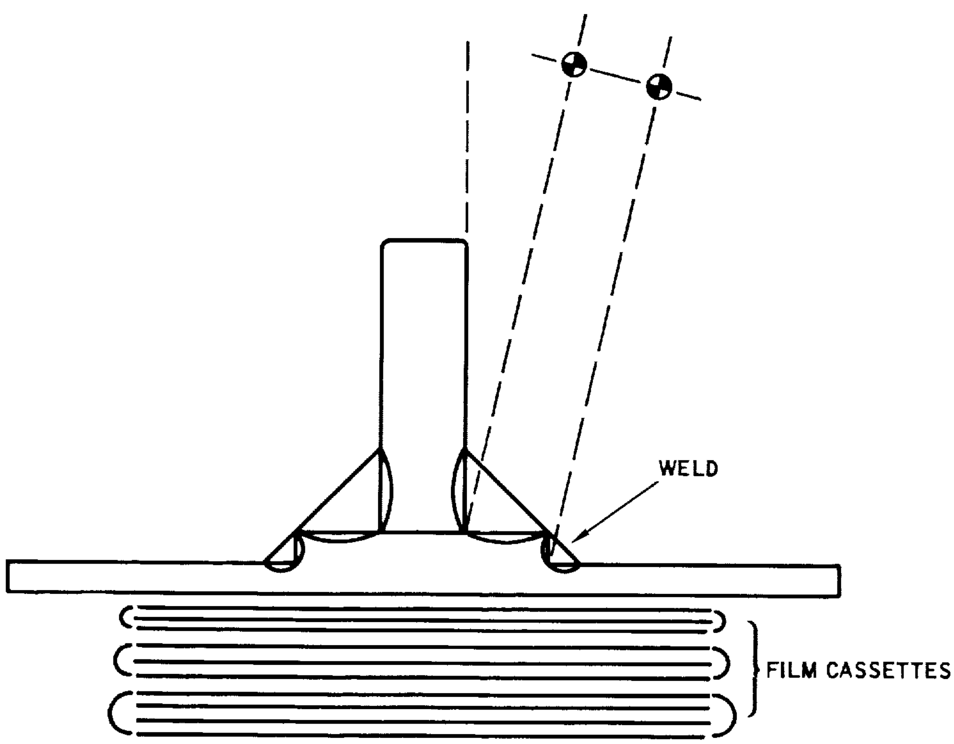


Figure 6-32. Closed Tank Application

11. RADIOGRAPHIC MULTIPLE COMBINATION APPLICATION

Figure 6-33 is a good method to use when setup is difficult, exposure time is excessive, or material type and thickness are unknown. It is not recommended as a standard practice because density and sensitivity do not always measure to the required values through the various screens behind the first cassette. The back screens will filter rather than intensify. This application permits a high degree of latitude with a single exposure. This application may be used for weld grind outs where the depth cannot be checked or is unknown, or when the weld may have multiple grind outs of varying depths. This system gives varying degrees of film density from the top film through the various films and screens to the back film.



1. VARY VOLTAGE, AMPERAGE, AND TIME
2. VARY DISTANCE (36 IN. MINIMUM)
3. VARY THICKNESS AND ATOMIC NUMBER OF TUBE HEAD FILTERS
4. VARY FILM TYPES AND COMBINATIONS
5. VARY SCREEN AND NON-SCREEN COMBINATIONS
6. VARY NUMBER OF CASSETTES UNDER SPECIMEN WITH ABOVE COMBINATIONS

Figure 6-33. Multiple Combination Application

12. RADIOGRAPHIC APPLICATION ON HEMISPHERICAL SECTIONS

All welds or seams on a hemispherical section may be radiographed with a radioisotope source as shown in Figure 6-34. The source is placed in the geometric center of the section and film is placed over all the welds. The gamma ray exposes all areas simultaneously. This procedure is time saving and is often used when gamma radiography is acceptable.

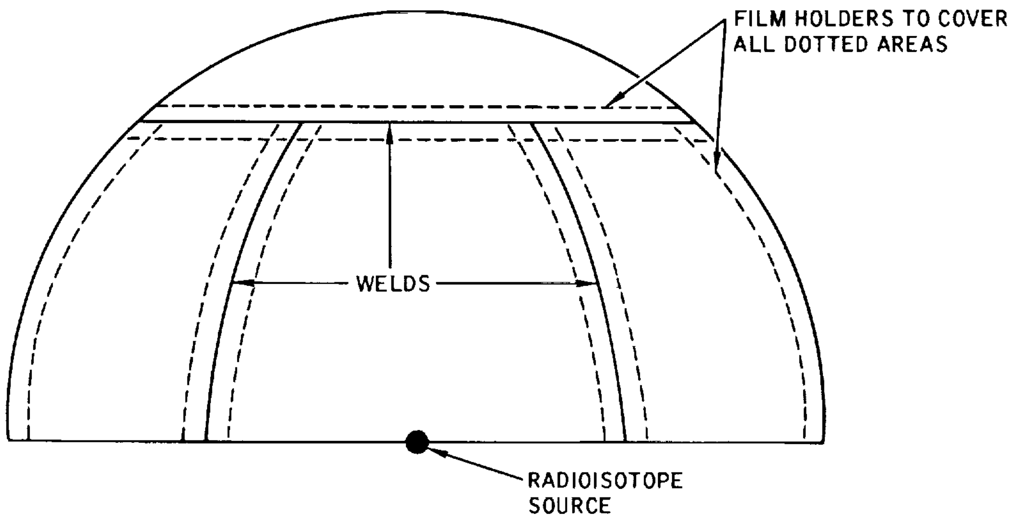


Figure 6-34. Hemispherical Section

13. RADIOGRAPHIC PANORAMIC APPLICATION

Figures 6-35 and 6-36 illustrate two examples of panoramic exposure application. Figure 6-35 depicts a means of radiographing welds on piping whose diameter is great enough to permit insertion of a rod anode X-ray tube. The beam of this type tube will expose the entire circumference of the pipe. The X-ray tube is placed in the center of the pipe so that the beam strikes the area of interest (the weld). Exposure calculations are based on the weld thickness. If gamma radiography is acceptable, a radioisotope source may be used in the same manner as a rod anode tube. The arrangement shown in Figure 6-36 is used when a sufficient number of similar small articles are to be radiographed.

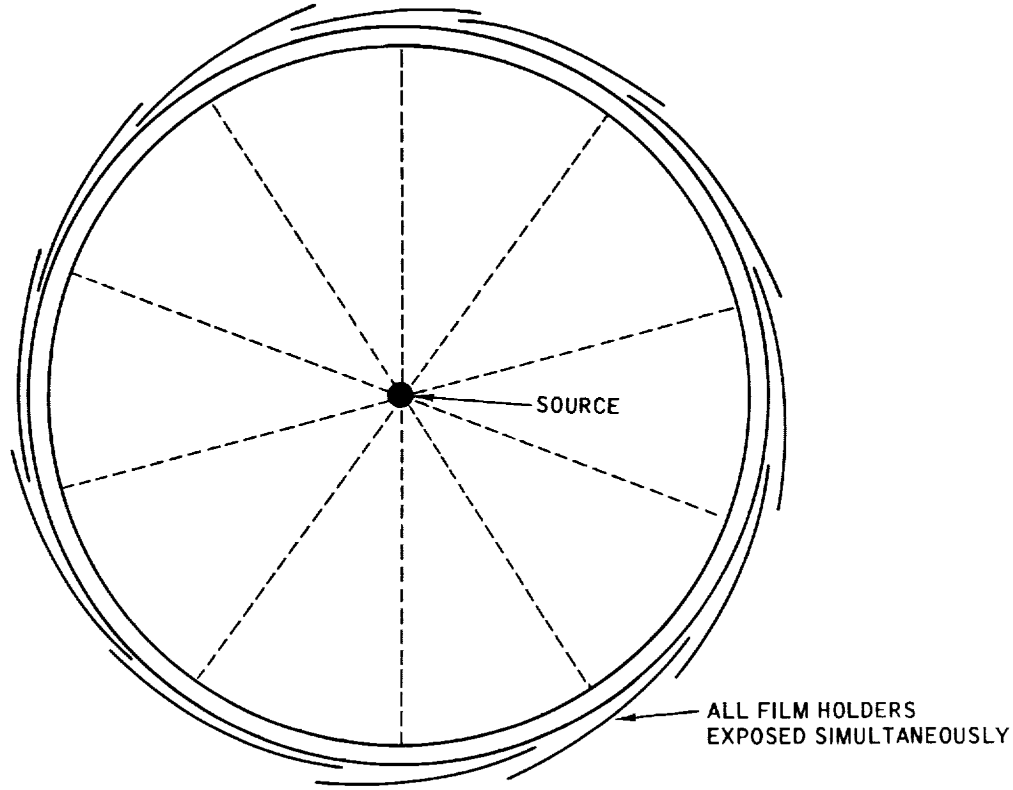


Figure 6-35. Panoramic Application, Large Pipe Weld

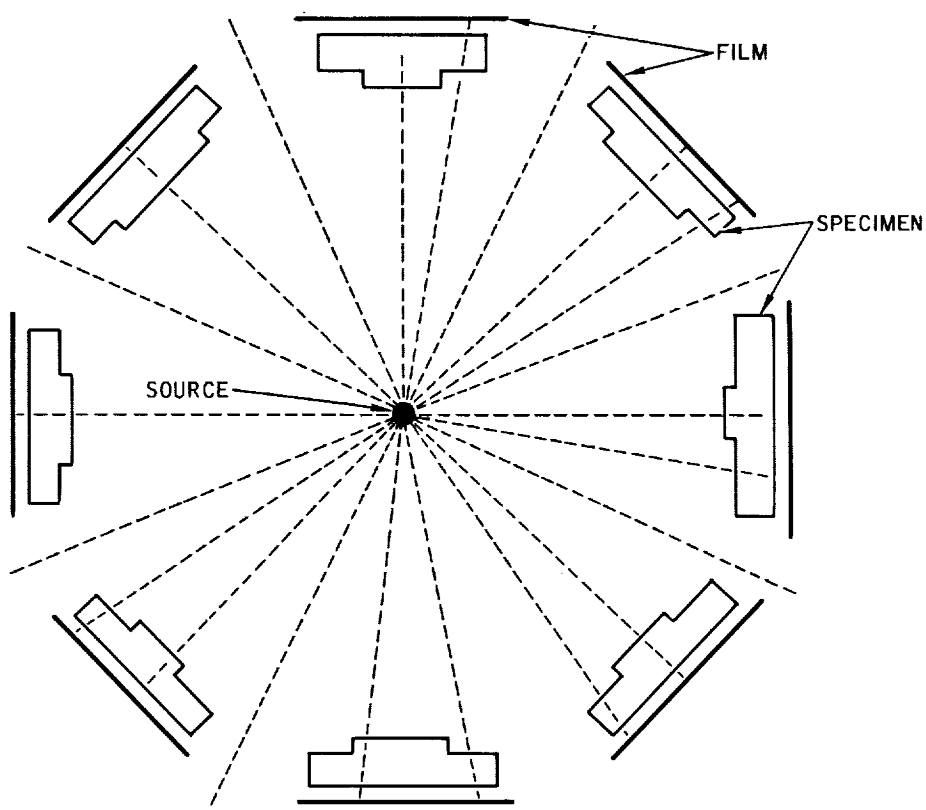


Figure 6-36. Panoramic Application, Similar Articles

[redacted]

14. RADIOGRAPHIC APPLICATION ON LARGE PIPE WELDS

Recommended radiographic procedure for large pipe welds that cannot be handled by elliptical or single wall shots is shown in Figure 6-37. In the figure it is evident that the thickness of the specimen along path "a" is much less than that at path "b", which is tangential to the pipe. Since it is impractical to obtain the desired results with a single exposure, the circumference of the weld is divided into three or more segments, and each segment is radiographed. Exposure calculations and penetrameter and shim selection are based on the thickness of the specimen (double wall) penetrated in the area of interest of each segment.

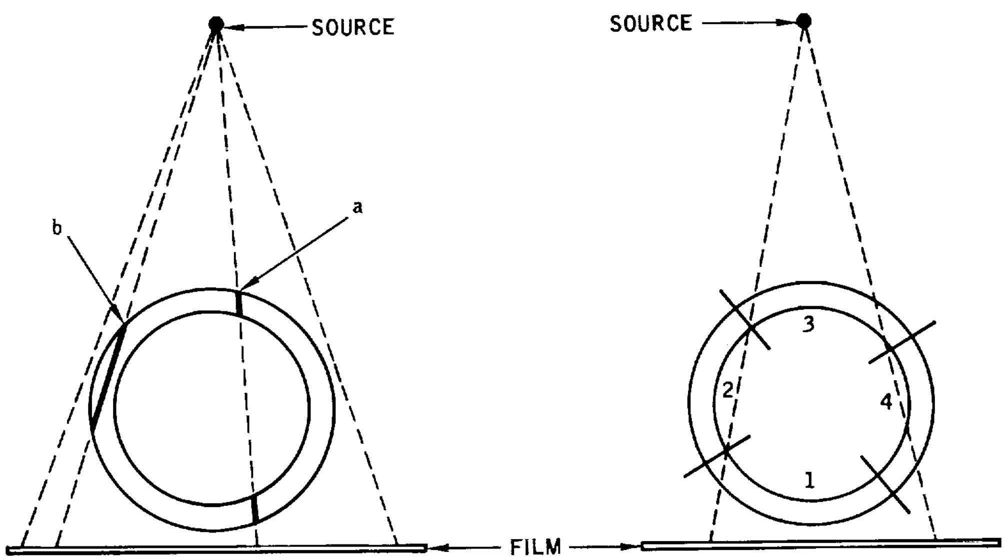
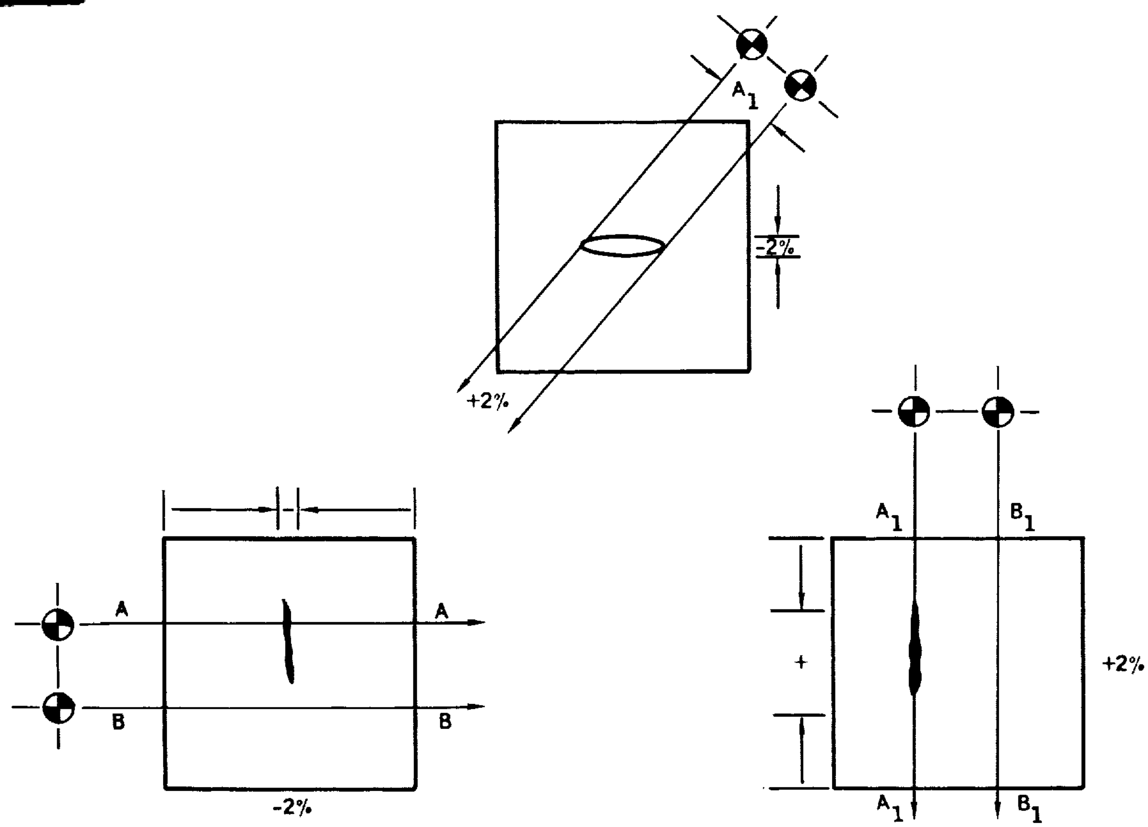


Figure 6-37. Large Pipe Welds

15. RADIOGRAPHIC TECHNIQUES OF DISCONTINUITY LOCATION

a. Alignment. Figure 6-38 illustrates why discontinuities are often not recorded on the radiograph. Either the discontinuity cross sections are less than 2% of the overall specimen thickness or the longitudinal alignment of the discontinuity is not aligned with the radiation path. The diagram on the left shows incorrect discontinuity alignment because the width of the discontinuity is less than 2% of the overall thickness. The diagram on the right shows correct discontinuity alignment because the length of the discontinuity is more than 2% of the total thickness. Consequently, several possible angles should be used when performing a radiographic examination.



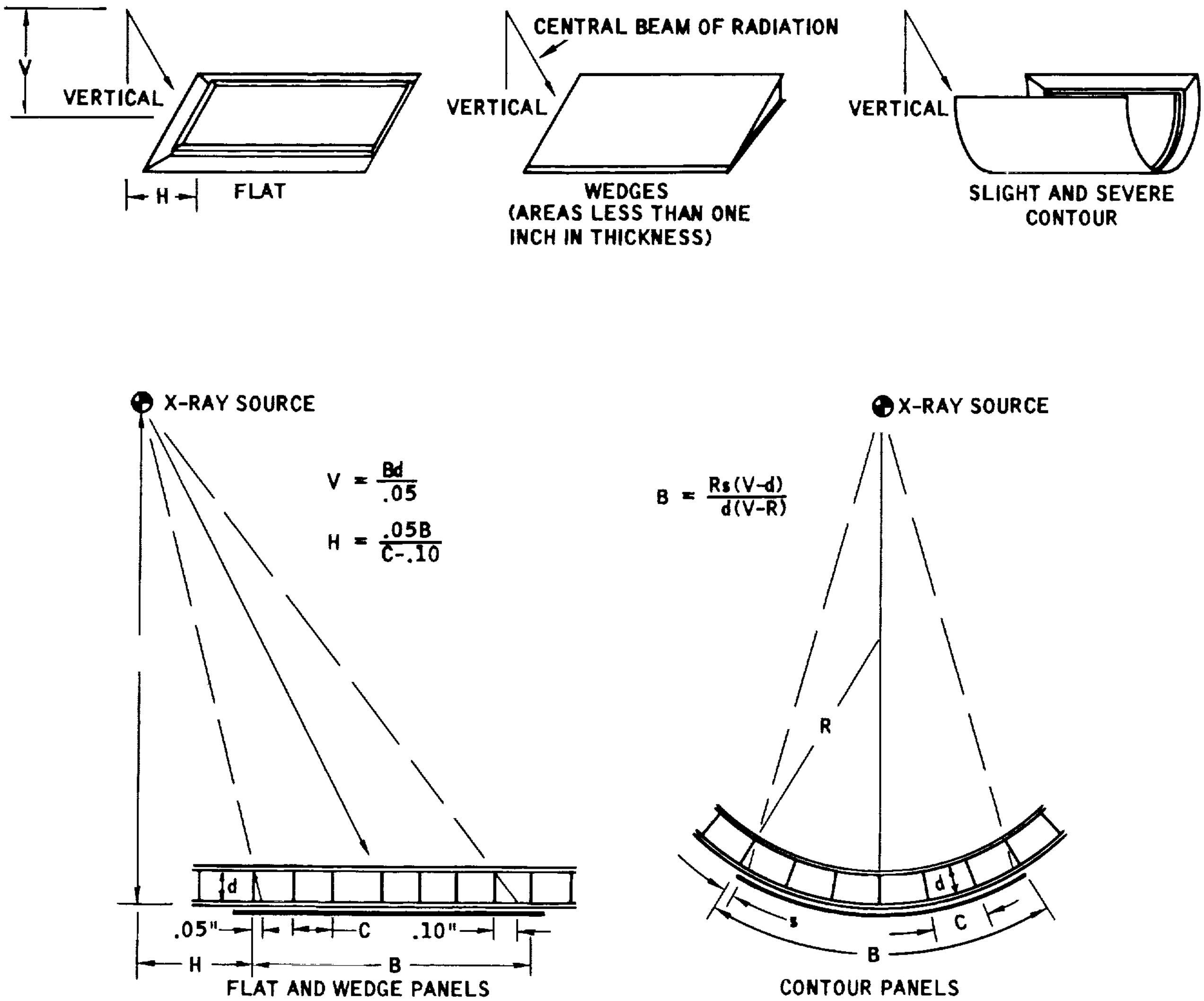
FINE DISCONTINUITIES ARE DETECTED MORE EASILY WHEN THE X-RAY IS DIRECTED ALONG PATH $A_1 A_1$ RATHER THAN ALONG AA.

Figure 6-38. Angulation and Flaw Alignment

b. Single Exposure - Superimpose. This technique of discontinuity location may also be used. It involves exposing two separate films, each at a precise density, then laying one film over the other, superimposing the two back markers. The shift of the discontinuity is measured and calculated. A simpler variation is to expose two separate films and superimpose the two back markers. If the shift of the discontinuity is less than one-half the shift of the discontinuity of the front marker, the discontinuity is nearer the film. If the shift of the discontinuity is greater than one-half the shift of the front marker, the discontinuity is nearer the top or away from the film.

16. RADIOGRAPHIC APPLICATION ON BRAZED/BONDED HONEYCOMB

Figures 6-39 through 6-42 illustrate four types of exposures used to evaluate brazed or bonded honeycomb. Other special applications may be used; however, they normally will be variations of these four and are used for X-ray of a specific detail or area.



V = PERPENDICULAR DISTANCE FROM TUBE TO FILM PLANE.
H = HORIZONTAL DISTANCE FROM PERPENDICULAR TO SECTION OF CORE BEING X-RAYED.
B = LENGTH OF CORE SECTION BEING X-RAYED.
C = CELL SIZE.
d = THICKNESS OF CORE SECTION.
R = RADIUS OF CONTOUR OF COMPONENT.
s = ARC LENGTH.

Figure 6-39. Double Surface Application

a. Double Surface. Variations of this technique should be used to radiograph panels less than one inch thick. The following conditions should be satisfied on all exposures:

(1) The upper surface fillet of any cell in the area X-rayed should not overlap the extreme lower fillet of the adjacent cell.

(2) The upper surface fillet of any cell in the area X-rayed should not be superimposed on any other fillet.

(3) The direction of the central beam of radiation should always be normal to the core ribbon direction as shown in Figure 6-39.

b. Single Surface. Variations of this application should be used to radiograph panels one inch or greater in thickness. The upper surface fillets (those closest to the X-ray tube) should be sufficiently blurred to permit adequate viewing of all lower surface fillets within the area X-rayed.

A wedge shaped copper filter should be used at the X-ray tube, as illustrated in Figure 6-40, to obtain a more uniform density over the area exposed. Filter size and thickness should be adjusted for each X-ray tube.

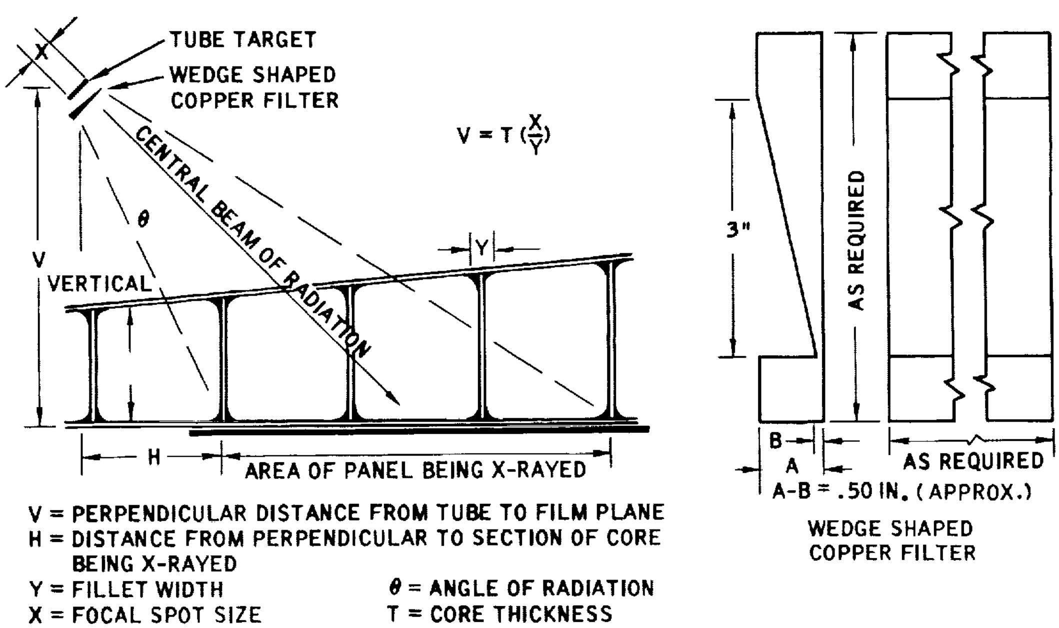


Figure 6-40. Single Surface Application

[redacted]

c. Edge Member Exposures. Two basic setups for edge member exposures are illustrated in Figure 6-41. Variations of these setups shall be used on all edge member exposures as outlined.

View A illustrates the setup for Z-edge member exposures. In most instances, adequate coverage will be obtained (on flat and slight contour panels) on core exposures.

View B illustrates the setup for wedge U-channel (rib and spar) exposures. Both surfaces shall be X-rayed separately. This permits determination of the amount of void area in both edge member surface.

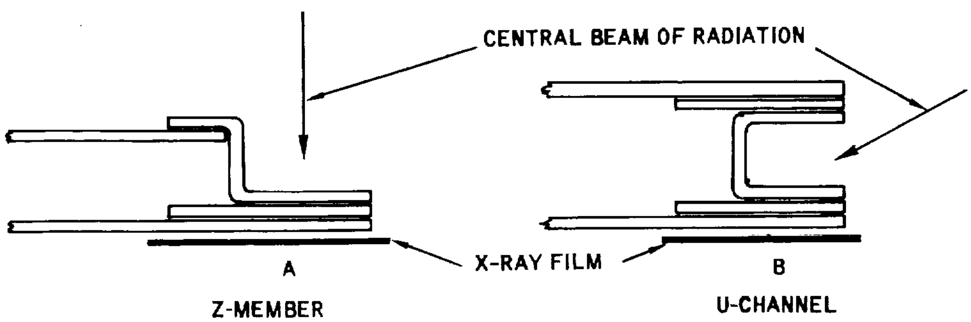


Figure 6-41. Edge Member Application

d. Vertical Tie Exposure. Figure 6-42 illustrates the basic setups for vertical tie exposures. Variations of these setups should be used on all exposures made to evaluate the braze between the core vertical edge and the Z-member vertical or the U-channel vertical leg. The setup for vertical braze evaluation (Z-member) on contour panels and special exposures on flat panels is illustrated in view A.

The vertical leg of the Z-member should be inclined approximately 8 to 10 degrees from the horizontal. The central beam of radiation should be vertical and directly over the vertical leg of the Z.

An alternate setup would be with the vertical leg of the Z horizontal and parallel to the film. The central beam of radiation should be 8 to 10 degrees off of vertical and directed toward the center of the area being radiographed.

The setup for vertical braze evaluation (U-Channels) on wedges and special exposures on all other panels is illustrated in view B. The lower surface (left hand part) should be the farthest from the X-ray tube and must be in the horizontal plane.

The central beam of radiation should be at an angle and distance so the projected vertical member height will not be less than half and not greater than the actual vertical leg height.

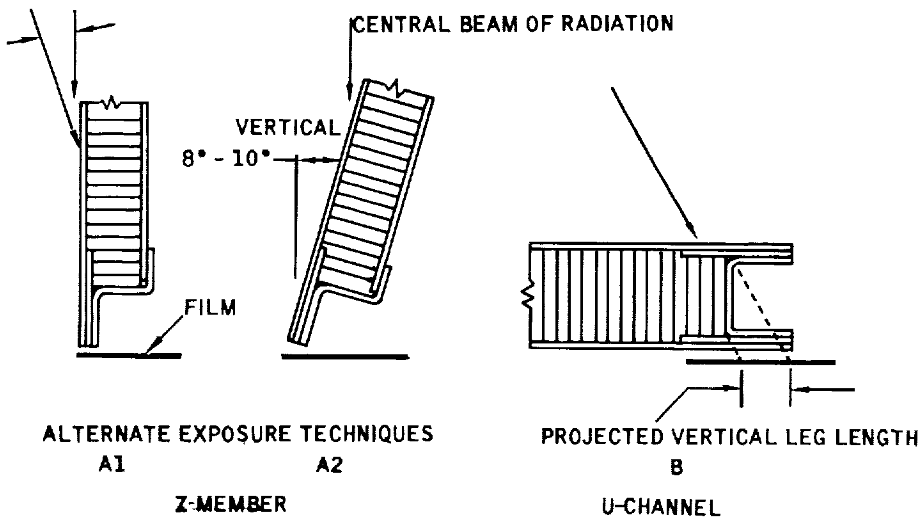


Figure 6-42. Vertical Tie Exposure

17. RADIOGRAPHIC APPLICATION ON SEMICONDUCTORS

a. General. The application of radiography to semiconductors is somewhat different than applications discussed previously. With semiconductors two major areas are of concern after the electrical acceptance tests have been completed. These areas of concern are inconsistent internal construction and internal foreign material. Specific discontinuities associated with semiconductors are listed below. (See Figure 6-43.)

(1) Loose particles, solder balls, flakes, weld splash, and wire

(2) Loose or discontinuous connecting leads between internal elements and external terminals

(3) Extraneous matter, excessive solder or weld extrusions

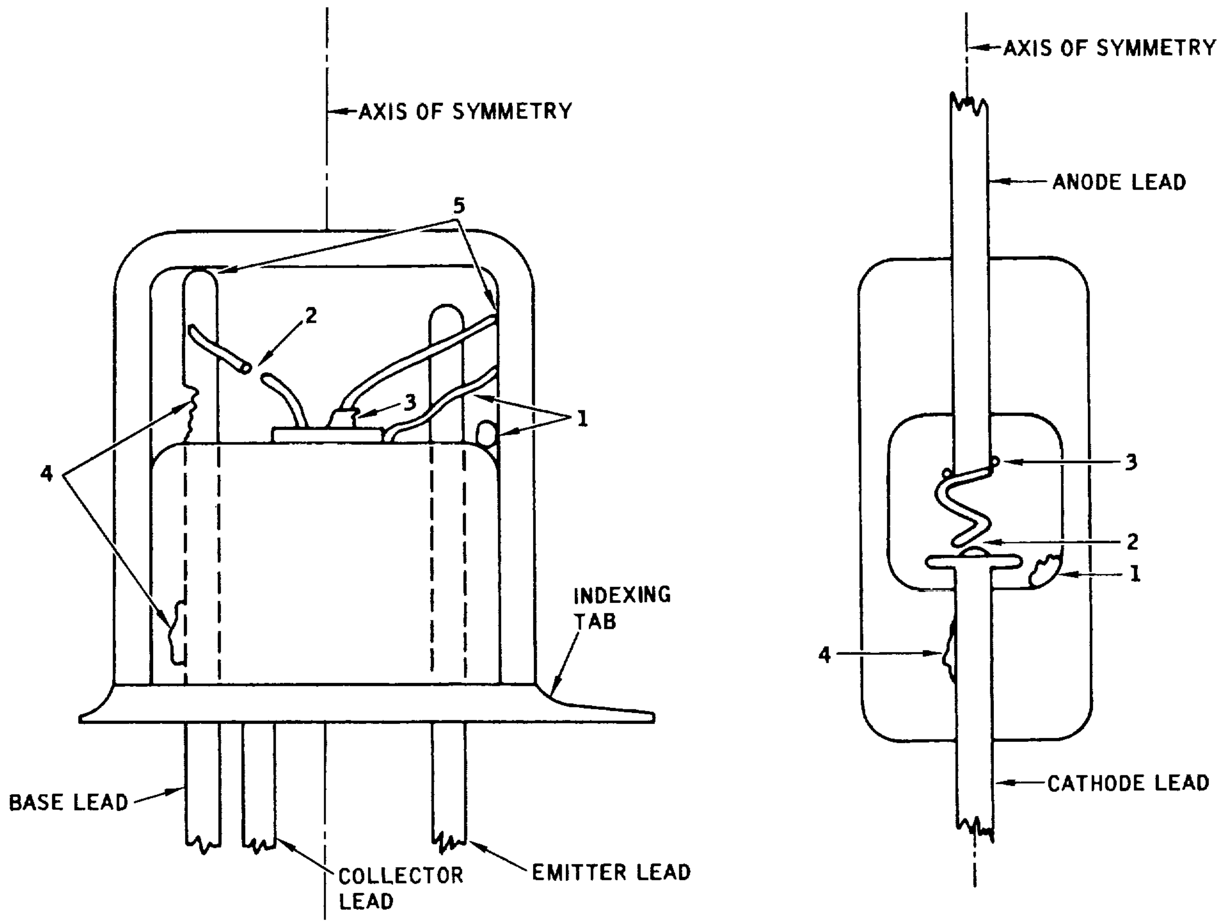
(4) Inclusions or voids in seals or around lead connections or insufficient sealing material

(5) Inadequate clearance

b. Techniques of Semiconductor Radiography. The following parameters must be taken into consideration to obtain satisfactory test results.

(1) A beryllium tube head or equivalent should be used.

(2) Voltage must not exceed 150 KV; there is no limitation on current.



TRANSISTOR   DIODE

1. LOOSE PARTICLES, SOLDER BALLS, FLAKES, WELD SPLASH, WIRE.
2. LOOSE OR OPEN LEADS BETWEEN INTERNAL ELEMENTS AND EXTERNAL TERMINALS.
3. EXTRANEOUS MATTER, EXCESSIVE SOLDER, OR WELD EXTRUSIONS.
4. INCLUSIONS OR VOIDS IN SEALS OR AROUND LEAD CONNECTIONS.
5. INADEQUATE CLEARANCE.

Figure 6-43. Transistor and Diode Defects

(3) To avoid parallax use extra fine grain, single coated emulsion film.

(4) Use 20 power magnification and sufficient light intensity during film interpretation to enable identification of 0.001 inch discontinuities.

(5) Use correct semiconductor alignment.

(6) Correctly locate radiographic source.

(7) Assure proper density in area of interest.

[redacted]

The last two parameters are discussed further in succeeding paragraphs.

c. Alignment of Semiconductors. Figure 6-44 illustrates a typical holding fixture designed to curve the film in order to maintain equal FFD from the outer edge of the film to the center. The semiconductors should be mounted consistently, that is with the same pin on each facing the target.

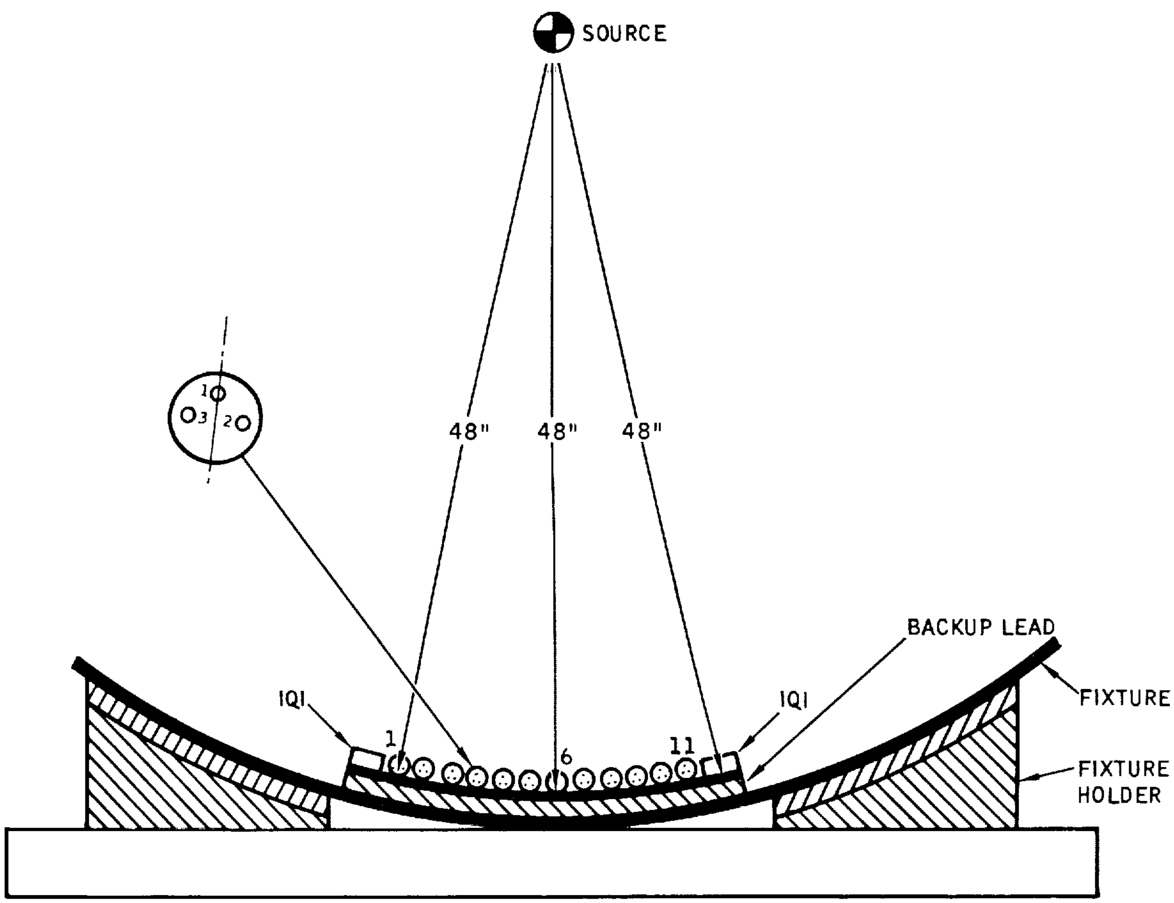


Figure 6-44. Semiconductor Holding Fixture

d. Radiographic Views

(1) Figure 6-45 illustrates the views required for satisfactory coverage of a transistor. Other views may be required to detect a specific type of discontinuity.

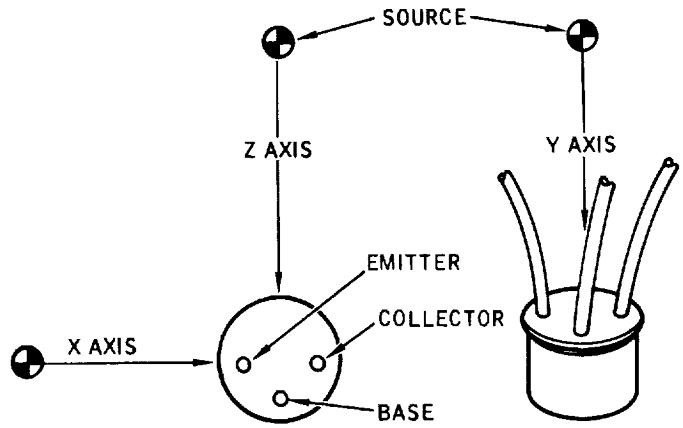


Figure 6-45. Suggested Views of Transistor

(2) Figure 6-46 illustrates the views required for satisfactory coverage of diodes, resistors, and capacitors.

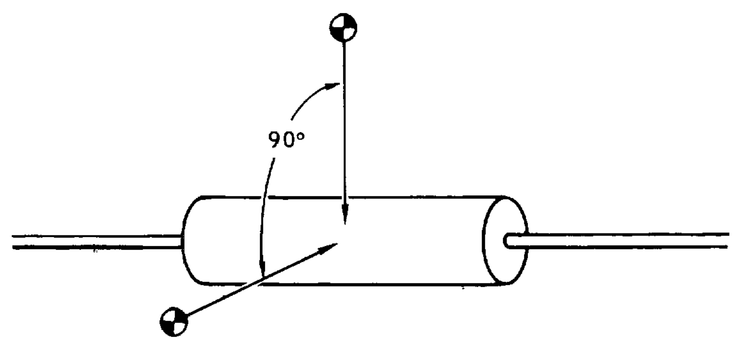


Figure 6-46. Suggested Views of Diode, Resistor, and Capacitor

e. Fluoroscopic Application. Another method for examining transistors, diodes, resistors, and capacitors is through the use of a fluoroscope in conjunction with closed circuit television. Such a system would permit viewing the part from different directions as it was rotated. The application of fluoroscopy is discussed further in paragraph 607.

606 UNSATISFACTORY RADIOGRAPHS

Table 6-6 lists many of the faults encountered in unsatisfactory radiographs, their probable causes, and the required corrective actions.

Table 6-6. Unsatisfactory Radiographs

DEFECT	PROBABLE CAUSE	CORRECTIVE ACTION
HIGH DENSITY	OVEREXPOSURE	VIEW WITH HIGHER INTENSITY ILLUMINATION. CHECK X-RAY TIMER AND METERS; IF CORRECT, REDUCE EXPOSURE 30% OR MORE.
	OVERDEVELOPMENT	CHECK DARKROOM TIMER CHECK FOR HIGH DEVELOPER TEMPERATURE.
	FOG	AS INDICATED LATER.
LOW DENSITY	UNDEREXPOSURE	CHECK X-RAY TIMER AND METERS; IF CORRECT, INCREASE EXPOSURE 40% OR MORE.
	UNDERDEVELOPMENT	CHECK DARKROOM TIMER. CHECK FOR LOW DEVELOPER TEMPERATURE. CHECK FOR WEAK (DEPLETED) DEVELOPER.
	MATERIAL BETWEEN SCREEN AND FILM	AS INDICATED
HIGH CONTRAST	HIGH SUBJECT CONTRAST.	INCREASE KILOVOLTAGE.
	HIGH FILM CONTRAST	USE FILM WITH LOWER CONTRAST CHARACTERISTICS.
LOW CONTRAST	LOW SUBJECT CONTRAST	REDUCE KILOVOLTAGE.
	LOW FILM CONTRAST	USE FILM WITH HIGHER CONTRAST CHARACTERISTICS.
	UNDERDEVELOPMENT	CHECK DARKROOM TIMER. CHECK FOR LOW DEVELOPER TEMPERATURE. CHECK FOR WEAK (DEPLETED) DEVELOPER.
POOR DEFINITION	OVERLONG SPECIMEN-TO-FILM DISTANCE	IF POSSIBLE, DECREASE SPECIMEN-TO-FILM DISTANCE; IF NOT, INCREASE SOURCE-TO-FILM DISTANCE.
	TOO SHORT SOURCE-TO-FILM DISTANCE	INCREASE SOURCE-TO-FILM DISTANCE.
	TOO LARGE FOCAL SPOT	USE TUBE WITH SMALLER FOCAL SPOT OR INCREASE THE TUBE-TO-FILM DISTANCE.
	TOO LARGE GAMMA RAY SOURCE	USE SMALLER GAMMA RAY SOURCE OR INCREASE SOURCE-TO-FILM DISTANCE.
	SCREENS AND FILM NOT IN CLOSE CONTACT	AS INDICATED.
	FILM GRAININESS	USE FINER GRAINED FILM.
FOG	LIGHT LEAKS IN THE DARKROOM	WITH DARKROOM UNLIGHTED, TURN ON ALL LIGHTS IN ADJOINING ROOMS, SEAL ANY LIGHT LEAKS NOTED.
	EXPOSURE TO SAFELIGHT	CHECK SAFELIGHT LAMPS FOR CORRECT WATTAGE. CHECK SAFELIGHT FILTERS.
	STORED FILM NOT PROTECTED FROM RADIATION	ATTACH A STRIP OF LEAD TO A LOADED FILM HOLDER AND PLACE THE HOLDER IN THE FILM STORAGE AREA. DEVELOP THE TEST FILM AFTER 2 OR 3 WEEKS; IF AN IMAGE OF THE STRIP IS EVIDENT, IMPROVE THE PROTECTION IN THE STORAGE AREA.
	EXPOSURE TO HEAT, HUMIDITY, OR GASES.	STORE FILM IN A COOL, DRY PLACE NOT SUBJECT TO GASES OR VAPORS.
	OVERDEVELOPMENT	CHECK DARKROOM TIMER. CHECK FOR HIGH DEVELOPER TEMPERATURE.
	DEVELOPER SOLUTION	CHECK DEVELOPER SOLUTION FOR CONTAMINATION; IF CONTAMINATED, REPLACE.
	EXPOSURE DURING PROCESSING	DO NOT INSPECT FILM DURING PROCESSING UNTIL FIXING IS COMPLETED.

Table 6-6. Unsatisfactory Radiographs (Cont)

DEFECT	PROBABLE CAUSE	CORRECTIVE ACTION
FINELY MOTTLED FOG	STALE FILM	
FOG ON EDGE OR CORNER	DEFECTIVE CASSETTE	
YELLOW STAIN	DEPLETED DEVELOPER	REPLACE DEVELOPER SOLUTION.
	FAILURE TO USE STOP BATH OR TO RINSE	USE STOP BATH OR RINSE THOROUGHLY.
	DEPLETED FIXER	REPLACE FIXER SOLUTION.
DARK CIRCULAR MARKS	FILM SPLASHED WITH DEVELOPER PRIOR TO IMMERSION	USE CARE IN IMMERSING FILM IN THE DEVELOPER
DARK SPOTS OR MARBLE-LIKE AREAS	LACK OF FIXATION	USE FRESH FIXING SOLUTION AND CORRECT FIXING TIME.
DARK BRANCHED LINES AND SPOTS	STATIC DISCHARGE	REMOVE FILM CAREFULLY FROM WRAPPER. DO NOT RUB ONE FILM AGAINST ANOTHER. AVOID CLOTHING PRODUCTIVE OF STATIC ELECTRICITY.
DARK FINGERPRINTS	TOUCHING UNDEVELOPED FILM WITH CHEMICALLY CONTAMINATED FINGERS	AS INDICATED.
DARK SPOTS OR STREAKS	FILM CONTAMINATION BY METALLIC SALTS	INSURE THAT DEVELOPER SOLUTION IS NOT CON-TAMINATED.
CRESCENT-SHAPED LIGHT AREAS	FAULTY FILM HANDLING	KEEP FILM FLAT DURING HANDLING. USE ONLY CLEAN, DRY FILM HANGERS.
LIGHT CIRCULAR PATCHES	AIR BUBBLES ON FILM DURING DEVELOPMENT	AGITATE IMMEDIATELY UPON IMMERSION OF FILM IN DEVELOPER.
LIGHT FINGERPRINTS	TOUCHING UNDEVELOPED FILM WITH OILY OR GREASY FINGERS	AS INDICATED.
CIRCULAR OR DROP-SHAPED LIGHT PATCHES	FILM SPLASHED WITH WATER OR FIXER PRIOR TO DEVELOPMENT	AS INDICATED
LIGHT SPOTS OR AREAS	DUST OR LINT BETWEEN SCREENS AND FILM	KEEP SCREENS CLEAN.
SHARPLY OUTLINED LIGHT OR DARK AREAS	NON-UNIFORM DEVELOPMENT	AGITATE FILM DURING DEVELOPMENT.
WAVY MARBLELIKE MARKS	NON-UNIFORM DEVELOPMENT	AGITATE FILM DURING DEVELOPMENT.
RETICULATION (LEATHER GRAIN APPEARANCE)	TEMPERATURE DIFFERENCES IN PROCESSING SOLUTIONS	MAINTAIN ALL PROCESSING SOLUTIONS AT SAME CONSTANT TEMPERATURE.
FRILLING (LOOSENING OF FILM EMULSION FROM THE FILM BASE)	OVERLY WARM OR DEPLETED FIXER SOLUTION	MAINTAIN CORRECT FIXER TEMPERATURE AND REPLACE FIXER AS REQUIRED.

607 SPECIAL TECHNIQUES

1. GENERAL

Radiography is defined as a method using the penetration and differential absorption characteristics of X- and gamma rays to examine material for internal discontinuities. In the discussions of the previous chapters, the method of recording the effects of X- and gamma radiation has been film. In this chapter, special radiographic techniques, including those that do not use film as a recording medium, will be discussed.

2. FLUOROSCOPY

Fluoroscopy is the process in which an X-ray produced image is observed visually on a fluorescent screen (Figure 6-47). It is a relatively low-cost, high-speed process and is easily adapted to production line requirements. Its disadvantages are:

a. Cannot be used with specimens that are thick or of dense material since the intensity of the radiation passing through the specimen would be too low to sufficiently brighten the screen.

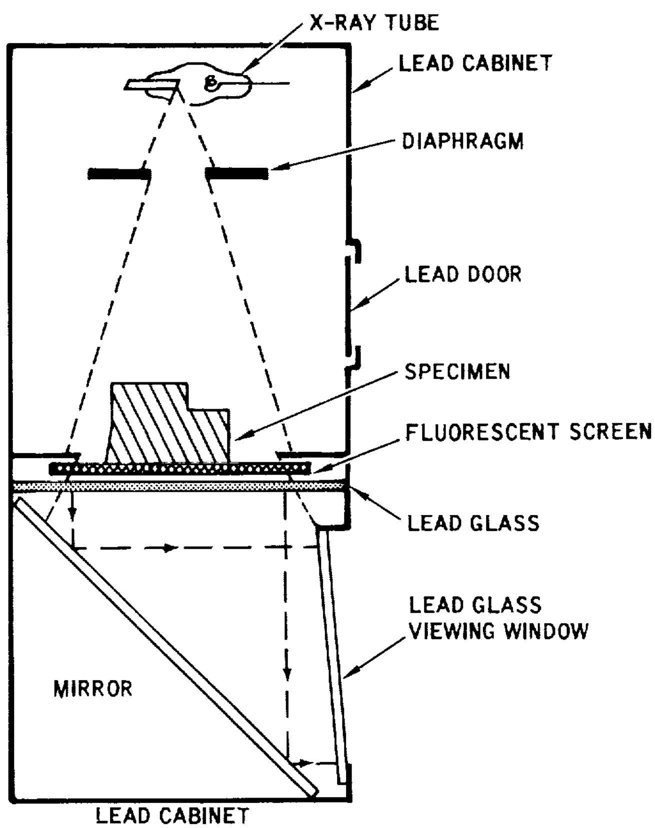


Figure 6-47. Schematic Diagram of a Fluoroscope

b. Relatively poor sensitivity because of the short source-to-screen distance required to obtain sufficient brightness, and the low contrast and coarse grain of the screen.

c. Subjects the operator to greater amounts of radiation than other radiographic methods.

d. Is dependent upon the human eye.

e. Does not produce a permanent record.

3. USE OF FLUOROSCOPY

Despite the foregoing disadvantages, fluoroscopy is widely used in applications where rapid scanning of articles for gross internal discontinuities or abnormal conditions is desirable. By use of fluoroscopy, a large number of articles can be screened prior to submitting the lot to radiographic test, and those with gross defects immediately rejected, with resultant cost savings.

4. IMAGE AMPLIFIER

The image amplifier is designed to overcome the disadvantages of fluoroscopy caused by the relatively low brightness of the image. It also serves to protect the operator from radiation. It consists of an image tube and an optical system (Figure 6-48). The image tube converts the X-ray image on the fluorescent screen to electrons, and accelerates and electrostatically focuses the electrons to produce the image on the smaller fluorescent screen. The optical system magnifies the image on the small screen and it appears to the viewer as if he were looking directly at a normal sized screen. The brightness amplification factor is the product of the reduction in screen area and the energy of electron acceleration. Dependent upon image tube design and

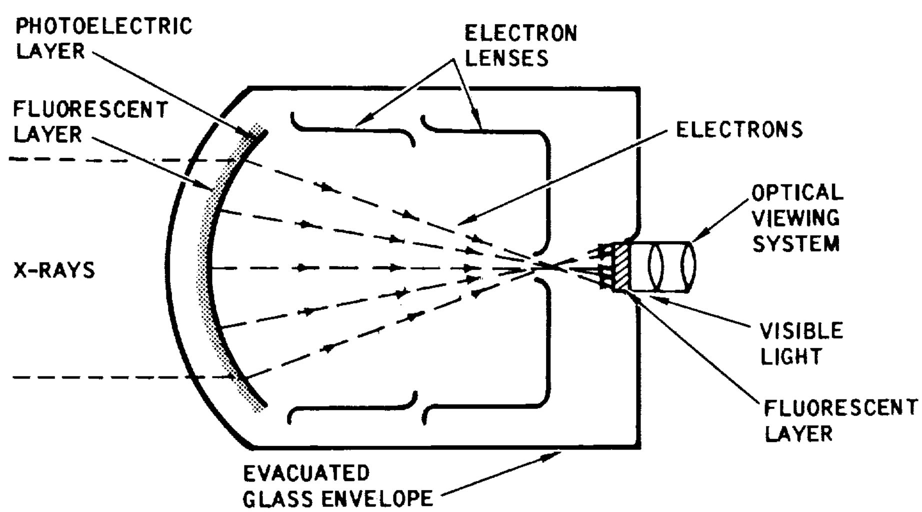


Figure 6-48. Schematic of an Image Amplifier

[redacted]

construction, this factor ranges from 100 to 1000. By use of a suitable camera and a closed circuit television system, the X-ray image produced by the image amplifier may be viewed on a monitor screen. Or, if desired, the image may be photographed to produce a permanent record.

5. TELEVISION RADIOGRAPHY

The television technique mentioned in the paragraph on fluoroscopy is relatively inefficient since there is a large energy loss incurred in converting the X-rays into light, which is in turn converted into electrical signals that energize the television system. Advanced techniques are available that use television equipment specifically designed for radiographic applications. The X-ray sensitive vidicon tube is an example of this type of equipment. The tube differs from normal vidicon tubes in that it is X-ray sensitive rather than photosensitive. It is widely used to permit instant image reproduction, combined with observer protection from exposure. The tube is the key part of a system (Figure 6-49), otherwise consisting of an X-ray source which provides an intense small diameter beam, a unit for handling and positioning test specimens, and a closed circuit television readout. The system is designed for radiographic inspection of small specimens such as electronic components and assemblies, and system components. It is highly suitable for in-motion X-ray inspection. Permanent records may be obtained, if desired, by photographing the monitor screen of the readout system.

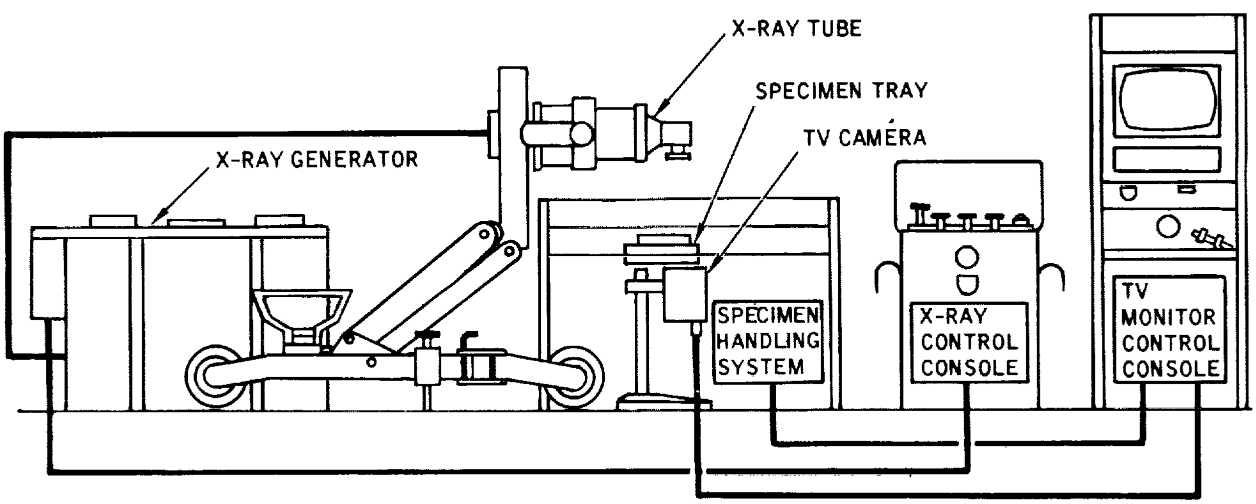


Figure 6-49. Typical Vidicon X-ray System

6. XERORADIOGRAPHY

Xeroradiography is a "dry" radiographic process that uses electrostatically charged plates to record an X-ray image. The basis of the process is the peculiar characteristic of selenium which causes it to become a relatively good electrical conductor when exposed to X-rays. The plate used to record the X-ray image consists of a thin layer of selenium bonded to a backing plate of aluminum. Under darkroom conditions an electrostatic charge is placed on the selenium by passing a high potential charging bar across the surface of the plate at a uniform velocity. The selenium having good insulation properties will retain the charge. The sensitized (charged) plate is then placed in a light-tight cassette, or holder, and used in X-ray exposures in the same way as film.

7. EXPOSURE

Under exposure, the X-rays cause the insulating properties of the selenium to break down and the charge leaks through (discharges) to the backing plate. Since the amount of discharge is determined by X-ray intensity, an image of the specimen remains on the plate in the form of charged and discharged (in various degrees), areas. The plate is developed after exposure by spraying it with light colored, sometimes fluorescent, finely divided charged powders, which cling to the charged areas in amounts determined by the degree of charge. The powder coating thus visually presents the X-ray image. (See Figure 6-50.)

8. TRANSFER PROCESS

If a permanent record is desired of a xeroradiograph, the image may be photographed or transferred to a special adhesive white paper. The transfer process uses paper coated with a plastic adhesive. When the paper is pressed on the xeroradiograph, it

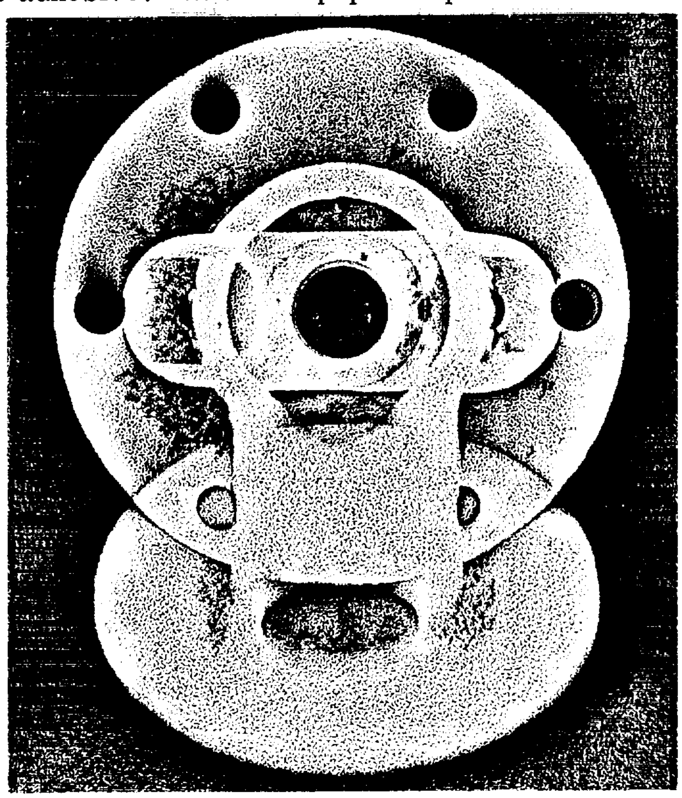


Figure 6-50. Sample Xeroradiograph

[redacted]

lifts the powder image from the selenium plate. The image is permanently affixed to the paper by applying sufficient heat to soften the plastic coating, and then permitting it to cool.

9. STEREORADIOGRAPHY AND DOUBLE EXPOSURE (PARALLAX)

A single radiographic image has length and width but does not have perspective. When it is necessary to know the depth of a flaw in a thick specimen two radiographic methods are available, stereoradiography and double exposure (parallax).

10. STEREORADIOGRAPHY

Stereoradiography gives the viewer a three-dimensional effect by use of two radiographs of the specimen, and a stereoscope. The two radiographs are made with two different positions of the X-ray tube in relation to the specimen. The two positions are displaced from each other by a distance equal to the separation of a human's eyes. The stereoscope, through optical means, permits the viewer to view the two radiographs simultaneously while allowing each eye of the viewer to see only one of the radiographs. The right eye sees the image of the right shift position of the X-ray tube, and the left eye sees the image of the left shift position. The brain combines and merges the two images into one in which true perspective and spatial relationships are apparent. Stereography is little used in industrial radiography but is of value in flaw location or structural visualization. (See Figure 6-51.)

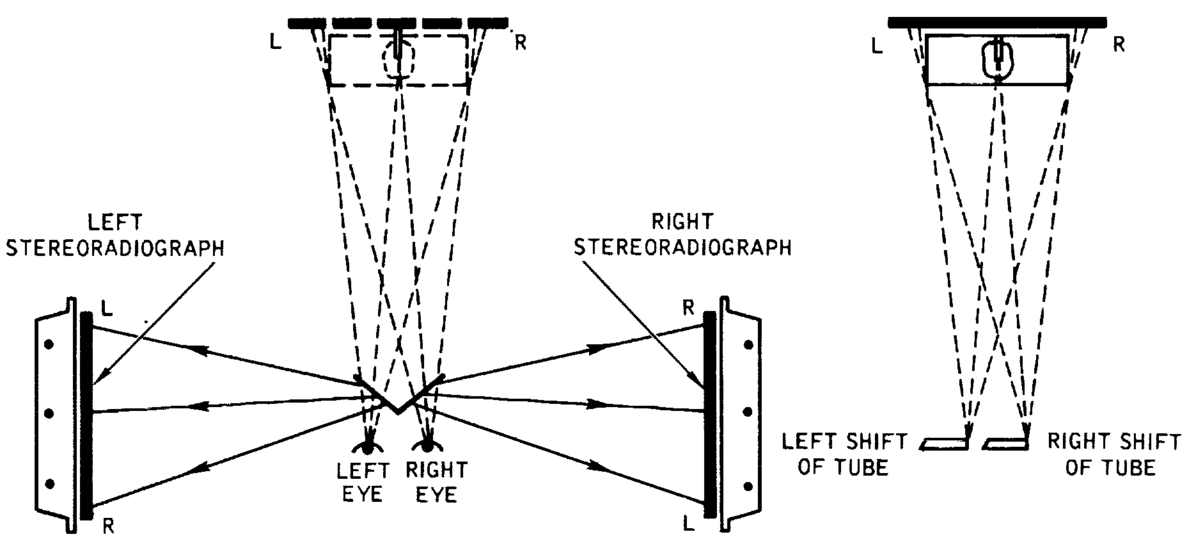


Figure 6-51. Stereoscopic Radiography

[redacted]

11. DOUBLE EXPOSURE (PARALLAX)

Double exposure (parallax) methods of determining flaw depth in a specimen are more positive than stereoradiography, since they are based on physical measurements of the radiographic image, and do not depend on human depth perception. One such method is illustrated in Figure 6-52. Lead markers M1 and M2 are respectively attached to the front and back surfaces of the specimen. Two exposures, each one approximately one-half the time required for a normal exposure, are made. The distance between F1 and F2 is predetermined and the tube is located at F1 for one exposure and at F2 for the other. The position of the film image of the flaw and of M1 will perceptibly change as a result of the tube shift, while the M2 image shift will be small if not imperceptible. The distance of the flaw from the film plane is determined by the following equation.

$$d = \frac{bt}{a + b}$$

where d = distance of the flaw from the film plane

a = distance of tube position shift

b = change in position of the flaw image

t = focus-film distance.

a. If film fog, or the small size of the flaw, does not permit use of the double exposure technique, two separate radiographs may be made. The two radiographs are aligned by superimposing images of the M2 markers, the change in position of the flaw image is measured, and the foregoing equation is applied.

b. For flaw depth determination when all that is required is knowledge of which specimen surface the flaw is nearer to, the relationship between the image shift of the M1 marker and the image shift of the flaw provides the answer. If the flaw image shift is greater than half the shift of the M1 image, the flaw is nearer the top surface of the specimen; if less than half, the flaw is nearer the bottom surface.

12. FLASH RADIOGRAPHY

Flash radiography permits the observation of high-speed events in opaque materials. It is used primarily for observation of explosive or rupture processes. Analagous to flash photography, flash radiography freezes the motion of projectiles, high-speed machinery etc. by use of high voltage, high current, extremely short time duration exposures. The tube and the high voltage circuits of flash radiography equipment differ in design from conventional X-ray equipment. The tube has a cold cathode, and electron emission is initiated by a third electrode located near the cathode. The high

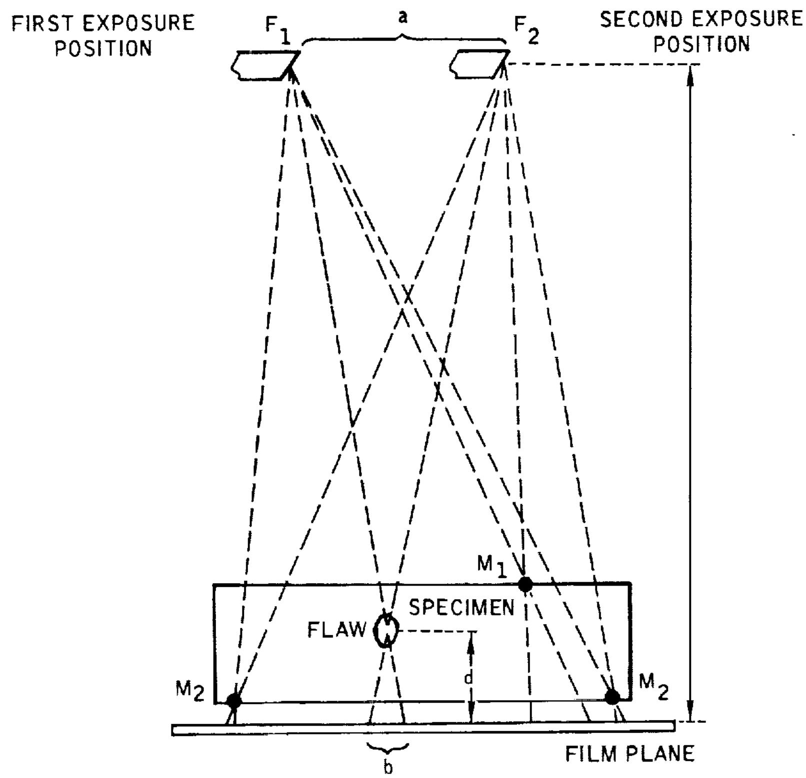


Figure 6-52. Parallax Technique

voltage circuit contains capacitors which are charged to peak voltage and then discharged in a high voltage pulse. Tube current reaches as high as 2000 amperes but, because of the fractional microsecond duration of the exposure, the tube is not damaged.

13. IN-MOTION RADIOGRAPHY

In-motion radiography is any radiographic method wherein the source of radiation, the specimen, or the film, is moving during the exposure. Many special in-motion radiographic techniques are in use, each of them designed to serve a specific purpose and application. These techniques use mechanical arrangements to move the X-ray machine, the specimen, or, in many cases, motion picture cameras loaded with X-ray film. The one requirement for in-motion radiography is that during exposure the position of the film and the specimen relative to each other must remain fixed. This requirement is met by synchronizing the movement of the specimen and the film, or by fixing the specimen and film in position and moving only the source of radiation. The multiple variations of in-motion technique are all based on the requirements mentioned and on the calculations and procedures discussed in this chapter.

CHAPTER 7: COMPARISON AND SELECTION OF NDT PROCESSES
TABLE OF CONTENTS

TABLE OF CONTENTS (CONT)

[redacted]

CHAPTER 7: COMPARISON AND SELECTION OF NDT PROCESSES

700 GENERAL

The purpose of this chapter is to summarize the characteristics of various types of discontinuities, and to list the NDT methods which may be employed to detect each type of discontinuity.

The relationship between the various NDT methods and their capabilities and limitations when applied to the detection of a specific discontinuity will be shown. Such variables as type of discontinuity (inherent, process, or service), manufacturing processes (heat treating, machining, or plating), and limitations (metallurgical, structural, or processing) all will help determine the sequence of testing and the ultimate selection of one test method over another.

701 METHOD IDENTIFICATION

Figures 7-1 through 7-5 illustrate five NDT methods. Each illustration shows the three elements involved in all five tests, the different methods in each test category, and tasks that may be accomplished with a specific method.

702 NDT DISCONTINUITY SELECTION

The discontinuities that will be reviewed in paragraphs 706 through 732 are only a part of the many hundreds that are associated with the various products of the aerospace industry. During the selection of discontinuities for inclusion in this section, only a few of those discontinuities which would not be radically changed under different conditions of design, configuration, standards, and environment were chosen.

703 DISCONTINUITY CATEGORIES

Each of the specific discontinuities are divided into three general categories: inherent, processing, and service. Each of these categories is further classified as to whether the discontinuity is associated with ferrous or nonferrous materials, the specific material configuration, and the manufacturing processes if applicable.

1. INHERENT DISCONTINUITIES

Inherent discontinuities are those discontinuities that are related to the solidification of the molten metal. There are two types.

a. Wrought. Inherent wrought discontinuities cover those discontinuities which are related to the melting and original solidification of the metal or ingot.

[redacted]

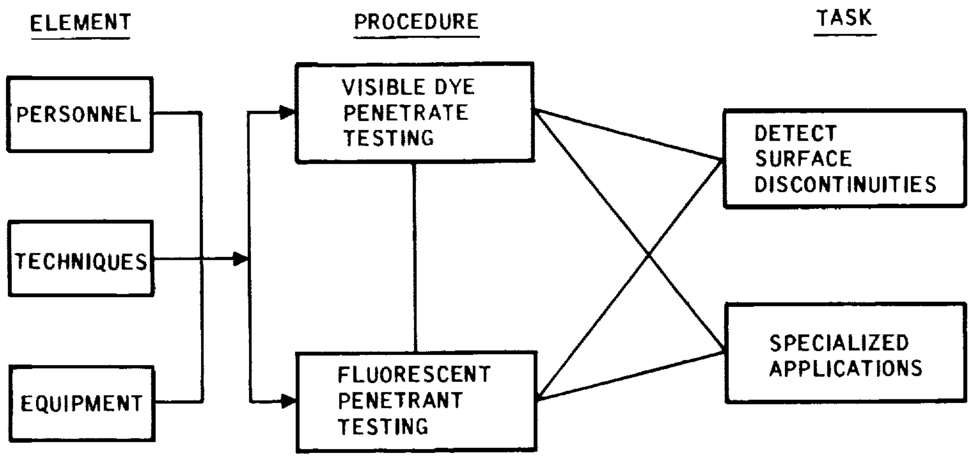


Figure 7-1. Liquid Penetrant Test

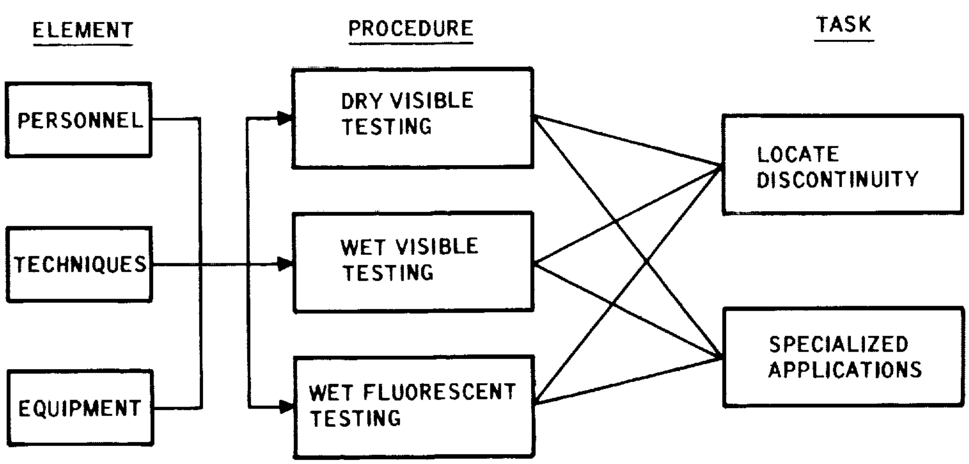


Figure 7-2. Magnetic Particle Test

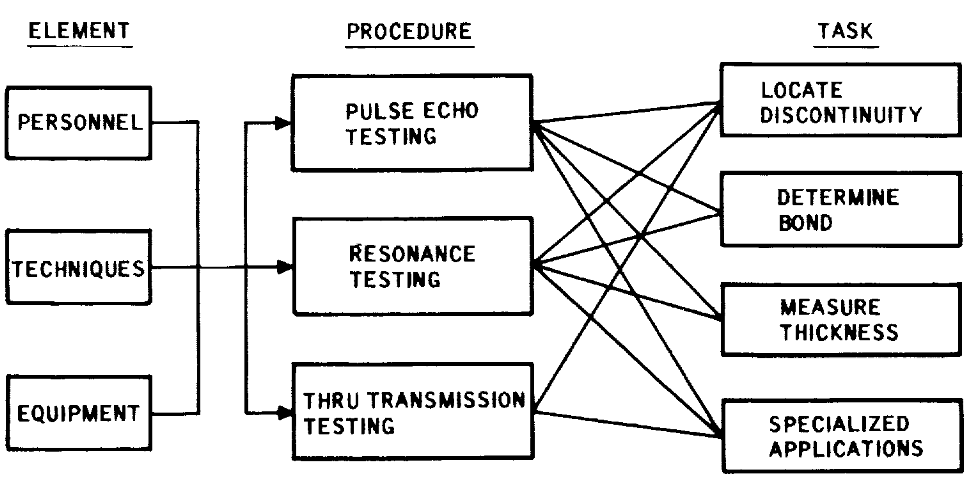


Figure 7-3. Ultrasonic Test

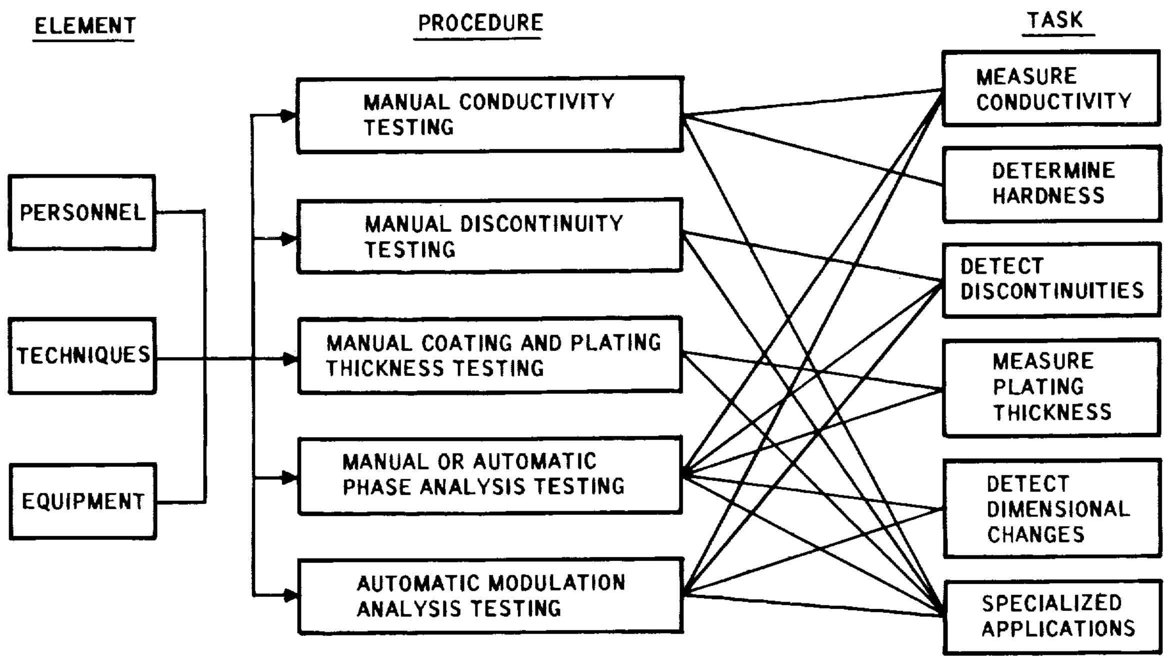


Figure 7-4. Eddy Current Test

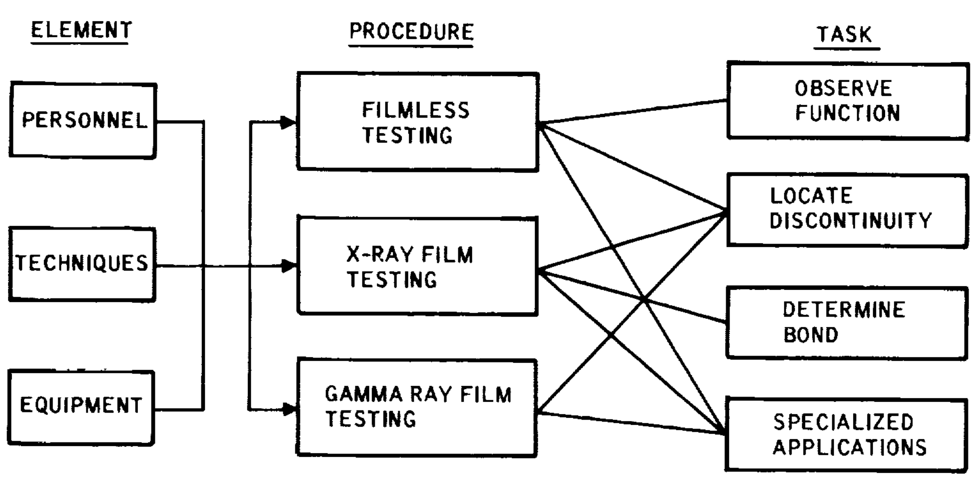


Figure 7-5. Radiographic Test

b. Cast. Inherent cast discontinuities are those discontinuities which are related to the melting, casting, and solidification of the cast article. It includes those discontinuities that would be inherent to manufacturing variables such as inadequate feeding, gating, excessively high pouring temperature, entrapped gases, handling, and stacking.

2. PROCESSING DISCONTINUITIES

Processing discontinuities are those discontinuities that are related to the various manufacturing processes such as machining, forming, extruding, rolling, welding, heat treating, and plating.

3. SERVICE DISCONTINUITIES

Service discontinuities cover those discontinuities that are related to the various service conditions such as stress corrosion, fatigue, and errosion.

704 DISCONTINUITY CHARACTERISTICS AND METALLURGICAL ANALYSIS

Discontinuity characteristics encompasses an analysis of the specific discontinuity and reference actual photos that illustrate examples of the discontinuity. The discussion will cover:

a. Origin and location of discontinuity (surface, near surface, or internal).

b. Orientation (parallel or normal to the grain).

c. Shape (flat, irregularly shaped, or spiral).

d. Photo (micrograph and/or typical overall view of the discontinuity).

e. Metallurgical analysis (how the discontinuity is produced and at what stage of manufacture).

705 NDT METHODS APPLICATION AND LIMITATIONS

1. GENERAL

The technological accomplishments in the field of nondestructive testing have brought the level of test reliability and reproducibility to a point where the design engineer may now selectively zone the specific article. This zoning is based upon the structural application of the end product and takes into consideration the environment as well as the loading characteristics of the article. Such an evaluation in no way reduces the end reliability of the product, but it does reduce needless rejection of material that otherwise would have been acceptable.

Just as the structural application within the article varies, the allowable discontinuity size will vary depending on the method of manufacture and configuration. For example, a die forging that has large masses of material and extremely thin web sections would not require the same level of acceptance for the whole forging. The forging can be zoned for rigid control where the structural applications are higher, and zoned for less rigid control where the structural requirements permit larger discontinuities.

The nondestructive testing specialist must also select the method which will satisfy the design objective of the specific article and not assume that all NDT methods can produce the same reliability for the same type of discontinuity.

2. SELECTION OF THE NDT METHOD

In selecting the NDT method for the evaluation of a specific discontinuity it should be kept in mind that NDT methods may supplement each other and that several NDT methods may be capable of performing the same task. The selection of one method over another is based upon variables such as:

a. Type and origin of discontinuity

b. Material manufacturing processes

c. Accessibility of article

d. Level of acceptability desired

e. Equipment available

f. Cost

To satisfactorily develop knowledge of the above variables, a planned analysis of the task must be made for each article requiring NDT testing.

The NDT methods listed for each discontinuity in paragraphs 706 through 732 are in order of preference for that particular discontinuity. However, when reviewing that portion of the chapter it should be kept in mind that the rapidly developing NDT field and new techniques may alter the order of test preference.

3. LIMITATIONS

The limitations applicable to the various NDT methods will vary with the applicable standard, the material, and the service environment. Limitations not only affect the NDT test, but in many cases the structural reliability of the test article is affected. For these reasons, limitations that are listed for one discontinuity may also be applicable to other discontinuities under slightly different conditions of material or environment. In addition, the many combinations of environment, location, material, and test capability do not permit mentioning all limitations that may be associated with a specific discontinuity. The intent of this chapter is fulfilled if you are made aware of the many factors that influence the selection of a valid NDT test.

706 BURST

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Surface or internal. Straight or irregular cavities varying in size with large interfaces or very tight. Usually parallel with the grain. Found in wrought material which required forging, rolling, or extruding. (See Figure 7-6.)

4. METALLURGICAL ANALYSIS

   a. Forging bursts are surface or internal ruptures which are attributed to processing at an incorrect temperature, or excessive working or metal movement during the forging, rolling, or extruding operation.

   b. A burst does not have a spongy appearance and, therefore, is distinguishable from a pipe, even if it should occur at the center.

   c. Bursts are often large and very seldom healed during subsequent working.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. ULTRASONIC TESTING METHOD

      (1) Normally used for the detection of internal bursts.

      (2) Bursts are definite breaks in the material and they resemble a crack, producing a very sharp reflection on the scope.

      (3) Ultrasonic testing is capable of detecting varying degrees of burst which could not be detected by other NDT methods.

      (4) Nicks, gouges, raised areas, tool tears, foreign material, gas bubbles on the article may produce adverse ultrasonic test results.

   b. EDDY CURRENT TESTING METHOD. Not normally used. Testing is restricted to wire, rod, and other articles under 0.250 inch diameter.

   c. MAGNETIC PARTICLE TESTING METHOD

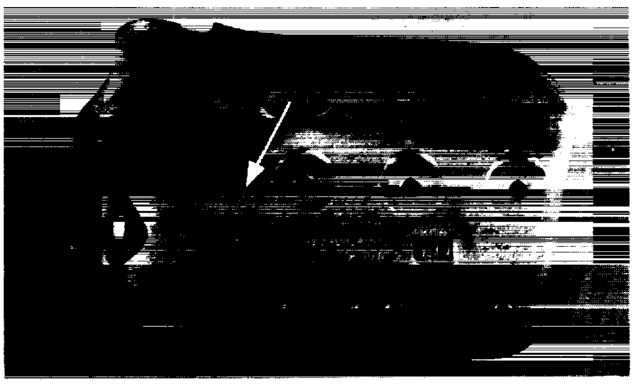
      (1) Usually used on wrought ferrous material that has surface or exposed internal burst.

      (2) Results are limited to surface and near surface evaluation.

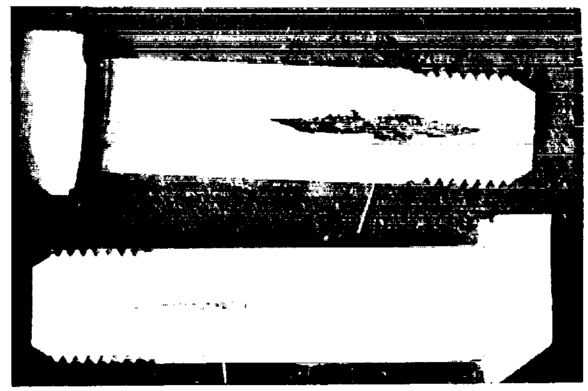
   d. LIQUID PENETRANT TESTING METHOD. Not normally used. When fluorescent penetrant is to be applied to an article previously dye penetrant tested, all traces of dye penetrant should first be removed by prolonged cleaning in applicable solvent.

[redacted]

e. RADIOGRAPHIC TESTING METHOD. Not normally used. Such variables as the direction of the burst, close interfaces, wrought material, discontinuity size, and material thickness restrict the capability of radiography.

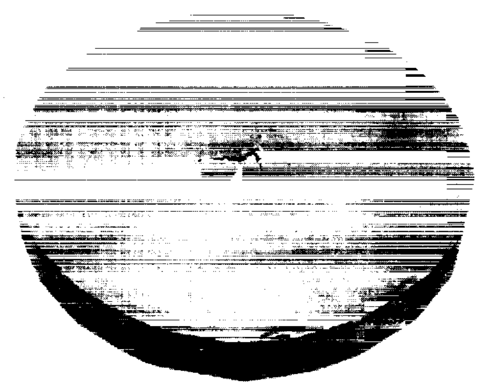


A FORGING EXTERNAL BURST



B BOLT INTERNAL BURST

C ROLLED BAR INTERNAL BURST



D FORGED BAR INTERNAL BURST

Figure 7-6. Burst Discontinuities

707 COLD SHUTS

1. CATEGORY. Inherent

2. MATERIAL. Ferrous and Nonferrous Cast Material

3. DISCONTINUITY CHARACTERISTICS

Surface and subsurface. Generally smooth indentations on the cast surface resembling a forging lap. (See Figure 7-7.)

4. METALLURGICAL ANALYSIS

Cold shuts are produced during casting molten metal. They may result from splashing, surging, interrupted pouring, or meeting of two streams of metal coming from different directions. Also, solidification of one surface before the other metal flows over it, the presence of interposing surface films on cold, sluggish metal, or any factor that will prevent a fusion where two surfaces meet will produce cold shuts. They are more prevalent in castings which are formed in a mold with several sprues or gates.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. LIQUID PENETRANT TESTING METHOD.

(1) Normally used to evaluate surface cold shuts in both ferrous and nonferrous materials.

(2) Will appear as a smooth, regular, continuous, or intermittent indication, reasonably parallel to the cross section of the area in which it occurs.

(3) Liquid penetrant used for the testing of nickel base alloys (such as Inconel "X," Rene 41) should not exceed 0.5 percent sulfur.

(4) Certain castings may have surfaces which may be blind and from which removal of the excessive penetrants may be difficult.

(5) Geometric configuration (recesses, orifices, and flanges) may permit buildup of wet developer thereby masking any detection of a discontinuity.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used for the screening of ferrous materials.

(2) The metallurgical nature of 431 corrosion-resistant steel is such that in some cases magnetic particle testing indications are obtained which do not result from a crack or other harmful discontinuities. These indications arise from a duplex structure within the material, wherein one portion exhibits strong magnetic retentivity and the other does not.

[redacted]

c. RADIOGRAPHIC TESTING METHOD

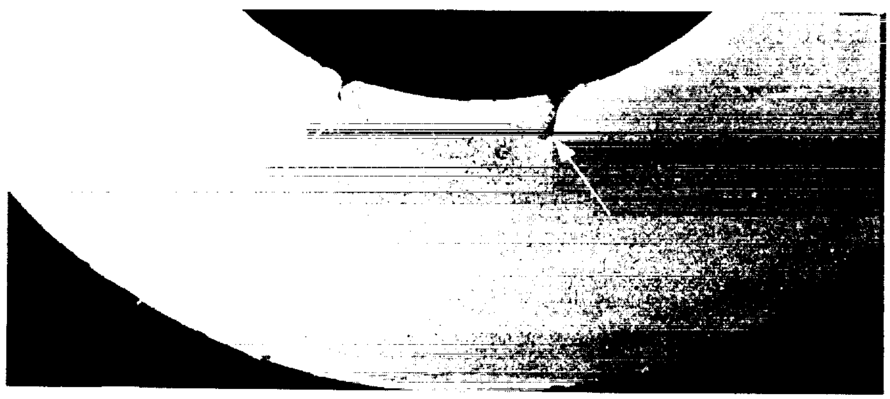
(1) Normally detectable by radiography while testing for other casting discontinuities.

(2) Appear as a distinct dark line or band of variable length and width, and definite smooth outline.

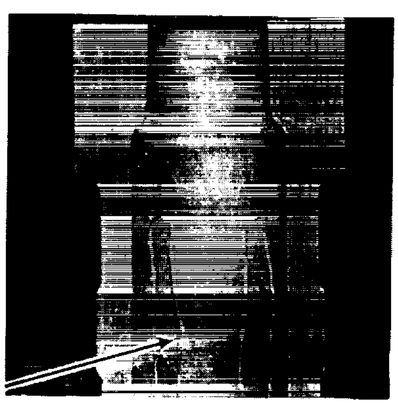
(3) Casting configuration may have inaccessible areas which can only be detected by radiography.

d. ULTRASONIC TESTING METHOD. Not recommended. Cast structure and article configuration do not as a general rule lend themselves to ultrasonic testing.

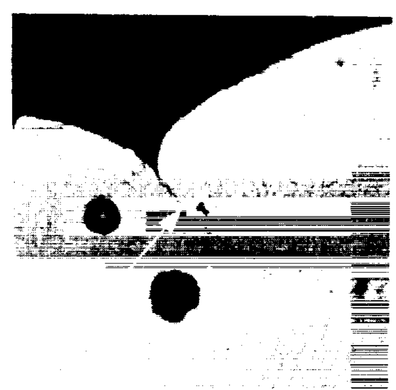
e. EDDY CURRENT TESTING METHOD. Not recommended. Article configuration and inherent material variables restrict the use of this method.



A SURFACE COLD SHUT



B INTERNAL COLD SHUT



C SURFACE COLD SHUT MICROGRAPH

Figure 7-7. Cold Shuts Discontinuity

[redacted]

708 FILLET CRACKS (BOLTS)

1. CATEGORY. Service

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Surface. Located at the junction of the fillet with the shank of the bolt and progressing inward. (See Figure 7-8.)

4. METALLURGICAL ANALYSIS

Fillet cracks occur where a marked change in diameter occurs, such as between the head-to-shank junction where stress risers are created. During the application of this bolt in service repeated loading takes place, whereby the tensile load fluctuates in magnitude due to the operation of the mechanism. These tensile loads can cause fatigue failure, starting at the point where the stress risers are built in. Fatigue failure, which is surface phenomenon, starts at the surface and propagates inward.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. ULTRASONIC TESTING METHOD

(1) Used extensively for service associated discontinuities of this type.

(2) A wide selection of transducers and equipment enable on the spot evaluation for fillet crack.

(3) Being a definite break in the material, the scope pattern will be a very sharp reflection. (Actual propagation can be monitored by using ultrasonics.)

(4) Ultrasonic equipment has extreme sensitivity, and established standards should be used to give reproducible and reliable results.

b. LIQUID PENETRANT TESTING METHOD

(1) Normally used during in-service overhaul or troubleshooting.

(2) May be used for both ferrous and nonferrous bolts, although usually confined to the nonferrous.

(3) Will appear as a sharp clear indication.

(4) Structural damage may result from exposure of high strength steels to paint strippers, alkaline coating removers, deoxidizer solutions, etc.

(5) Entrapment under fasteners, in holes, under splices, and in similar areas may cause corrosion due to the penetrant's affinity for moisture.

c. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used on ferrous bolts.

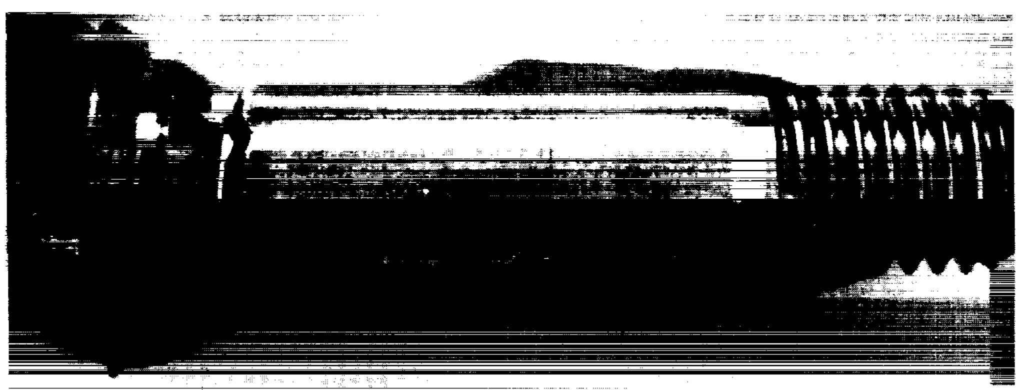
(2) Will appear as clear sharp indication with a heavy buildup.

(3) Sharp fillet areas may produce non-relevant magnetic indications.

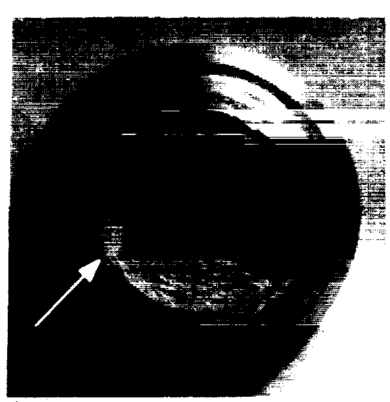
(4) 17.7 pH is only slightly magnetic in the annealed condition, but becomes strongly magnetic after heat treatment, when it may be magnetic particle tested.

d. EDDY CURRENT TESTING METHOD. Not normally used for detection of fillet cracks. Other NDT methods are more compatible to the detection of this type of discontinuity.

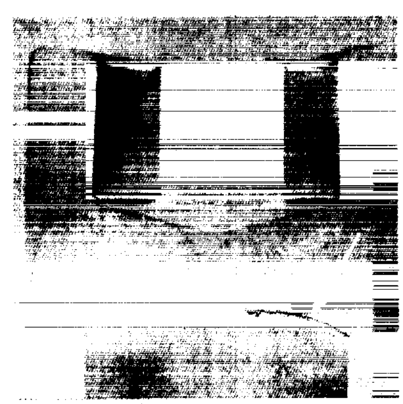
e. RADIOGRAPHIC TESTING METHOD. Not normally used for detection of fillet cracks. Surface discontinuities of this type would be difficult to evaluate due to size of crack in relation to the thickness of material.



A FILLET FATIGUE FAILURE



B FRACTURE AREA OF (A) SHOWING TANGENCY POINT OF FAILURE



C CROSS-SECTIONAL AREA OF FATIGUE CRACK IN FILLET SHOWING TANGENCY POINT IN RADIUS

Figure 7-8. Fillet Crack Discontinuity

709 GRINDING CRACKS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Very shallow and sharp at the root. Similar to heat treat cracks and usually, but not always, occur in groups. Grinding cracks are generally at right angles to the direction of grinding. They are found in highly heat treated articles, chrome plated, case hardened and ceramic materials that are subjected to grinding operations. (See Figure 7-9.)

4. METALLURGICAL ANALYSIS

Grinding of hardened surfaces frequently introduces cracks. These thermal cracks are caused by local overheating of the surface being ground. The overheating is usually caused by lack of or poor coolant, a dull or improperly ground wheel, too rapid feed, or too heavy cut.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. LIQUID PENETRANT TESTING METHOD

(1) Normally used on both ferrous and nonferrous materials for the detection of grinding cracks.

(2) Liquid penetrant indication will appear as irregular, checked, or shattered pattern of fine lines.

(3) Cracks are the most difficult discontinuity to indicate and require the longest penetration time.

(4) Articles that have been degreased may still have solvent entrapped in the discontinuity and should be allowed sufficient time for evaporation prior to the application of the penetrant.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Restricted to ferrous materials.

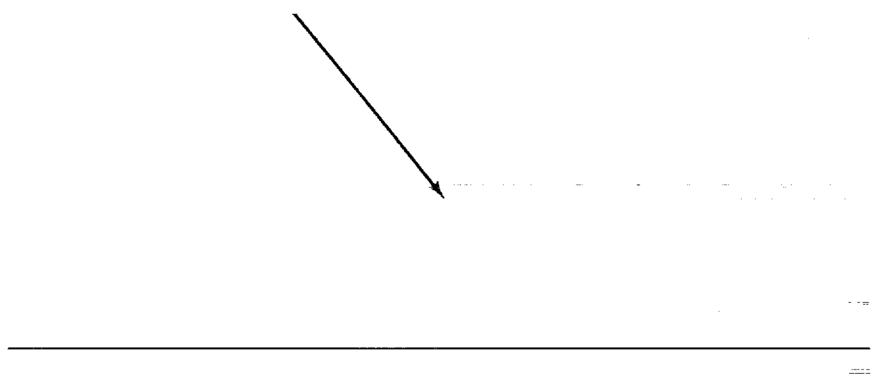
(2) Grinding cracks are generally at right angles to grinding direction, although in extreme cases a complete network of cracks may appear, in which case they may be parallel to the magnetic field.

(3) Magnetic sensitivity decreases as the size of grinding crack decreases and as its depth below the surface increases.

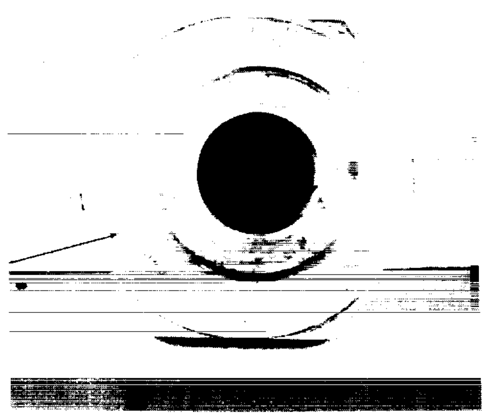
c. EDDY CURRENT TESTING METHOD. Not normally used for detection of grinding cracks. Eddy current equipment has the capability and can be developed for a specific nonferrous application.

d. ULTRASONIC TESTING METHOD. Not normally used for detection of grinding cracks. Other forms or NDT are more economical, faster, and better adapted to this type of discontinuity than ultrasonics.

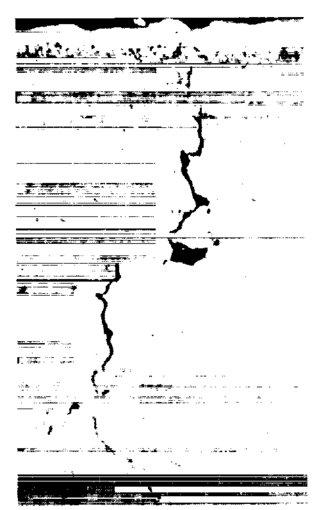
e. RADIOGRAPHIC TESTING METHOD. Not recommended for detection of grinding cracks. Grinding cracks are too tight and small. Other NDT methods are more suitable for detection of grinding cracks.



A TYPICAL CHECKED GRINDING CRACK PATTERN



B GRINDING CRACK PATTERN NORMAL TO GRINDING



C MICROGRAPH OF GRINDING CRACK

Figure 7-9. Grinding Crack Discontinuity

710 CONVOLUTION CRACKS

1. CATEGORY. Processing

2. MATERIAL. Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Range in size from micro fractures to open fissures. Situated on the periphery of the convolutions and extend longitudinally in direction of rolling. (See Figure 7-10.)

4. METALLURGICAL ANALYSIS

The rough 'orange peel' effect of convolution cracks is the result of either a forming operation which stretches the material or from chemical attack such as pickling treatment. The roughened surface contains small pits which form stress risers. Subsequent service application (vibration and flexing) may introduce stresses that act on these pits and form fatigue cracks as shown in the accompanying photograph.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. RADIOGRAPHIC TESTING METHOD

      (1) Used extensively for this type of failure.

      (2) Configuration of article and location of discontinuity limits detection almost exclusively to radiography.

      (3) Orientation of convolutions to X-ray source is very critical since those discontinuities which are not normal to X-ray may not register on the film due to the lack of difference in density.

      (4) Liquid penetrant and magnetic particle testing may supplement but not replace radiographic and ultrasonic testing.

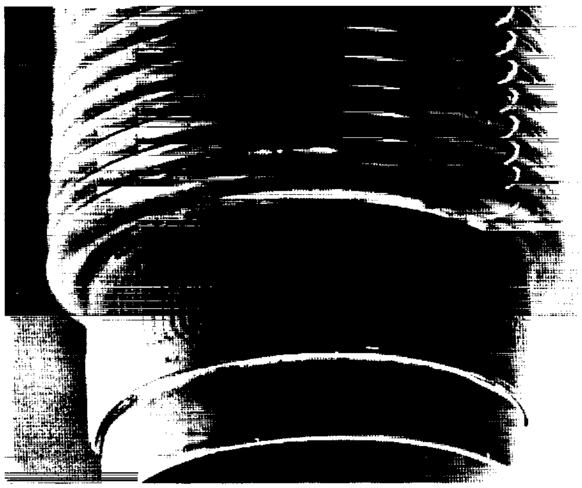
      (5) The type of marking material (e.g., grease pencil on titanium) used to identify the area of discontinuities may affect the structure of the article.

   b. ULTRASONIC TESTING METHOD. Not normally used for the detection of convolution cracks. Configuration of the article (double-walled convolutions) and internal micro fractures are all factors which restrict the use of ultrasonics.

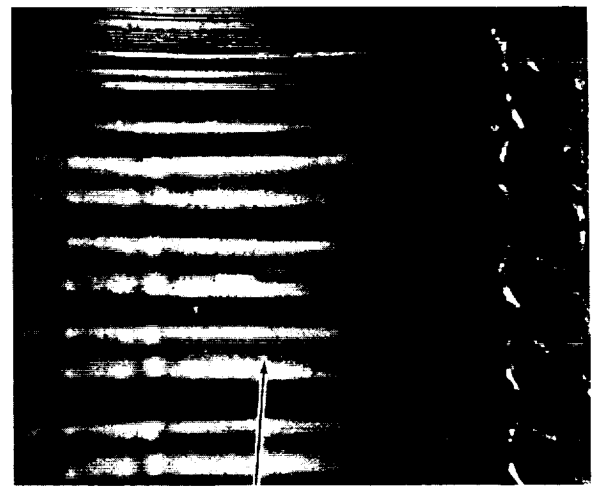
   c. EDDY CURRENT TESTING METHOD. Not normally used for the detection of convolution cracks. As in the case of ultrasonic testing, the configuration does not lend itself to this method of testing.

d. LIQUID PENETRANT TESTING METHOD. Not recommended for the detection of convolution cracks. Although the discontinuities are surface, they are internal and are superimposed over an exterior shell which creates a serious problem of entrapment.

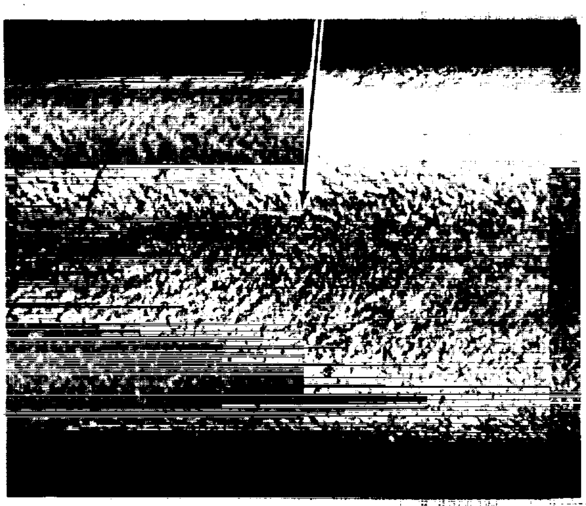
e. MAGNETIC TESTING METHOD. Not applicable. Material is nonferrous.



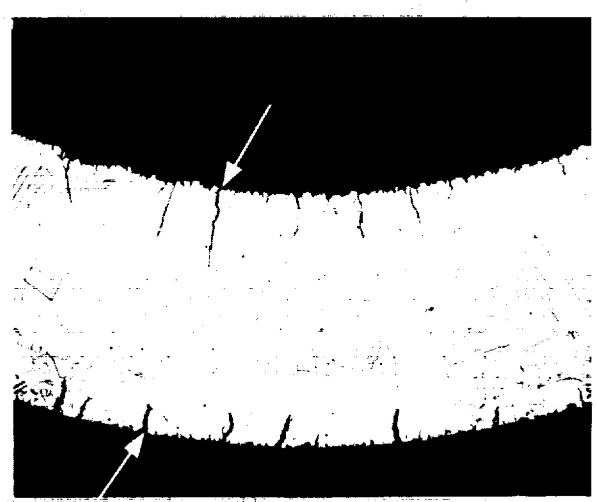
A TYPICAL CONVOLUTION DUCTING



B CROSS-SECTION OF CRACKED CONVOLUTION



C HIGHER MAGNIFICATION OF CRACK SHOWING ORANGE PEEL



D MICROGRAPH OF CONVOLUTION WITH PARTIAL CRACKING ON SIDES

Figure 7-10. Convolution Cracks Discontinuity

[redacted]

711 HEAT-AFFECTED ZONE CRACKING

1. CATEGORY. Processing (Weldments)

2. MATERIAL. Ferrous and Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Often quite deep and very tight. Usually parallel with the weld in the heat-affect zone of the weldment. (See Figure 7-11.)

4. METALLURGICAL ANALYSIS

Hot cracking of heat-affected zones of weldments increases in severity with increasing carbon content. Steels that contain more than 0.30% carbon are prone to this type of failure and require preheating prior to welding.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. MAGNETIC PARTICLE TESTING METHOD

      (1) Normally used for ferrous weldments.

      (2) Prod burns are very detrimental, especially on highly heat treated articles. May contribute to structural failure of article.

      (3) Demagnetization of highly heat treated articles can be very difficult due to metallurgical structure.

   b. LIQUID PENETRANT TESTING METHOD

      (1) Normally used for nonferrous weldments.

      (2) Material that has had its surface obliterated, blurred, or blended due to manufacturing processes should not be penetrant tested until the smeared surface has been removed.

      (3) Liquid penetrant testing after the application of certain types of chemical film coatings may be invalid due to the covering or filling of the discontinuities.

   c. RADIOGRAPHIC TESTING METHOD. Not normally used for the detection of heat-affected zone cracking. Discontinuity orientation and surface origin make other NDT methods more suitable.

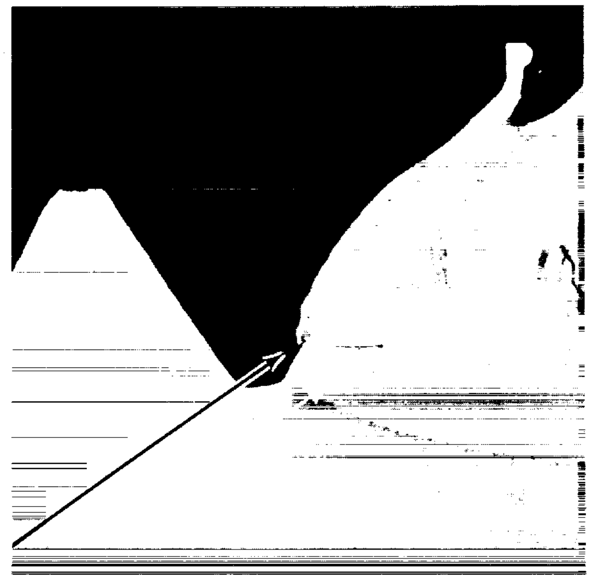
   d. ULTRASONIC TESTING METHOD

      (1) Used where specialized applications have been developed.

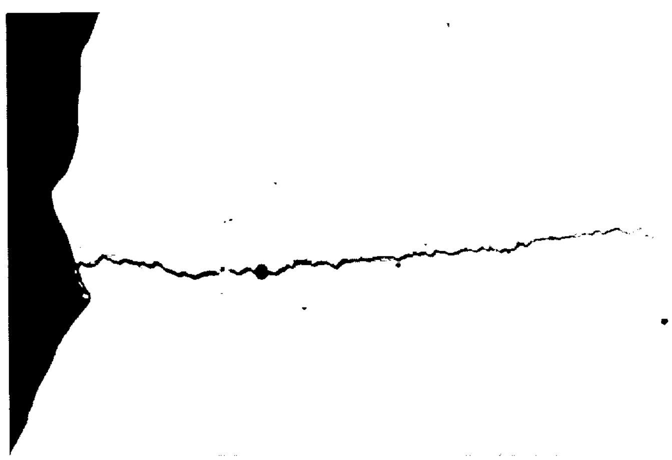
      (2) Rigid standards and procedures are required to develop valid tests.

      (3) The configuration of the surface roughness (i.e., sharp versus rounded root radii and the slope condition) are major factors in deflecting the sound beam.

e. EDDY CURRENT TESTING METHOD. Not normally used for the detection of heat-affected zone cracking. Eddy current equipment has capability of detecting nonferrous surface discontinuities; however, it is not as universally used as magnetic particle or liquid penetrant.



A MICROGRAPH OF WELD AND HEAT-AFFECTED ZONE SHOWING CRACK NOTE COLD LAP WHICH MASKS THE ENTRANCE TO THE CRACK



B MICROGRAPH OF CRACK SHOWN IN (A)

Figure 7-11. Heat-Affected Zone Cracking Discontinuity

[redacted]

712 HEAT TREAT CRACKS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Wrought and Cast Material

3. DISCONTINUITY CHARACTERISTICS

Surface. Usually deep and forked. Seldom follow a definite pattern and can be in any direction on the part. Originate in areas with rapid change of material thickness, sharp machining marks, fillets, nicks, and discontinuities which have been exposed to the surface of the material. (See Figure 7-12.)

4. METALLURGICAL ANALYSIS

During the heating and cooling process localized stresses may be set up by unequal heating or cooling, restricted movement of the article, or unequal cross-sectional thickness. These stresses may exceed the tensile strength of the material causing it to rupture. Where built-in stress risers occur (keyways or grooves) additional cracks may develop.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. MAGNETIC PARTICLE TESTING METHOD

(1) For ferrous materials, heat treat cracks are normally detected by magnetic particles testing.

(2) The magnetic particles indications will normally be straight, forked, or curved indications.

(3) Likely points of origin are areas that would develop stress risers, such as keyways, fillets, or areas with rapid changes in material thickness.

(4) Metallurgical structure of age hardenable and heat treatable stainless steels (17.4, 17.7, and 431) may produce irrelevant indications.

b. LIQUID PENETRANT TESTING METHOD

(1) For nonferrous materials liquid penetrant testing is the recommended method.

(2) Likely points of origin would be the same as those listed above for magnetic particle testing.

(3) Materials or articles that will eventually be used in LOX systems must be tested with compatible penetrants.

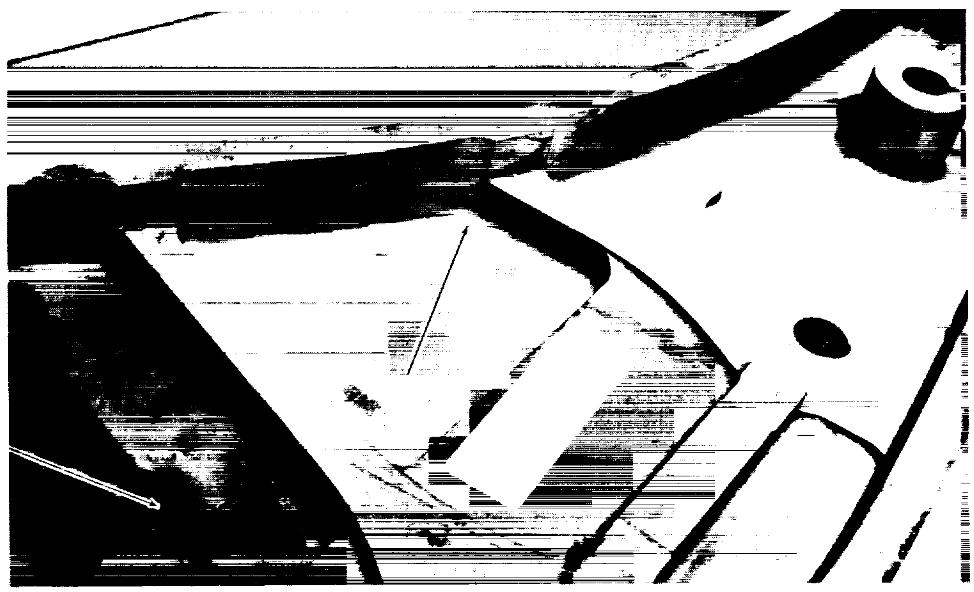
c. EDDY CURRENT TESTING METHOD

(1) Normally not used.

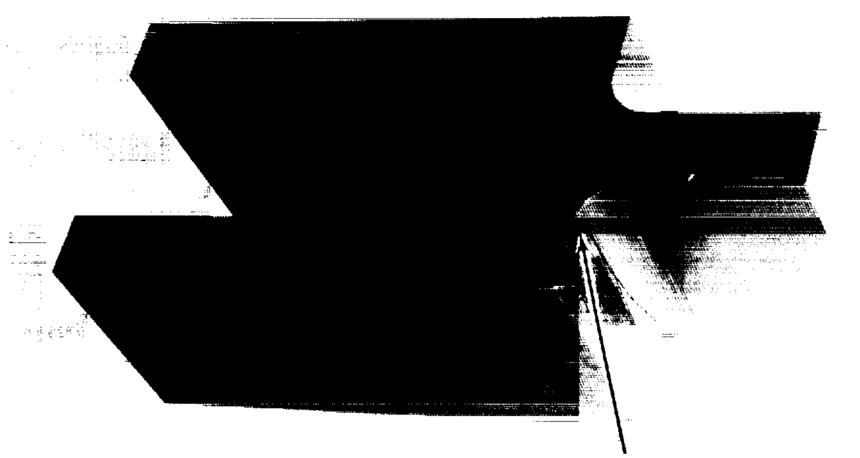
(2) Magnetic particles and liquid penetrant are more direct and economical.

d. ULTRASONIC TESTING METHOD. Not normally used for detection of heat treat cracks. If used the scope pattern will show a definite indication of a discontinuity. Recommended wave mode would be surface.

e. RADIOGRAPHIC TESTING METHOD. Not normally used for detection of heat treat cracks. Surface discontinuities are more easily detected by other NDT methods designed for surface application.



A FILLET AND MATERIAL THICKNESS CRACKS (TOP CENTER)
RELIEF RADIUS CRACKING (LOWER LEFT)



B HEAT TREAT CRACK DUE TO SHARP MACHINING MARKS

Figure 7-12. Heat Treat Cracks Discontinuity

[redacted]

713 SURFACE SHRINK CRACKS

1. CATEGORY. Processing (Welding)

2. MATERIAL. Ferrous and Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Situated on the face of the weld, fusion zone, and base metal. Range in size from very small, tight, and shallow, to open and deep. Cracks may run parallel or transverse the direction of welding. (See Figure 7-13.)

4. METALLURGICAL ANALYSIS

Surface shrink cracks are generally the result of improper heat application, either in heating or welding of the article. Heating or cooling in a localized area may set up stresses that exceed the tensile strength of the material causing the material to crack. Restriction of the movement (contraction or expansion) of the material during heating, cooling, or welding may also set up excessive stresses.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. LIQUID PENETRANT TESTING METHOD

      (1) Surface shrink cracks are normally detected by liquid penetrant.

      (2) Liquid penetrant equipment is easily portable and can be used during in-process control for both ferrous and nonferrous weldments.

      (3) Assemblies which are joined by bolting, riveting, intermittent welding, or press fittings will retain the penetrant, which will seep out after developing and mask the adjoining surfaces.

      (4) When articles are dried in a hot air dryer or by similar means, excessive drying temperature should be avoided to prevent evaporation of the penetrant.

   b. MAGNETIC PARTICLE TESTING METHOD

      (1) Ferrous weldments are normally tested by magnetic particle method.

      (2) Surface discontinuities that are parallel to the magnetic field will not produce indications since they do not interrupt or distort the magnetic field.

      (3) Areas of grease fittings, bearing races, or other similar items that might be damaged or clogged by the suspension solution or magnetic solids should be masked before testing.

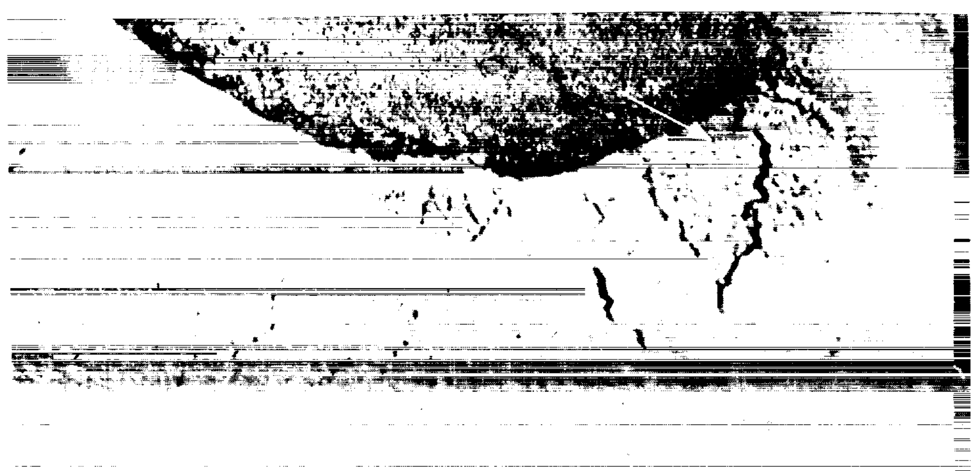
c. EDDY CURRENT TESTING METHOD

(1) Normally confined to nonferrous welded pipe and tubing.

(2) Probe or encircling coil could be used where article configuration permits.

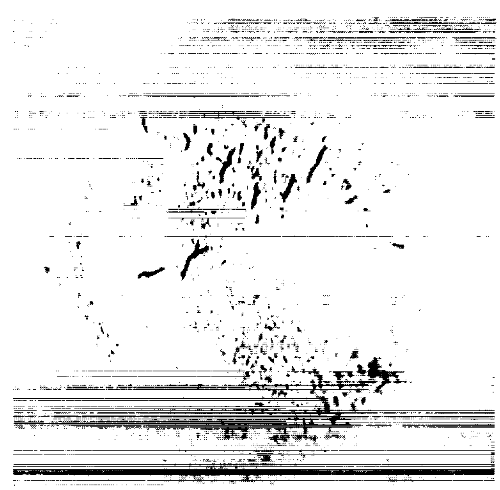
d. RADIOGRAPHIC TESTING METHOD. Not normally used for the detection of surface discontinuities. During the radiographic testing of weldments for other types of discontinuities, surface indications may be detected.

e. ULTRASONIC TESTING METHOD. Not normally used for detection of surface shrink cracks. Other forms of NDT (liquid penetrant and magnetic particle) give better results, are more economical, and are faster.



A TRANSVERSE CRACKS IN HEAT-AFFECTED ZONE

B TYPICAL STAR-SHAPED CRATER CRACK



C SHRINKAGE CRACK AT WELD TERMINAL

Figure 7-13. Surface Shrink Crack Discontinuity

[redacted]

714 THREAD CRACKS

1. CATEGORY. Service

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Surface. Cracks are transverse to the grain (transgranular) starting at the root of the thread. (See Figure 7-14.)

4. METALLURGICAL ANALYSIS

Fatigue failures of this type are not uncommon. High cyclic stresses resulting from vibration and/or flexing act on the stress risers created by the thread roots and produce cracks. Fatigue cracks may start as fine submicroscopic discontinuities and/or cracks and propagate in the direction of applied stresses.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. LIQUID PENETRANT TESTING METHOD

      (1) Fluorescent penetrant is recommended over non-fluorescent.

      (2) Low surface tension solvents such as gasoline and kerosene are not recommended cleaners.

      (3) When applying liquid penetrant to components within an assembly or structure, the adjacent areas should be effectively masked to prevent overspraying.

   b. MAGNETIC PARTICLE TESTING METHOD

      (1) Normally used on ferrous materials.

      (2) Irrelevent magnetic indications may result from the thread configuration.

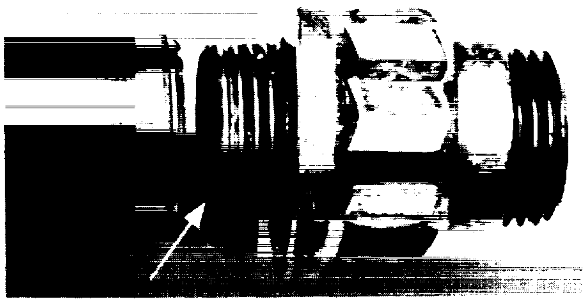
      (3) Cleaning titanium and 440C stainless in halogeneated hydrocarbons may result in structural damage to the material.

   c. EDDY CURRENT TESTING METHOD. Not normally used for detecting thread cracks. The article configuration would require specialized equipment if adaptable.

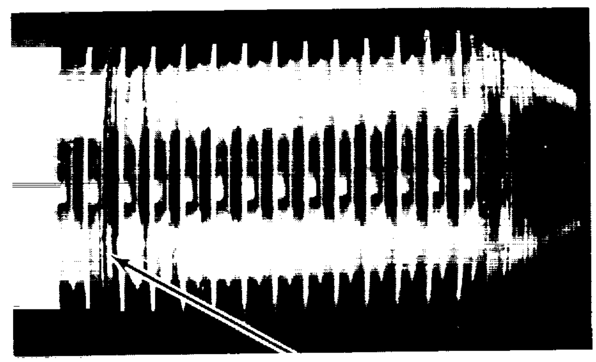
   d. ULTRASONIC TESTING METHOD. Not recommended for detecting thread cracks. Thread configuration does not lend itself to ultrasonic testing.

[redacted]

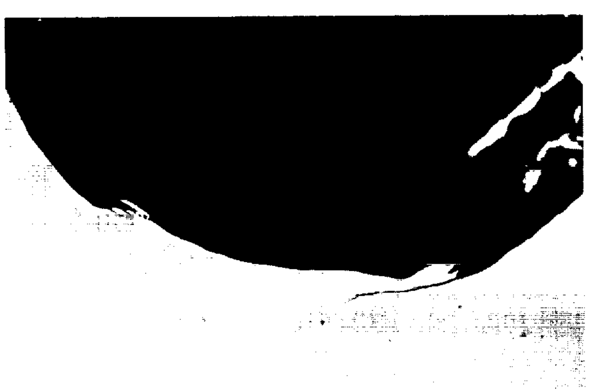
e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting thread cracks. Surface discontinuities are best screened by NDT method designed for the specific condition. Fatigue cracks of this type are very tight and surface connected, their detection by radiography would be extremely difficult.



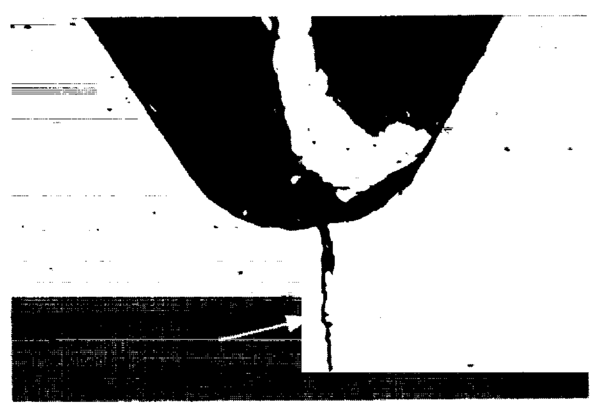
A COMPLETE THREAD ROOT FAILURE



B TYPICAL THREAD ROOT FAILURE



C MICROGRAPH OF (A) SHOWING CRACK AT BASE OF ROOT



D MICROGRAPH OF (B) SHOWING TRANSGRANULAR CRACK AT THREAD ROOT

Figure 7-14. Thread Crack Discontinuity

[redacted]

715 TUBING CRACKS (INCONEL "X")

1. CATEGORY. Inherent

2. MATERIAL. Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Tubing cracks formed on the inner surface (I.D.), parallel to direction of grain flow. (See Figure 7-15.)

4. METALLURGICAL ANALYSIS

Tubing I. D. cracks may be attributed to one or a combination of the following:

a. Improper cold reduction of the tube during fabrication.

b. Foreign material may have been embedded on the inner surface of the tubes causing embrittlement and cracking when the cold worked material was heated during the annealing operation.

c. Insufficient heating rate to the annealing temperature with possible cracking occurring in the 1200-1400° F range.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. EDDY CURRENT TESTING METHOD

(1) Normally used for detection of this type of discontinuity.

(2) The diameter (1 inch) and wall thickness (0. 156 inch) are well within equipment capability.

(3) Testing of ferro-magnetic material may be difficult.

b. ULTRASONIC TESTING METHOD

(1) Normally used on heavy gauge tubing.

(2) A wide variety of equipment and transducers are available for screening tubing for internal discontinuities of this type.

(3) Ultrasonic transducers have varying temperature limitations.

(4) Certain ultrasonic contact couplants may have high sulfur content which will have an adverse effect on high nickel alloys.

c. RADIOGRAPHIC TESTING METHOD

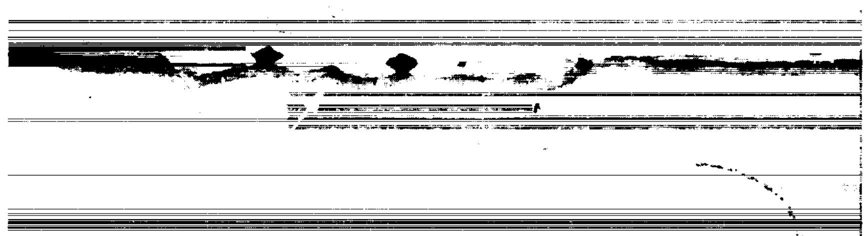
(1) Not normally used for detecting tubing cracks.

(2) Discontinuity orientation and thickness of material govern the radiographic sensitivity.

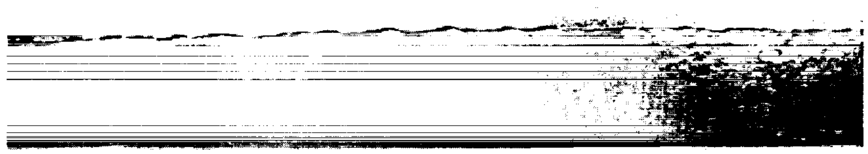
(3) Other forms of NDT (eddy current and ultrasonic) are more economical, faster, and reliable.

d. LIQUID PENETRANT TESTING METHOD. Not recommended for detecting tubing cracks. Internal discontinuity would be difficult to process and interpret.

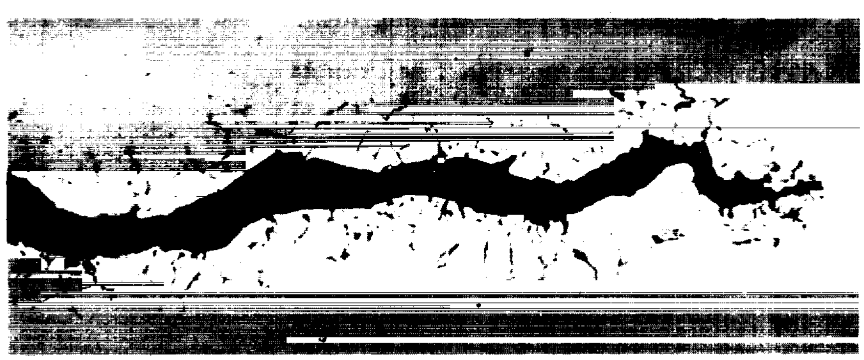
e. MAGNETIC PARTICLES TESTING METHOD. Not applicable. Material is nonferrous under normal conditions.



A TYPICAL CRACK ON INSIDE OF TUBING SHOWING COLD LAP



B ANOTHER PORTION OF SAME CRACK SHOWING CLEAN FRACTURE



C MICROGRAPH OF (B)

Figure 7-15. Tubing Crack Discontinuity

[redacted]

716 HYDROGEN FLAKE

1. CATEGORY. Processing

2. MATERIAL. Ferrous

3. DISCONTINUITY CHARACTERISTICS

Internal fissures in a fractured surface, flakes appear as bright silvery areas. On an etched surface they appear as short discontinuities. Sometimes known as chrome checks and hairline cracks when revealed by machining, flakes are extremely thin and generally aligned parallel with the grain. They are usually found in heavy steel forgings, billets, and bars. (See Figure 7-16.)

4. METALLURGICAL ANALYSIS

Flakes are internal fissures attributed to stresses produced by localized transformation and decreased solubility of hydrogen during cooling after hot working. Usually found only in heavy alloy steel forgings.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. ULTRASONIC TESTING METHOD

(1) Used extensively for the detection of hydrogen flake.

(2) Material in the wrought condition can be screened successfully using either the immersion or the contact method. The surface condition will determine the method most suited.

(3) On the A-scan presentation, hydrogen flake will appear as hash on the screen or as loss of back reflection.

(4) All foreign materials (loose scale, dirt, oil, grease) should be removed prior to any testing. Surface irregularities such as nicks, gouges, tool marks, and scarfing may cause loss of back reflection.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used on finished machined articles.

(2) Flakes appear as short discontinuities and resemble chrome checks or hairline cracks.

(3) Machined surfaces with deep tool marks may obliterate the detection of the flake.

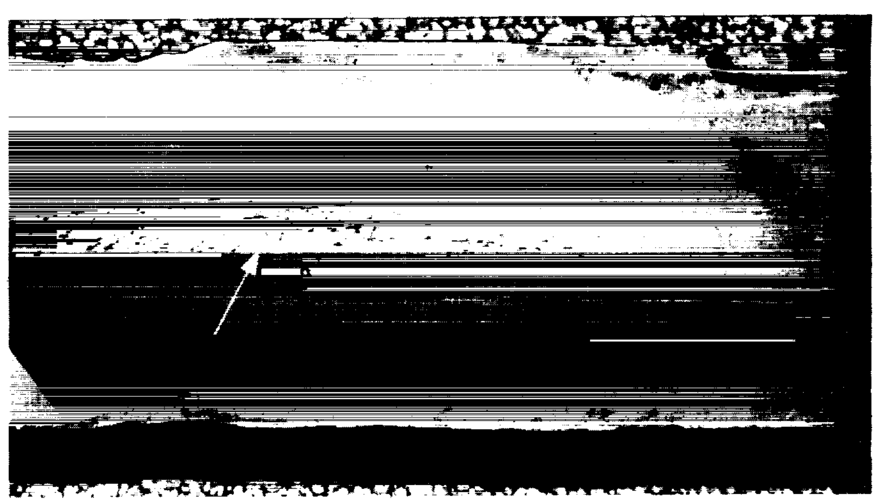
(4) Where the general direction of a discontinuity is questionable, it may be necessary to magnetize in two or more directions.

c. LIQUID PENETRANT TESTING METHOD. Not normally used for detecting flakes. Discontinuities are very small and tight and would be difficult to detect by liquid penetrant.

d. EDDY CURRENT TESTING METHOD. Not recommended for detecting flakes. The metallurgical structure of ferrous materials limits their adaptability to the use of eddy current.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting flakes. The size of the discontinuity, its location and orientation with respect to the material surface restricts the application of radiography.

A 4340 CMS HAND FORGING REJECTED FOR HYDROGEN FLAKE



B CROSS-SECTION OF (A) SHOWING FLAKE CONDITION IN CENTER OF MATERIAL

Figure 7-16. Hydrogen Flake Discontinuity

[redacted]

717 HYDROGEN EMBRITTLEMENT

1. CATEGORY. Processing and Service

2. MATERIAL. Ferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Small, nondimensional (interface) with no orientation or direction. Found in highly heat treated material that was subjected to pickling and/or plating or in material exposed to free hydrogen. (See Figure 7-17.)

4. METALLURGICAL ANALYSIS

Operations such as pickling and cleaning prior to electroplating or electroplating generate hydrogen at the surface of the material. This hydrogen penetrates the surface of the material creating immediate or delayed embrittlement and cracking.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. MAGNETIC PARTICLES TESTING METHOD

(1) Magnetic indications appear as a fractured pattern.

(2) Hydrogen embrittlement cracks are randomly orientated and may follow the magnetic field.

(3) Magnetic particle testing should be accomplished before and after plating.

(4) Care should be taken to produce no confusing or irrelevant indications or cause damage to the article by overheating.

(5) 301 corrosion resistant steel is non-magnetic in the annealed condition, but becomes magnetic with cold working.

b. LIQUID PENETRANT TESTING METHOD

(1) Not normally used for detecting hydrogen embrittlement.

(2) Discontinuities on the surface are extremely tight, small, and difficult to detect. Subsequent plating deposit may mask the discontinuity.

c. ULTRASONIC TESTING METHOD

(1) Not normally used for detecting hydrogen embrittlement.

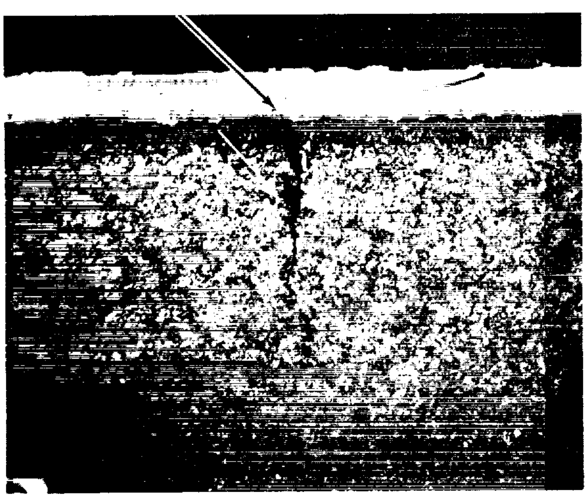
(2) Article configurations and size do not, in general, lend themselves to this method of testing.

(3) Equipment has capability of detecting hydrogen embrittlement. Recommend surface wave technique.

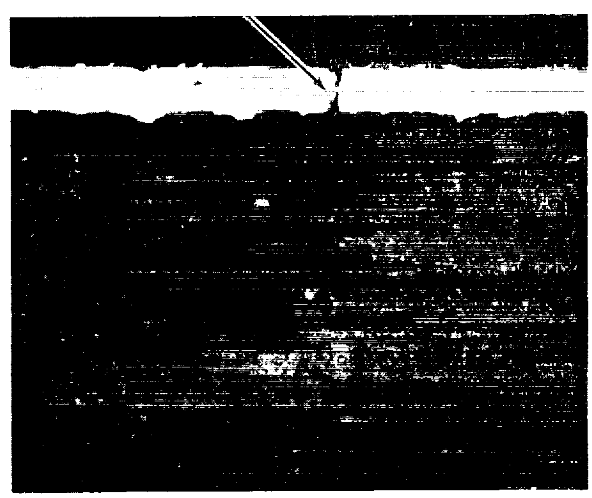
d. EDDY CURRENT TESTING METHOD. Not recommended for detecting hydrogen embrittlement. Many variables inherent in the specific material may produce conflicting patterns.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting hydrogen embrittlement. The sensitivity required to detect hydrogen embrittlement is in most cases in excess of radiographic capabilities.

A DETAILED CRACK PATTERN OF HYDROGEN EMBRITTLEMENT



B HYDROGEN EMBRITTLEMENT UNDER CHROME PLATE



C HYDROGEN EMBRITTLEMENT PROPAGATED THROUGH CHROME PLATE

Figure 7-17. Hydrogen Embrittlement Discontinuity

718 INCLUSIONS

1. CATEGORY. Processing (Weldments)

2. MATERIAL. Ferrous and Nonferrous Welded Material

3. DISCONTINUITY CHARACTERISTICS

Surface and subsurface. Inclusions may be any shape. They may be metallic or non-metallic and may appear singly or be linearly distributed or scattered throughout the weldment. (See Figure 7-18.)

4. METALLURGICAL ANALYSIS

Metallic inclusions are generally particles of metals of different density as compared to the weld or base metal. Non-metallic inclusions are oxides, sulphides, slag or other non-metallic foreign material entrapped in the weld or between the weld metal and the base metal.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHIC TESTING METHOD

(1) This NDT method is universally used.

(2) Metallic inclusions appear on the radiograph as sharply defined, round, erratically shaped, or elongated white spots and may be isolated or in small linear or scattered groups.

(3) Non-metallic inclusions will appear on the radiograph as shadows of round globules or elongated or irregularly shaped contours occurring singly, linearly, or scattered throughout the weldment. They will generally appear in the fusion zone or at the root of the weld. Less absorbent material is indicated by a greater film density and more absorbent materials by a lighter film density.

(4) Foreign material such as loose scales, splatter, or flux may invalidate test results.

b. EDDY CURRENT TESTING METHOD

(1) Normally confined to thin wall welded tubing.

(2) Established standards may be required if valid results are to be obtained.

c. MAGNETIC PARTICLE TESTING METHOD

(1) Normally not used for detecting inclusions in weldments.

(2) Confined to machined weldments where the discontinuities are surface or near surface.

(3) The indications would appear jagged, irregularly shaped, individually or clustered, and would not be too pronounced.

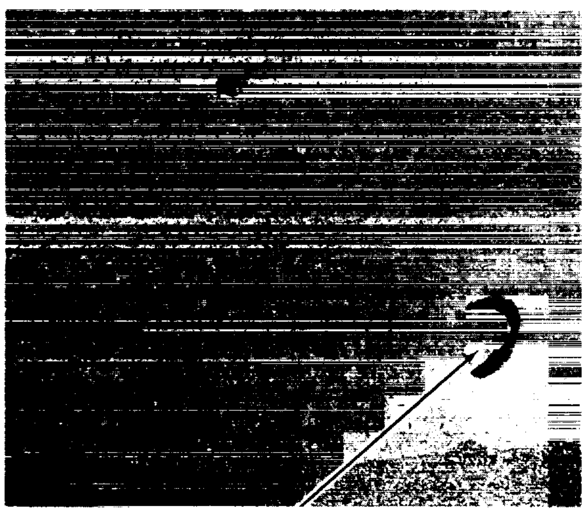
(4) Discontinuities may go undetected when improper contact exists between the magnetic particles and the surface of the article.

d. ULTRASONIC TESTING METHOD

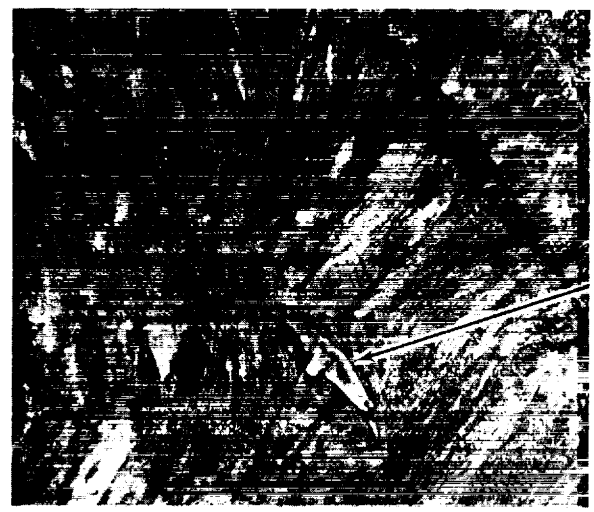
(1) Not normally used for detecting inclusions.

(2) Specific applications of design or of article configuration may require ultrasonic testing.

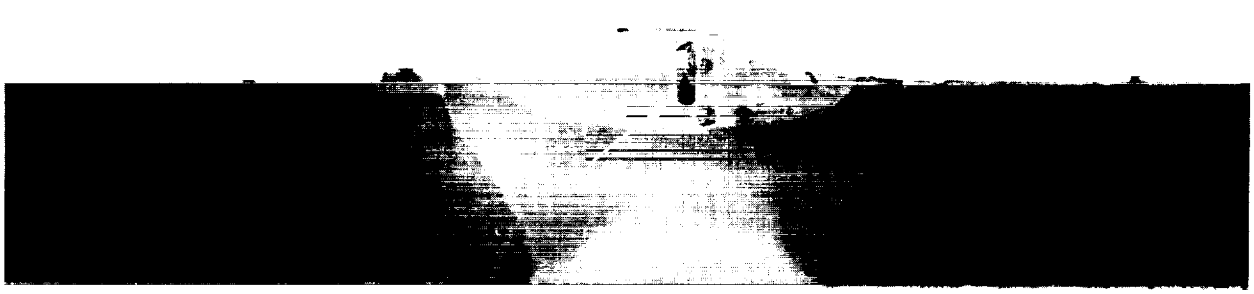
e. LIQUID PENETRANT TESTING METHOD. Not applicable. Inclusions are normally not open fissures.



A METALLIC INCLUSIONS



B INCLUSIONS TRAPPED IN WELD



C CROSS-SECTION OF WELD SHOWING INTERNAL INCLUSIONS

Figure 7-18. Weldment Inclusion Discontinuity

719 INCLUSIONS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Subsurface (original bar) or surface (after machining). There are two types: one is non-metallic with long straight lines parallel to flow lines and quite tightly adherent. Often short and likely to occur in groups. The other type is non-plastic, appearing as a comparatively large mass and not parallel to flow lines. Found in forged, extruded, and rolled material. (See Figure 7-19.)

4. METALLURGICAL ANALYSIS

Non-metallic inclusions (stringers) are caused by the existence of slag or oxides in the billet or ingot. Non-plastic inclusions are caused by particles remaining in the solid state during billet melting.

5. NDT METHODS APPLICATIONS AND LIMITATIONS

a. ULTRASONIC TESTING METHOD

(1) Normally used to evaluate inclusions in wrought material.

(2) Inclusions will appear as definite interfaces within the metal. Small clustered condition or conditions on different planes causing a loss in back reflection. Numerous small scattered conditions cause excessive "noise".

(3) Inclusion orientation in relationship to ultrasonic beam is critical.

(4) The direction of the ultrasonic beam should be perpendicular to the direction of the grain flow whenver possible.

b. EDDY CURRENT TESTING METHOD

(1) Normally used for thin wall tubing and small diameter rods.

(2) Testing of ferro-magnetic materials can be difficult.

c. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used on machined surface.

(2) Inclusions will appear as a straight intermittent or as a continuous indication. They may be individual or clustered.

(3) The magnetic technique should be such that a surface or near surface inclusion can be satisfactorily detected when its axis is in any direction.

(4) A knowledge of the grain flow of the material is critical since inclusions will be parallel to that direction.

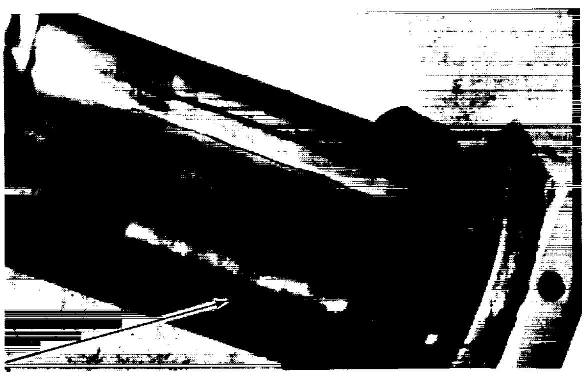
(5) Certain types of steels are more prone to inclusions than other.

d. LIQUID PENETRANT TESTING METHOD

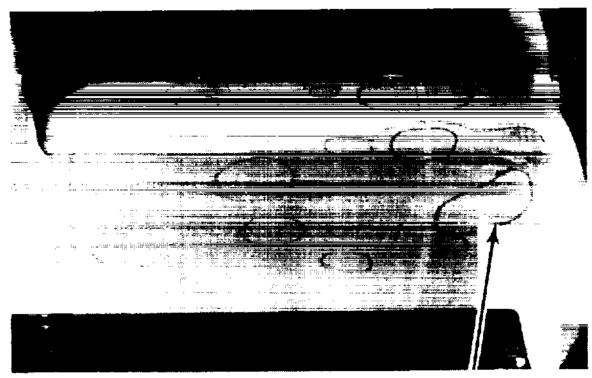
(1) Not normally used for detecting inclusions in wrought material.

(2) Inclusions are generally not openings in the material surface.

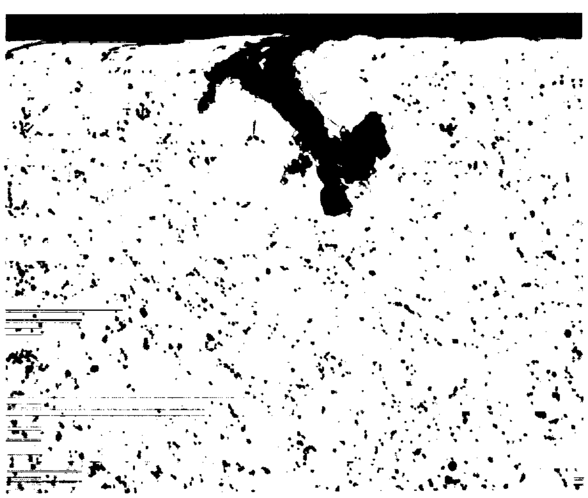
e. RADIOGRAPHIC TESTING METHOD. Not recommended. NDT methods designed for surface testing are more suitable for detecting surface inclusions.



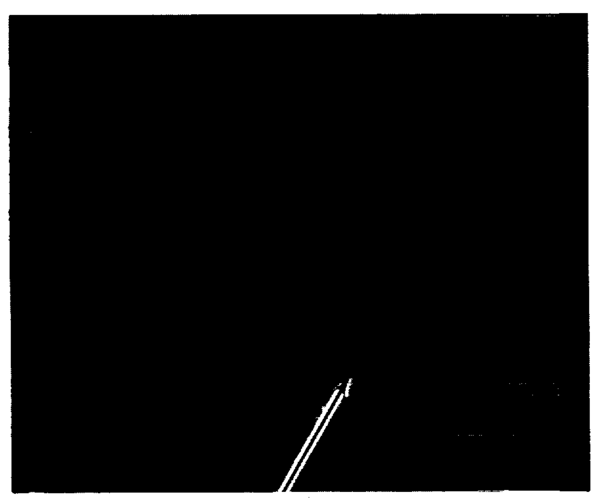
A TYPICAL INCLUSION PATTERN ON MACHINED SURFACES



B STEEL FORGING SHOWING NUMEROUS INCLUSIONS



C MICROGRAPH OF TYPICAL INCLUSION



D LONGITUDINAL CROSS-SECTION SHOWING ORIENTATION OF INCLUSIONS

Figure 7-19. Wrought Inclusion Discontinuity

[redacted]

720 LACK OF PENETRATION

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Weldments

3. DISCONTINUITY CHARACTERISTICS

Internal or external. Generally irregular and filamentary occuring at the root and running parallel with the weld. (See Figure 7-20.)

4. METALLURGICAL ANALYSIS

Caused by root face of joint not reaching fusion temperature before weld metal was deposited. Also caused by fast welding rate, too large a welding rod, or too cold a bead.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHIC TESTING METHOD

(1) Used extensively on a wide variety of welded articles to determine the lack of penetration.

(2) Lack of penetration will appear on the radiograph as an elongated dark area of varying length and width. It may be continuous or intermittent and may appear in the center of the weld at the junction of multipass bends.

(3) Lack of penetration orientation in relationship to the radiographic source is critical.

(4) Sensitivity levels govern the capability to detect small or tight discontinuities.

b. ULTRASONIC TESTING METHOD

(1) Commonly used for specific applications.

(2) Complex weld configurations, or thin wall weldments do not lend themselves to ultrasonic testing.

(3) Lack of penetration will appear on the scope as a definite break or discontinuity resembling a crack and will give a very sharp reflection.

(4) Repeatability of ultrasonic test results is difficult unless equipment is standardized.

c. EDDY CURRENT TESTING METHOD

(1) Normally used to determine lack of penetration in nonferrous welded pipe and tubing.

(2) Eddy current can be used where other nonferrous articles can meet the configuration requirement of the equipment.

d. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used where backside of weld is visible.

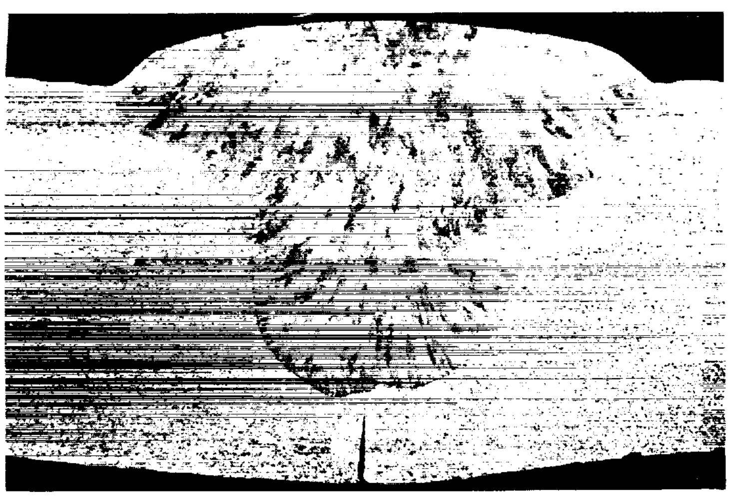
(2) Lack of penetration appears as an irregular indication of varying width.

e. LIQUID PENETRANT TESTING METHOD

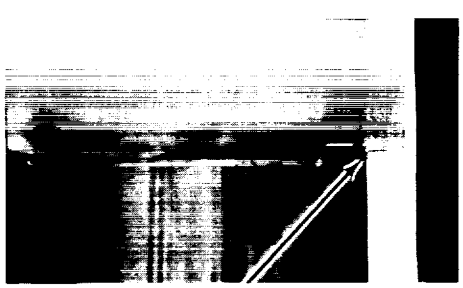
(1) Normally used where backside of weld is visible.

(2) Lack of penetration appears as an irregular indication of varying width.

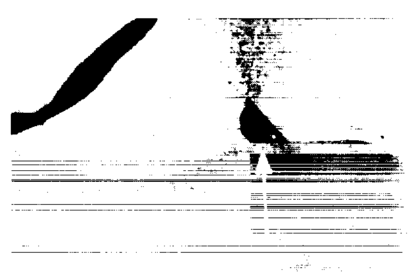
(3) Residue left by the penetrant and the developer could contaminate any re-welding operation.



A INADEQUATE ROOT PENETRATION



B INADEQUATE ROOT PENETRATION OF BUTT WELDED TUBE



C INADEQUATE FILLET WELD PENETRATION KNOWN AS BRIDGING

Figure 7-20. Lack of Penetration Discontinuity

721 LAMINATIONS

1. CATEGORY. Inherent

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Surface and internal. Flat, extremely thin, generally aligned parallel to the work surface of the material. May contain a thin film of oxide between the surfaces. Found in forged, extruded, and rolled material. (See Figure 7-21.)

4. METALLURGICAL ANALYSIS

Laminations are separations or weaknesses generally aligned parallel to the work surface of the material. They may be the result of pipe, blister, seam, inclusions, or segregations elongated and made directional by working. Laminations are flattened impurities that are extremely thin.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. ULTRASONIC TESTING METHOD

(1) For heavier gauge material the geometry and orientation of lamination (normal to the beam) makes their detection limited to ultrasonic.

(2) Numerous wave modes may be used depending upon the material thickness or method selected for testing. Automatic and manual contact or immersion methods are adaptable.

(3) Lamination will appear as a definite interface with a loss of back reflection.

(4) Through transmission and reflection techniques are applicable for very thin sections.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Articles fabricated from ferrous materials are normally tested for lamination by magnetic particle.

(2) Magnetic indication will appear as a straight, intermittent indication.

(3) Magnetic particle testing is not capable of determining the over-all size or depth of the lamination.

c. LIQUID PENETRANT TESTING METHOD

(1) Normally used on nonferrous materials.

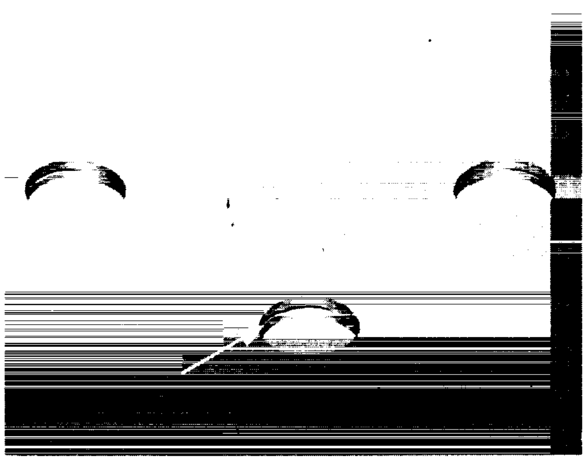
[redacted]

(2) Machining, honing, lapping, or blasting may smear surface of material and thereby close or mask surface lamination.

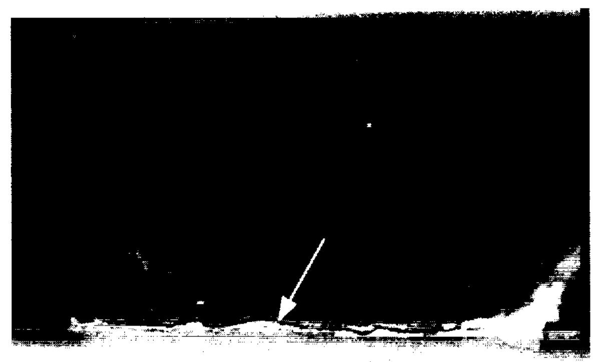
(3) Acid and alkalines seriously limit the effectiveness of liquid penetrant testing. Thorough cleaning of the surface is essential.

d. EDDY CURRENT TESTING METHOD. Not normally used to detect laminations. If used, the method must be confined to thin sheet stock.

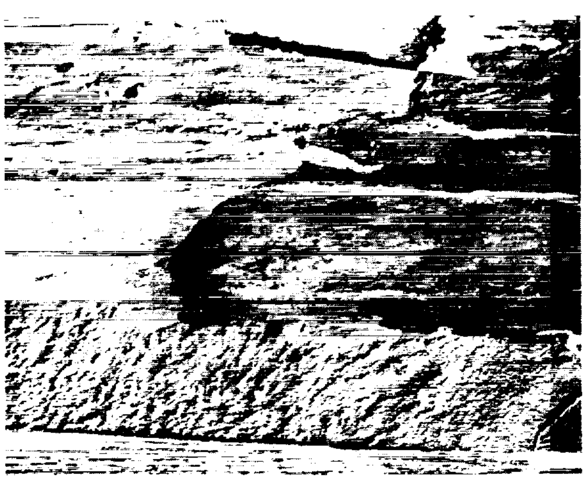
e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting laminations Laminations have very small thickness changes in the direction of the X-ray beam, thereby making radiographic detection almost impossible.



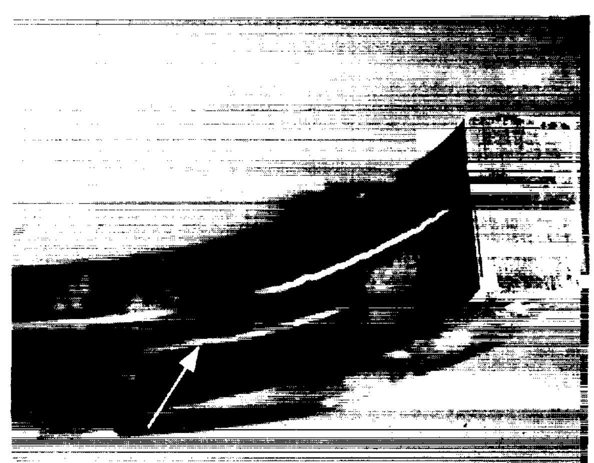
A LAMINATION IN 0.250 IN. PLATE



B LAMINATION IN 0.040 TITANIUM SHEET



C LAMINATION IN PLATE SHOWING SURFACE ORIENTATION



D LAMINATION IN 1 IN. BAR SHOWING SURFACE ORIENTATION

Figure 7-21. Lamination Discontinuity

[redacted]

722 LAPS AND SEAMS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Rolled Threads

3. DISCONTINUITY CHARACTERISTICS

Surface. Wavy lines, often quite deep and sometime very tight, appearing as hairline cracks. Found in rolled threads in the minor, pitch, and major diameter of the thread, and in direction of rolling. (See Figure 7-22.)

4. METALLURGICAL ANALYSIS

During the rolling operation, faulty or oversized dies or an overfill of material may cause material to be folded over and flattened into the surface of the thread but not fused.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. LIQUID PENETRANT TESTING METHOD

(1) Compatibility with both ferrous and nonferrous materials makes fluorescent liquid penetrant the first choice.

(2) Liquid penetrant indications will be circumferential, slightly curved, intermittent or continuous indications. Laps and seams may occur individually or in clusters.

(3) Foreign material may not only interfere with the penetration of the penetrant into the discontinuity but may cause an accumulation of penetrant in a nondefective area.

(4) Surface of threads may be smeared due to rolling operation, thereby sealing off laps and seams.

(5) Fluorescent and dye penetrants are not compatible. Dye penetrants tend to kill the fluorescent qualities in fluorescent penetrants.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Magnetic particle indications would generally appear the same as liquid penetrant.

(2) Irrelevent magnetic indications may result from the thread configuration.

(3) Questionable magnetic particles indications can be verified by liquid penetrant testing.

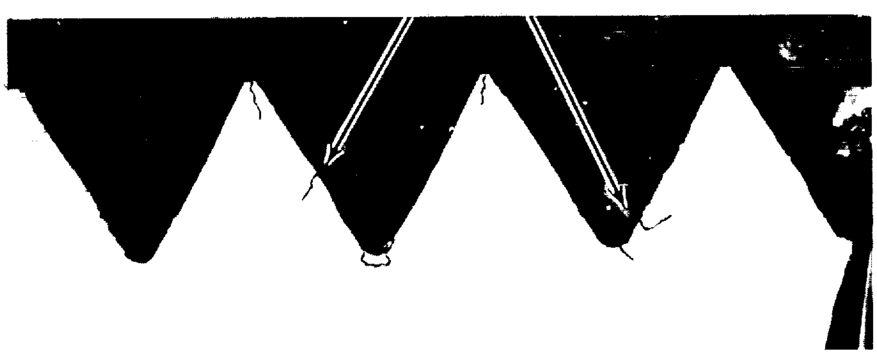
c. EDDY CURRENT TESTING METHOD. Not normally used for detecting laps and seams. Article configuration is the restricting factor.

d. ULTRASONIC TESTING METHOD. Not recommended for detecting laps and seams. Thread configurations restrict ultrasonic capability.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting laps and seams. Size and orientation of discontinuities restricts the capability of radiographic testing.

A TYPICAL AREAS OF FAILURE LAPS AND SEAMS

B FAILURE OCCURRING AT ROOT OF THREAD



C AREAS WHERE LAPS AND SEAMS USUALLY OCCUR

Figure 7-22. Laps and Seams Discontinuity in Rolled Threads

723 LAPS AND SEAMS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

   a. Lap Surface. Wavy lines usually not very pronounced or tightly adherent since they usually enter the surface at a small angle. Laps may have surface openings smeared closed. Found in wrought forgings, plate, tubing, bar, and rod. (See Figure 7-23.)

   b. Seam Surface. Lengthy, often quite deep and sometimes very tight, usually parallel fissures with the grain and at times spiral when associated with rolled rod and tubing.

4. METALLURGICAL ANALYSIS

Seams originate from blowholes, cracks, splits, and tears introduced in earlier processing and elongated in the direction of rolling or forging. The distance between adjacent innerfaces of the discontinuity is very small.

Laps are similar to seams and may result from improper rolling, forging, or sizing operations. During the processing of the material, corners may be folded over or an overfill may exist during the sizing resulting in material being flattened into the surface but not fused. Laps may occur on any part of the article.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. MAGNETIC PARTICLE TESTING METHOD

      (1) Magnetic particle is recommended for ferrous material.

      (2) Surface and near-surface laps and seams may be detected by this method.

      (3) Laps and seams may appear as a straight, spiral, or slightly curved indication. They may be individual or clustered and continuous or intermittent.

      (4) Magnetic buildup of laps and seams is very small. Therefore, a magnetizing current greater than that used for the detection of a crack is necessary.

      (5) Correct magnetizing technique should be used when examining for forging laps since the discontinuity may lie in a plane nearly parallel to the surface.

b. LIQUID PENETRANT TESTING METHOD

(1) Liquid penetrant is recommended for nonferrous material.

(2) Laps and seams may be very tight and difficult to detect especially by liquid penetrant.

(3) Liquid penetrant testing of laps and seams can be improved slightly by heating the article before applying the penetrant.

c. ULTRASONIC TESTING METHOD

(1) Normally used to test wrought material prior to machining.

(2) Surface wave technique permits accurate evaluation of the depth, length, and size of laps and seams.

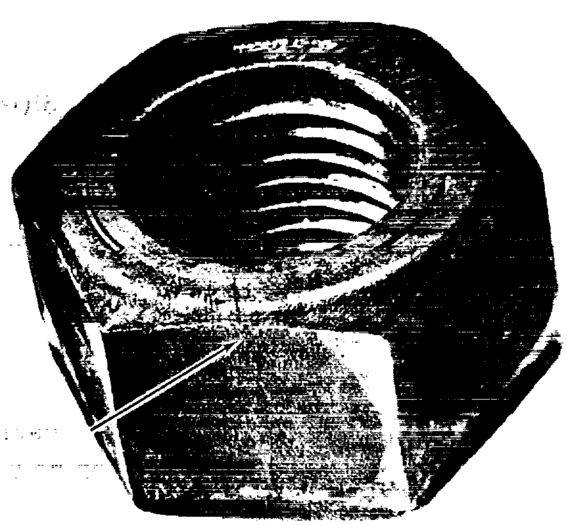
(3) Ultrasonic indication of laps and seams will appear as definite inner faces within the metal.

d. EDDY CURRENT TESTING METHOD

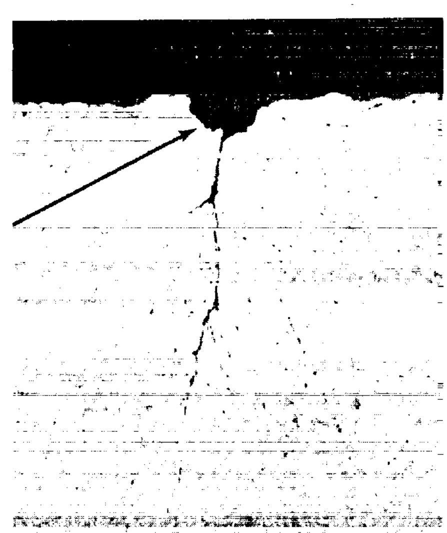
(1) Normally used for the evaluation of laps and seams in tubing and pipe.

(2) Other articles can be screened by eddy current where article configuration and size permit.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting laps and seams in wrought material. Although the ratio between the discontinuity size and the material thickness exceeds 2% of sensitivity in most cases, discontinuities have a very small thickness change in the direction of the X-ray beam, thereby making radiographic detection almost impossible.



A TYPICAL FORGING LAP



B MICROGRAPH OF A LAP

Figure 7-23. Laps and Seams Discontinuity in Wrought Material

724 MICRO-SHRINKAGE

1. CATEGORY. Processing

2. MATERIAL. Magnesium Casting

3. DISCONTINUITY CHARACTERISTICS

Internal. Small filamentary voids in the grain boundaries appear as concentrated porosity in cross section. (See Figure 7-24.)

4. METALLURGICAL ANALYSIS

Shrinkage occurs while the metal is in a plastic or semi-molten state. If sufficient molten metal cannot flow into different areas as it cools, the shrinkage will leave a void. The void is identified by its appearance and by the time in the plastic range it occurs. Micro-shrinkage is caused by the withdrawal of the low melting point constituent from the grain boundaries.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHIC TESTING METHOD

(1) Radiography is universally used to determine the acceptance level of micro-shrinkage.

(2) Micro-shrinkage will appear on the radiograph as an elongated swirl resembling feathery streaks or as dark irregular patches, which are indicative of cavities in the grain boundaries.

b. LIQUID PENETRANT TESTING METHOD

(1) Normally used on finished machined surfaces.

(2) Micro-shrinkage is not normally open to the surface. These conditions will, therefore, be detected in machined areas.

(3) The appearance of the indication depends on the plane through which the condition has been cut. The appearance varies from a continuous hairline to a massive porous indication.

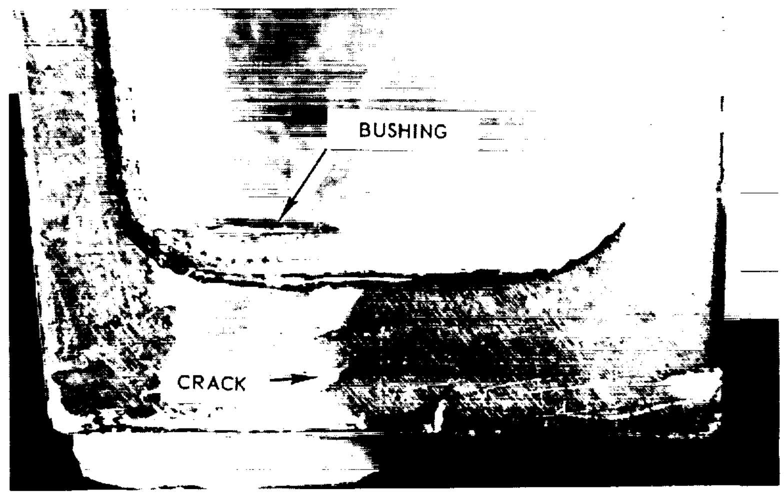
(4) Penetrant may act as a contaminant by saturating the micro porous casting affecting their ability to accept a surface treatment.

(5) Serious structural and a dimensional damage to the article can result from the improper use of acids or alkalies. They should never be used unless approval is obtained.

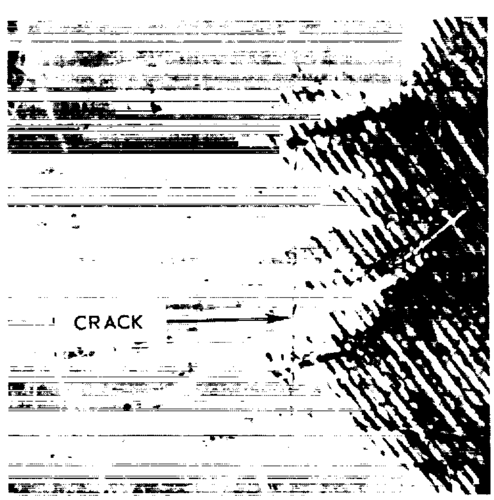
c. EDDY CURRENT TESTING METHOD. Not recommended for detecting micro-shrinkage. Article configuration and type of discontinuity do not lend themselves to eddy current.

d. ULTRASONIC TESTING METHOD. Not recommended for detecting micro-shrinkage. Cast structure and article configuration are restricting factors.

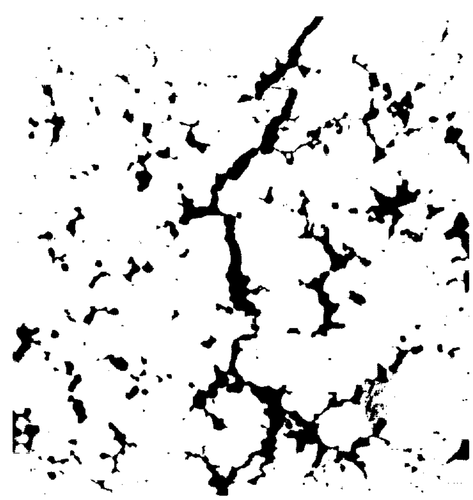
e. MAGNETIC PARTICLE TESTING METHOD. Not applicable. Material is nonferrous.



A CRACKED MAGNESIUM HOUSING



B CLOSE-UP VIEW OF (A)



C MICROGRAPH OF CRACKED AREA

Figure 7-24. Micro-Shrinkage Discontinuity

725 GAS POROSITY

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Weldments

3. DISCONTINUITY CHARACTERISTICS

Surface or subsurface. Rounded or elongated, teardrop shaped with or without a sharp discontinuity at the point. Scattered uniformly throughout the weld or isolated in small groups. May also be concentrated at the root or toe. (See Figure 7-25.)

4. METALLURGICAL ANALYSIS

Porosity in welds is caused by gas entrapment in the molten metal, too much moisture on the base or filler metal, or improper cleaning or preheating.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHY TESTING METHOD

(1) Radiography is the most universally used NDT method for the detection of gas porosity in weldments.

(2) The radiographic image of a 'round' porosity will appear as oval shaped spots with smooth edges, while 'elongated' porosity will appear as oval shaped spots with the major axis sometimes several times longer than the minor axis.

(3) Foreign material such as loose scale, flux, or splatter will affect validity of test results.

b. ULTRASONIC TESTING METHOD

(1) Ultrasonic testing equipment is highly sensitive, capable of detecting micro-separations. Established standards should be used if valid test results are to be obtained.

(2) Surface finish and grain size will affect the validity of the test results.

c. EDDY CURRENT TESTING METHOD

(1) Normally confined to thin wall welded pipe and tube.

(2) Penetration restricts testing to a depth of more than one-quarter inch.

d. LIQUID PENETRANT TESTING METHOD

(1) Normally confined to in-process control of ferrous and nonferrous weldments.

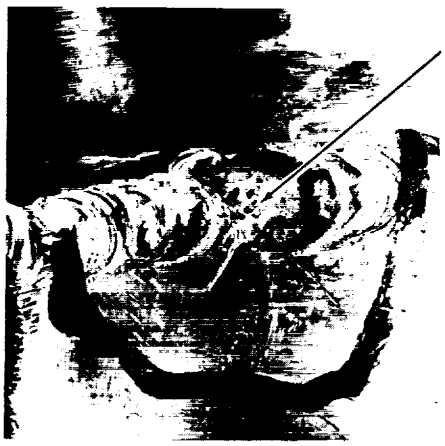
(2) Liquid penetrant testing, like magnetic particle, is restricted to surface evaluation.

(3) Extreme caution must be exercised to prevent any cleaning material, magnetic (iron oxide), and liquid penetrant materials from becoming entrapped and contaminating the rewelding operation.

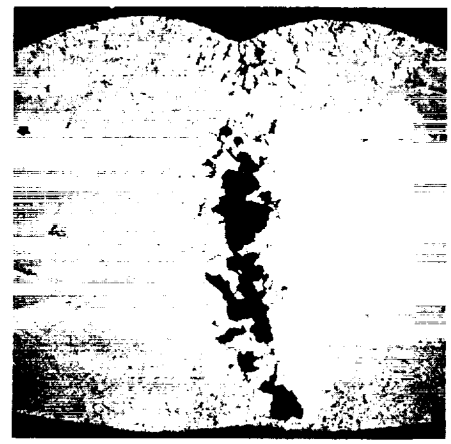
e. MAGNETIC PARTICLE TESTING METHOD

(1) Not normally used to detect gas porosity.

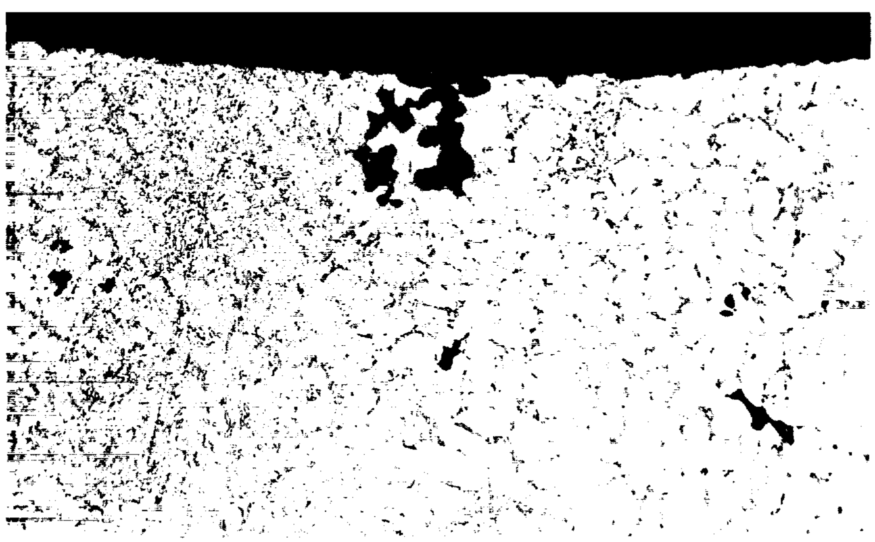
(2) Only surface porosity would be evident. Near surface porosity would not be clearly defined since it is neither strong or pronounced.



A TYPICAL SURFACE POROSITY



B CROSS-SECTION OF (A) SHOWING EXTENT OF POROSITY



C MICROGRAPH OF CROSS-SECTION SHOWING TYPICAL SHRINKAGE POROSITY

Figure 7-25. Gas Porosity Discontinuity

[redacted]

726 UNFUSED POROSITY

1. CATEGORY. Processing

2. MATERIAL. Aluminum

3. DISCONTINUITY CHARACTERISTICS

Internal. Wafer-thin fissures aligned parallel with the grain flow. Found in wrought aluminum which is rolled, forged, or extruded. (See Figure 7-26.)

4. METALLURGICAL ANALYSIS

Unfused porosity is attributed to porosity which is in the cast ingot. During the rolling, forging, or extruding operations it is flattened into wafer-thin shape. If the internal surface of these discontinuities is oxidized or is composed of a foreign material, they will not fuse during the subsequent processing, resulting in an extremely thin interface or void.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. ULTRASONIC TESTING METHOD

      (1) Used extensively for the detection of unfused porosity.

      (2) Material may be tested in the wrought as received configuration.

      (3) Ultrasonic testing fixes the location of the void in all three directions.

      (4) Where the general direction of the discontinuity is unknown, it may be necessary to test from several directions.

      (5) Method of manufacture and subsequent article configuration will determine the orientation of the unfused porosity to the material surface.

   b. LIQUID PENETRANT TESTING METHOD

      (1) Normally used on nonferrous machined articles.

      (2) Unfused porosity will appear as a straight line of varying lengths running parallel with the grain. Liquid penetrant is restricted to surface evaluation.

      (3) Surface preparations such as vapor blasting, honing, or sanding may obliterate by masking the surface discontinuities, thereby restricting the reliability of liquid penetrant testing.

      (4) Excessive agitation of powder in a large container may produce foaming.

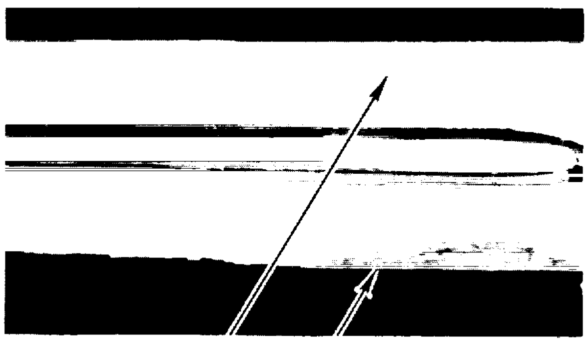
c. EDDY CURRENT TESTING METHOD. Not normally used for detecting unfused porosity.

d. RADIOGRAPHIC TESTING METHOD

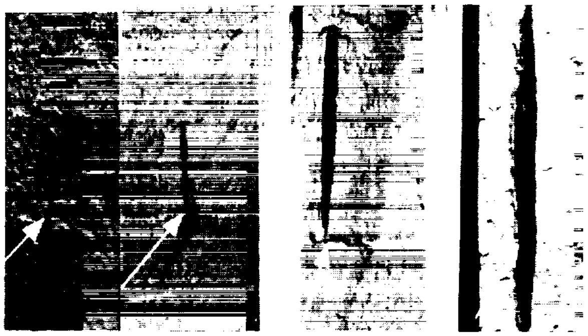
(1) Not normally used for detecting unfused porosity.

(2) Wafer-thin discontinuities are difficult to detect by a method which measures density or which requires that the discontinuity be parallel and perpendicular to the X-ray beam.

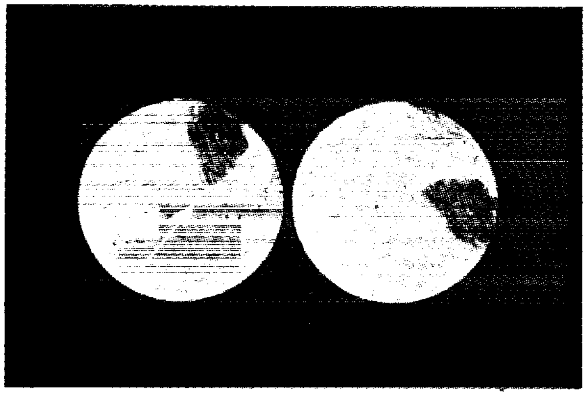
e. MAGNETIC PARTICLE TESTING METHOD. Not applicable. Material is nonferrous.



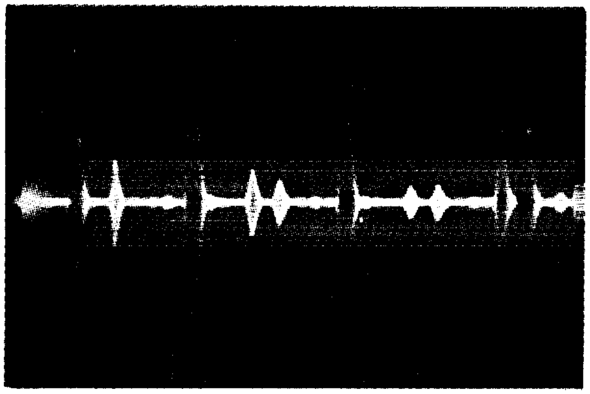
A FRACTURED SPECIMEN SHOWING UNFUSED POROSITY



B UNFUSED POROSITY EQUIVALENT TO 1/64, 3/64, 5/64 AND 8/64 (LEFT TO RIGHT)



C TYPICAL UNFUSED POROSITY



D ULTRASONIC SCOPE PATTERN OF (C)

Figure 7-26. Unfused Porosity Discontinuity

727 STRESS CORROSION

1. CATEGORY. Service

2. MATERIAL. Ferrous and Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface. Range from shallow to very deep, and usually follow the grain flow of the material; however, transverse cracks are also possible. (See Figure 7-27.)

4. METALLURGICAL ANALYSIS

Three factors are necessary for the phenomenon of stress corrosion to occur: 1) a sustained static tensile stress, 2) the presence of a corrosive environment, and 3) the use of a material that is susceptible to this type of failure. Stress corrosion is much more likely to occur faster at high levels of stress than at low levels of stress. The type of stresses include residual (internal) as well as those from external (applied) loading.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. LIQUID PENETRANT TESTING METHOD

(1) Liquid penetrant is normally used for the detection of stress corrosion.

(2) In the preparation, application, and final cleaning of articles, extreme care must be exercised to prevent over spraying and contamination of the surrounding articles.

(3) Chemical cleaning immediately before the application of liquid penetrant may seriously affect the test results if the solvents are not given time to evaporate.

(4) Service articles may contain moisture within the discontinuity which will dilute, contaminate, and invalid results if the moisture is not removed.

b. EDDY CURRENT TESTING METHOD

(1) Not normally used to detect stress corrosion.

(2) Eddy current equipment is capable of resolving stress corrosion where article configuration is compatible with equipment limitations.

c. ULTRASONIC TESTING METHOD

(1) Not normally used to detect stress corrosion.

(2) Discontinuities are perpendicular to surface of material and require surface technique.

d. MAGNETIC PARTICLE TESTING METHOD

(1) Not normally used to detect stress corrosion.

(2) Configuration of article and usual nonmagnetic condition exclude magnetic particle testing.

e. RADIOGRAPHIC TESTING METHOD

(1) Not normally used to detect stress corrosion.

(2) Surface indications are best detected by NDT method designed for such application. However, radiography can and has shown stress corrosion with the use of the proper technique.

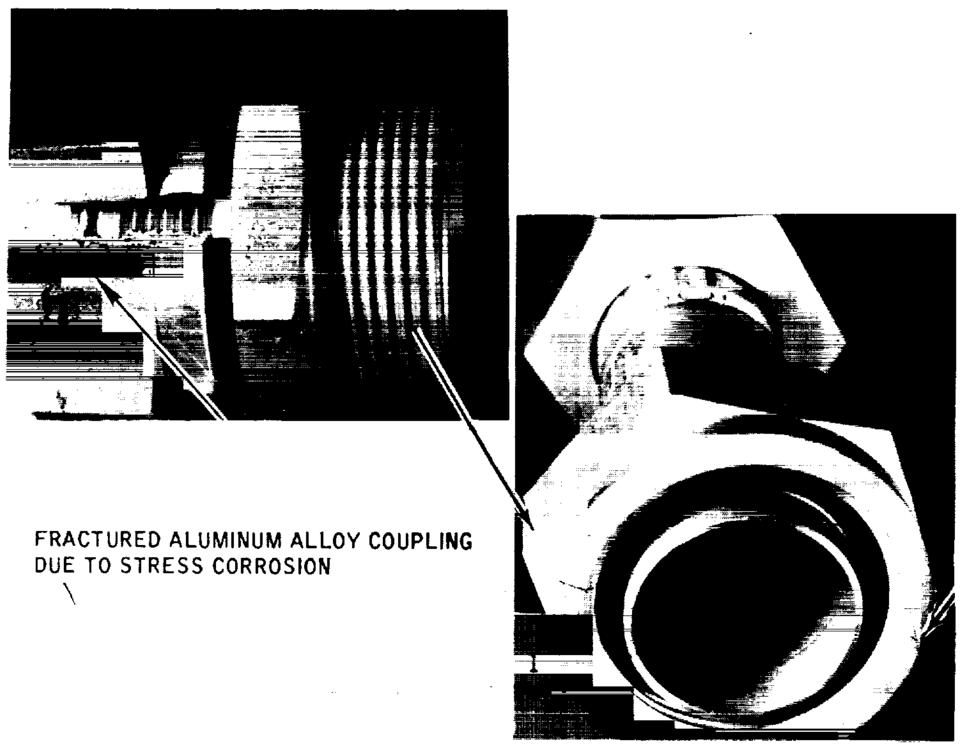


Figure 7-27. Stress Corrosion Discontinuity

[redacted]

728 HYDRAULIC TUBING

1. CATEGORY. Processing and Service

2. MATERIAL. Aluminum 6061-T6

3. DISCONTINUITY CHARACTERISTICS

Surface and internal. Range in size from short to long, shallow to very tight and deep. Usually they will be found in the direction of the grain flow with the exception of stress corrosion, which has no direction. (See Figure 7-28.)

4. METALLURGICAL ANALYSIS

Hydraulic tubing discontinuities are usually one of the following:

a. Foreign material coming in contact with the tube material and being embedded into the surface of the tube.

b. Laps which are the result of material being folded over and not fused.

c. Seams which originate from blowholes, cracks, splits and tears introduced in the eariler processing, and then are elongated during rolling.

d. Intergranular corrosion which is due to the presence of a corrosive environment.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. EDDY CURRENT TESTING METHOD

(1) Universally used for testing of nonferrous tubing.

(2) Heavier walled tubing (0.250 and above) may not be successfully tested due to the penetration ability of the equipment.

(3) The specific nature of various discontinuities may not be clearly defined.

(4) Test results may not be valid unless controlled by known standards.

(5) Testing of ferro-magnetic material may be difficult.

(6) All material should be free of any foreign material that would invalid the test results.

b. LIQUID PENETRANT TESTING METHOD

(1) Not normally used for detecting tubing discontinuities.

(2) Eddy current is more economical, faster, and with established standards is more reliable.

c. ULTRASONIC TESTING METHOD

(1) Not normally used for detecting tubing discontinuities.

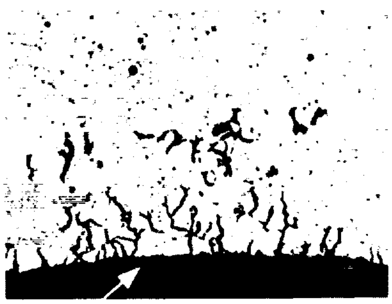
(2) Eddy current is recommended over ultrasonic testing since it is faster and more economical for this range of surface discontinuity and non-ferrous material.

d. RADIOGRAPHIC TESTING METHOD

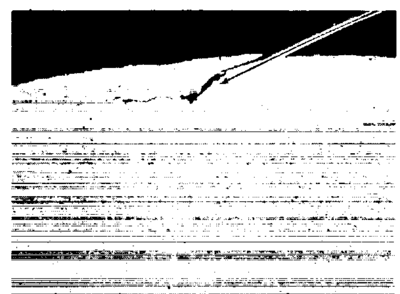
(1) Not normally used for detecting tubing discontinuities.

(2) The size and type of discontinuity and the configuration of the article limit the use of radiography for screening of material for this group of discontinuities.

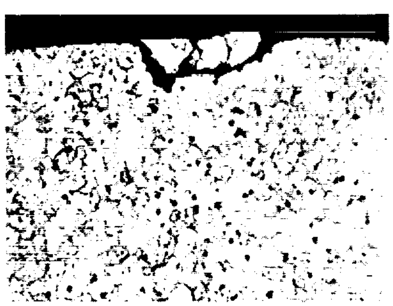
e. MAGNETIC PARTICLES TESTING METHOD. Not applicable. Material is nonferrous.



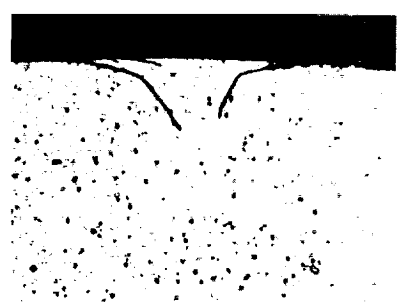
A INTERGRANULAR CORROSION



B LAP IN OUTER SURFACE OF TUBING



C EMBEDDED FOREIGN MATERIAL



D TWIN LAPS IN OUTER SURFACE OF TUBING

Figure 7-28. Hydraulic Tubing Discontinuity

[redacted]

729 MANDREL DRAG

1. CATEGORY. Processing

2. MATERIAL. Nonferrous Thick-Wall Seamless Tubing

3. DISCONTINUITY CHARACTERISTICS

Internal surface of thick-wall tubing. Range from shallow even gouges to ragged tears. Often a slug of the material will be embedded within the gouged area. (See Figure 7-29.)

4. METALLURGICAL ANALYSIS

During the manufacture of thick-wall seamless tubing, the billet is ruptured as it passes through the offset rolls. As the piercing mandrel follows this fracture, a portion of the material may break loose and be forced over the mandrel. As it does the surface of the tubing may be scored or have the slug embedded into the wall. Certain types of material are more prone to this type of failure than others.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. EDDY CURRENT TESTING METHOD

(1) Normally used for the testing of thin-wall pipe or tube.

(2) Eddy current testing may be confined to nonferrous materials.

(3) Discontinuities are qualitative, not quantative indications.

(4) Several factors simultaneously affect output indications.

b. ULTRASONIC TESTING METHOD

(1) Normally used for the screening of thick-wall pipe or tube for mandrel drag.

(2) Can be used to test both ferrous and nonferrous pipe or tube.

(3) Requires access from one side only.

(4) May be used in support of production line since it is adaptable for automatic instrumentation.

(5) Configuration of mandrel drag or tear will produce very sharp and noticeable indications on the scope.

c. RADIOGRAPHIC TESTING METHOD

(1) Not normally used although it has been instrumental in the detection of mandrel drag during examination of adjacent welds.

(2) Complete coverage requires several exposures around the circumference of the tube.

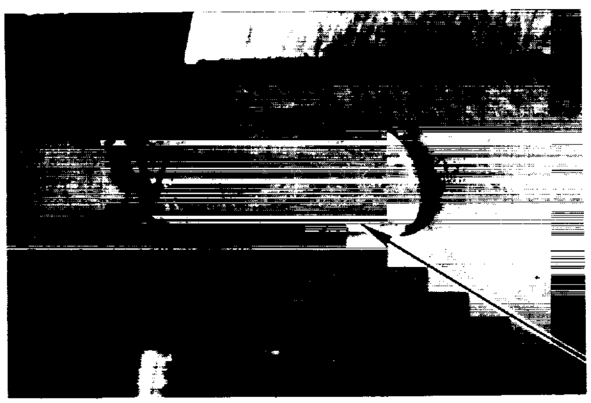
[redacted]

(3) This method is not designed for production support since it is very slow and costly for large volumes of pipe or tube.

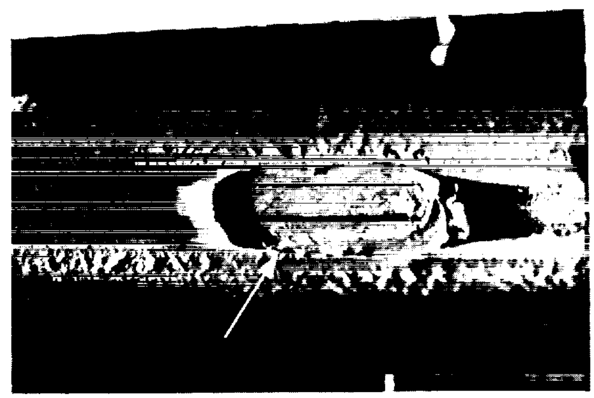
(4) Radiograph will disclose only two dimensions and not the third.

d. LIQUID PENETRANT TESTING METHOD. Not recommended for detecting mandrel drag since discontinuity is internal and would not be detectable.

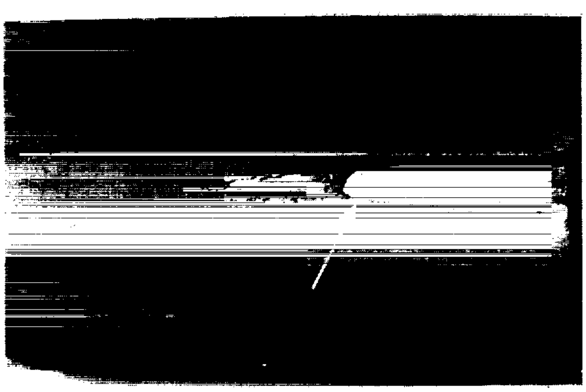
e. MAGNETIC PARTICLE TESTING METHOD. Not recommended for detecting mandrel drag. Discontinuities are not close enough to the surface to be detectable by magnetic particles. Most mandrel drag will occur in seamless stainless steel.



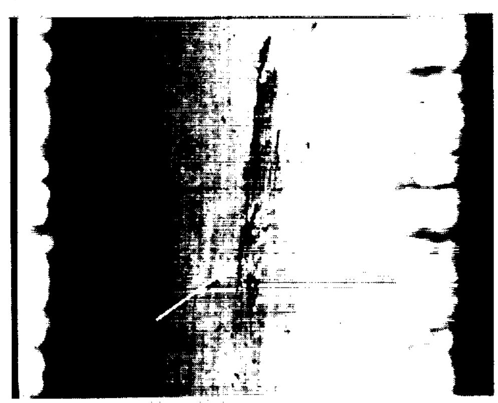
A EMBEDDED SLUG SHOWING DEEP GOUGE MARKS



B SLUG BROKEN LOOSE FROM TUBING WALL



C ANOTHER TYPE OF EMBEDDED SLUG



D GOUGE ON INNER SURFACE OF PIPE

Figure 7-29. Mandrel Drag Discontinuity

730 SEMICONDUCTORS

1. CATEGORY. Processing and Service

2. MATERIAL. Hardware

3. DISCONTINUITY CHARACTERISTICS

Internal. Appear in many sizes and shapes and various degrees of density. They may be misformed, aligned, damaged, or broken internal hardware. Found in transistors, diodes, resistors, and capacitors. (See Figure 7-30.)

4. METALLURGICAL ANALYSIS

Semiconductor discontinuities such as loose wire, weld splash, flakes, solder balls, loose leads, inadequate clearance between internal elements and case, and inclusions or voids in seals or around lead connections are the product of processing errors.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHIC TESTING METHOD

(1) Universally used as the NDT method for the detection of discontinuities in semiconductors.

(2) The configuration and internal structure of the various semiconductors limit the NDT method to radiography.

(3) Semiconductors that have copper heat sinks may require more than one technique due to the density of the copper.

(4) Internal wires in semiconductors are very fine and may be constructed from materials of different density such as copper, silver, gold and aluminum. If the latter is used with the others, special techniques may be needed to resolve its reliability.

(5) Micro-particles may require the highest sensitivity to resolve.

(6) The complexity of the internal structure of semiconductors may require additional views to exclude the possibility of non-detection of discontinuities due to masking by hardware.

(7) Positive positioning of each semiconductor will prevent invalid interpretation.

(8) Source angle should give minimum distortion.

(9) Preliminary examination of semiconductors may be accomplished using a vidcon system that would allow visual observation during 360 degree rotation of the article.

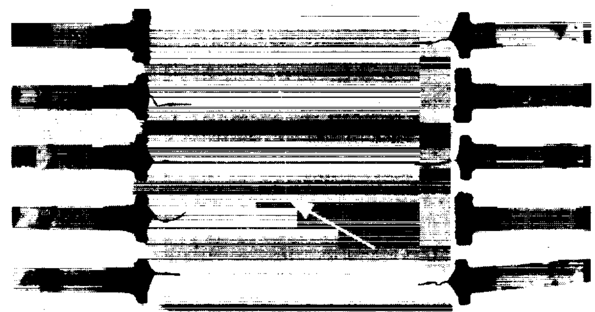
b. EDDY CURRENT TESTING METHOD. Not recommended for detecting semiconductor discontinuities. Nature of discontinuity and method of construction of the article do not lend themselves to this form of NDT.

c. MAGNETIC PARTICLE TESTING METHOD. Not recommended for detecting semiconductor discontinuities.

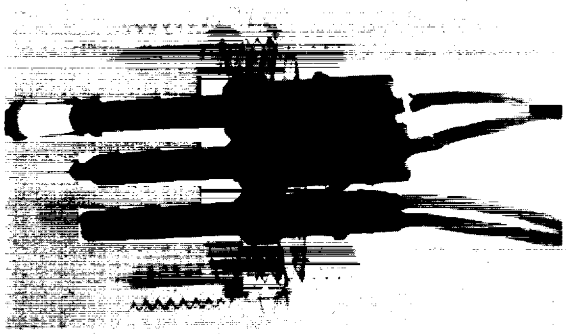
d. LIQUID PENETRANT TESTING METHOD. Not recommended for detecting semiconductor discontinuities.

e. ULTRASONIC TESTING METHOD. Not recommended for detecting semiconductor discontinuities.

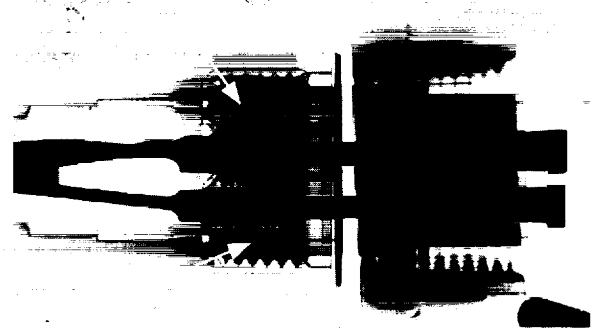
A STRANDS BROKEN IN HEATER BLANKET



B FINE CRACK IN PLASTIC CASING MATERIAL



C BROKEN ELECTRICAL CABLE



D FOREIGN MATERIAL WITHIN SEMICONDUCTOR

Figure 7-30. Semiconductor Discontinuity

731 HOT TEARS

1. CATEGORY. Inherent

2. MATERIAL. Ferrous Castings

3. DISCONTINUITY CHARACTERISTICS

Internal or near surface. Appear as ragged line of variable width and numerous branches. Occur singly or in groups. (See Figure 7-31.)

4. METALLURGICAL ANALYSIS

Hot cracks (tears) are caused by non-uniform cooling resulting in stresses which rupture the surface of the metal while its temperature is still in the brittle range. Tears may originate where stresses are set up by the more rapid cooling of thin sections that adjoin heavier masses of metal, which are slower to cool.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. RADIOGRAPHIC TESTING METHOD

(1) Radiographic testing is the first choice since the material is cast structure and the discontinuities may be internal and surface.

(2) Orientation of the hot tear in relation to the source may influence the test results.

(3) The sensitivity level may not be sufficient to detect fine surface hot tears.

b. MAGNETIC PARTICLE TESTING METHOD

(1) Hot tears that are exposed to the surface can be screened with magnetic particle method.

(2) Article configuration and metallurgical composition may make demagnization difficult.

(3) Although magnetic particle can detect near surface hot tears, radiography should be used for final analysis.

(4) Foreign material not removed prior to testing will cause an invalid test.

c. LIQUID PENETRANT TESTING METHOD

(1) Liquid penetrant is recommended for nonferrous cast material.

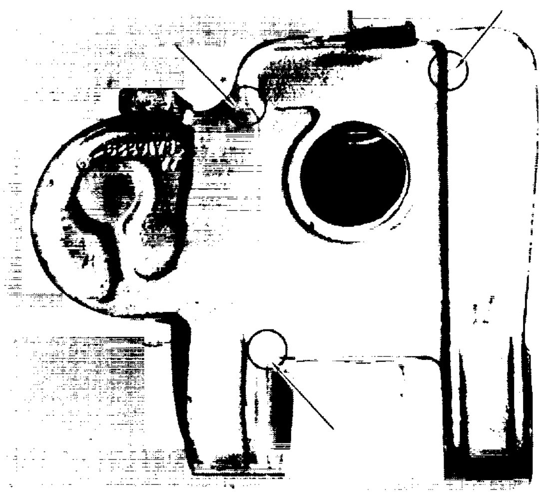
(2) Liquid penetrant is confined to surface evaluation.

(3) The use of penetrants on castings may act as a contaminant by saturating the porous structure and affect the ability to apply surface finish.

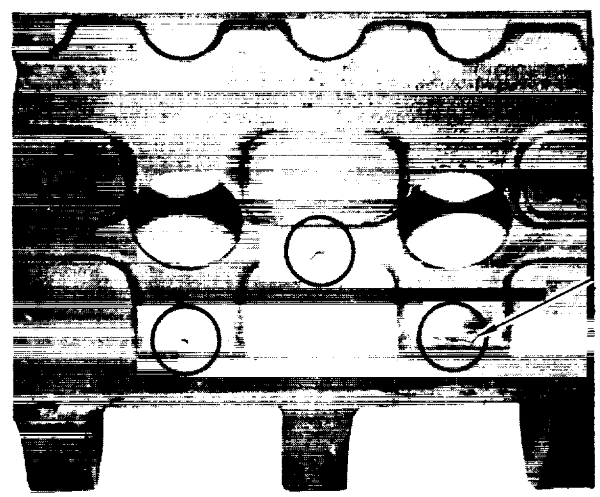
(4) Repeatability of indications may be poor after a long period of time.

d. ULTRASONIC TESTING METHOD. Not recommended for detecting hot tears. Discontinuities of this type when associated with cast structure do not lend themselves to ultrasonic testing.

e. EDDY CURRENT TESTING METHOD. Not recommended for detecting hot tears. Metallurgical structure along with the complex configurations do not lend themselves to eddy current testing.

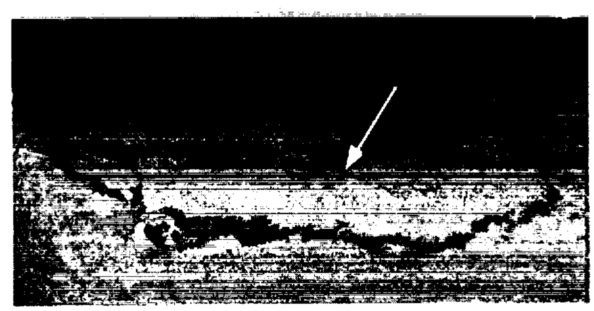


A TYPICAL HOT TEARS IN CASTING



B HOT TEARS IN FILLET OF CASTING

C CLOSE-UP OF HOT TEARS IN (A)



D CLOSE-UP OF HOT TEARS IN (B)

Figure 7-31. Hot Tear Discontinuity

[redacted]

732 INTERGRANULAR CORROSION

1. CATEGORY. Service

2. MATERIAL. Nonferrous

3. DISCONTINUITY CHARACTERISTICS

Surface or internal. A series of small micro-openings with no definite pattern. May appear singly or in groups. The insidious nature of intergranular corrosion results from the fact that very little corrosion or corrosion product is visible on the surface. Intergranular corrosion may extend in any direction following the grain boundaries of the material. (See Figure 7-32.)

4. METALLURGICAL ANALYSIS

Two factors that contribute to intergranular corrosion are:

a. Metallurgical structure of the material that is prone to intergranular corrosion such as unstabilized 300 series stainless steel.

b. Improper stress relieving or heat treat may create the susceptibility to intergranular corrosion. Either of these conditions coupled with a corrosive atmosphere will result in intergranular attack.

5. NDT METHODS APPLICATION AND LIMITATIONS

a. LIQUID PENETRANT TESTING METHOD

(1) Liquid penetrant is the first choice due to the size and location of this type of discontinuity.

(2) Chemical cleaning operations immediately before the application of liquid penetrant may contaminate the article and seriously affect the test results.

(3) Cleaning in solvents may release chlorine and accelerate intergranular corrosion.

(4) Trapped penetrant solution may present a cleaning or removal problem.

b. RADIOGRAPHIC TESTING METHOD

(1) Intergranular corrosion in the more advanced stages has been detected with radiography.

(2) Sensitivity levels may prevent the detection of fine intergranular corrosion.

(3) Radiography may not determine on which surface the intergranular corrosion will occur.

c. EDDY CURRENT TESTING METHOD

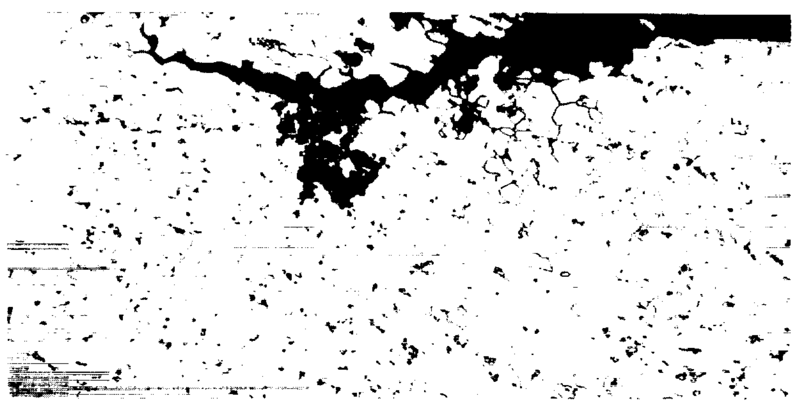
(1) Eddy current can be used for the screening of intergranular corrosion.

(2) Tube or pipe lend themselves readily to this method of NDT testing.

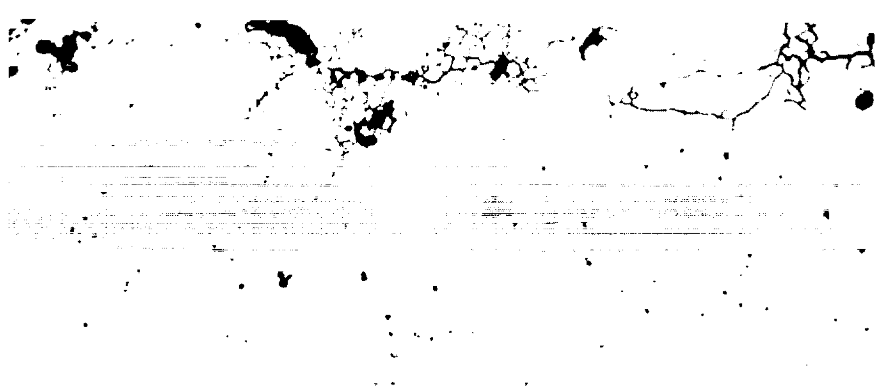
(3) Metallurgical structure of the material may seriously affect the output indications.

d. ULTRASONIC TESTING METHOD. Not normally used although the equipment has the capability to detect intergranular corrosion.

e. MAGNETIC PARTICLES TESTING METHOD. Not recommended for detecting intergranular corrosion. Type of discontinuity and material restrict the use of magnetic particles.



A MICROGRAPH OF INTERGRANULAR CORROSION SHOWING LIFTING OF SURFACE FROM SUBSURFACE CORROSION



B MICROGRAPH SHOWING NATURE OF INTERGRANULAR CORROSION. ONLY MINOR EVIDENCE OF CORROSION IS EVIDENT FROM SURFACE

Figure 7-32. Intergranular Corrosion Discontinuity