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Nondestructive Inspection Journeyman

Volume 4. Radiographic and Oil Analysis Inspection

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WELCOME TO career development course (CDC) 2A752, *Nondestructive Inspection Journeyman*, the final volume for nondestructive inspection (NDI).

This is the final volume, which includes the performance of one of the most tedious NDI methods and the hardest to master—radiography. The concept seems simple enough; X-ray a part, develop the film, and look for any defects. In reality, radiography is far more complex than these simple steps and takes years of experience to master. This volume also includes information about the Joint Oil Analysis Program (JOAP), principals of wear metals, analyzing samples, and introduces new NDI systems.

Unit 1 covers the basics of X-rays, including their origin, production, and interaction with materials. This unit provides you with a better understanding of how X-rays are generated and how they affect the structure of industrial film. You will also look at the types of equipment used in the field, and know the importance of radiation safety and responsibilities. A few process controls are required before radiation inspection can be accomplished, and we will look at some of the tasks performed as well as processing and interpreting film.

Unit 2 introduces fundamentals of digital radiography and equipment along with step-by-step process control procedures of each.

Unit 3 presents a general knowledge of lubricating systems and wear metals associated with oil analysis. We also identify basic facts of the scanning electron microscope/energy dispersive X-ray known as the (SEM/EDX). This unit will also walk you through the JOAP certification program and standardizing your unit. Lastly, we will go over some forms and evaluation trends needed to guide you through a decision making process.

Unit 4 wraps up the volume with an introduction to several specialized inspection techniques, which you may encounter depending on the weapon systems assigned to your base.

A glossary is included for your use.

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NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

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Unit 1. Radiographic Inspection

X-RAYS WERE DISCOVERED BY CHANCE IN 1895 by W.C. Roentgen. He noticed a screen painted in barium platinocyanide fluoresced when placed in close proximity to a cathode-ray tube. He called these X-rays because their nature was unknown. In 1912, M. Von Laue and other investigators identified X-rays as electromagnetic waves similar in nature to visible light; however, X-rays are invisible and they have far greater penetrating power than light.

Within this unit, we will discuss the principles and theory of X-rays, in order to better understand them, when examining the item of interest; how to create the X-rays; as well as the radiographic file used to capture the images desired using their properties. Next, we will consider the safety aspects that must be practiced when working with radiographic equipment, radiation, and inspections. Finally, we will discuss processing and interpreting the resulting radiographic film images.

1–1. Principles and Theory of Radiographic Inspection

X and gamma radiographic inspection uses penetrating abilities of electromagnetic radiation to examine the interior of objects. The following three prime factors determine the amount of information radiography can provide about an object:

- Composition.
- Material density.
- Energy of the X-ray incident.

In this section, you will learn about fundamentals of radiography, including their theory and production, the generation of X-rays, and the construction of film and the development process.

601. Understanding X-rays

X-rays are high-energy photons that are produced when electrons make transitions from one atomic orbit to another. If you send a photon into an atom with an energy greater than the binding energy of an electron in that atom, the photon can knock that electron out of its orbit, leaving a hole. Another electron in the atom giving off an X-ray in the transition to conserve energy can then fill this hole. This process is known as *fluorescence*. Fluorescence is characterized by the fact that it occurs only so long as the stimulus responsible for it is maintained. The characteristic X-radiation emitted, as a result of absorption of X-rays of higher frequency is a typical example of fluorescence. The property of emitting visible light is the result of (and only occurs during) radiant energy from another source being absorbed. Many different atomic electrons of different binding energies can fill this hole, so you would expect to see many energy peaks in an X-ray spectrum.

Altogether, X-rays, gamma rays, visible light, ultraviolet light, infrared radiation, microwaves, and radio waves make up the electromagnetic spectrum. Electromagnetic radiation is dualistic; meaning it exhibits some characteristics of a wave and some characteristics of a particle. In this case, the particle is called a *photon*, which is a quantum of light. Depending upon the application, X-rays might exhibit a more wave-like behavior.

Properties of X-rays and gamma rays

Several properties that X-rays possess make them useful for radiographic inspection. They both are the same form of energy as visible light and are part of the electromagnetic spectrum. Like light, both refract when passed through glass, a lens, or any other medium; however, the amount of refraction of an X or gamma ray using visible-light optics is so slight that it is unnoticeable. Although the properties of X, gamma, and visible light rays are theoretically similar because of differences in application, it is most convenient to consider X and gamma rays as being different since their observable effects are quite different from those of light. This is noted particularly in the ability to penetrate matter. The following summarizes some general properties of X and gamma rays:

- They are invisible to humans.
- They propagate in straight lines in free space.
- They consist of transverse electromagnetic vibrations, as does light.
- X-rays for nondestructive inspection (NDI) are produced by the interaction of high-energy electrons or ions with matter.
- X-rays and gamma rays expose (darken) photographic film.
- They stimulate fluorescence and phosphorescence in some materials.
- They are able to damage and kill living cells and to produce genetic mutations.
- They absorb or scatter by different media.
- X-rays may diffract by the crystalline structure of materials, which acts like a grating.

X-radiation

To understand how X-rays generate, we must first look at the atomic structure. An *atom* is the simplest unit in which an element can be divided and still exhibit the characteristic chemical property of that element. Although atoms of one element differ from those of another, all atoms have the same general structure. Atoms of all elements are made of three primary subatomic building blocks: *protons*, *neutrons*, and *electrons* (described in the following table). The nucleus contains both protons and neutrons of the subatomic building blocks, referred to collectively as *nucleons*.

Elements of Atoms	
Name	**Description**
Protons	The number of protons in an atomic nucleus is equal to the number of orbital electrons. Since the electron has an electrical charge of –1, the total atomic charge is zero and the complete atom is electrically neutral. The number of protons and electrons in an atom determines the element to which the atom belongs. They are responsible for the chemical properties of an atom that make it different from atoms of other elements. For example, all atoms of hydrogen have one proton and one orbital electron; all atoms of oxygen have eight protons and eight orbital electrons. The number of protons in an atom is called the atomic number (or proton number) of the atom.
Neutrons	Neutrons do not affect the atomic number (that is, the chemical behavior) of the element, but they do affect the atomic mass. For example, the sum of the number of protons and neutrons in an atom is the atomic mass number. Thus, hydrogen (atomic number 1) also has a mass number of one because in its common form, it does not have any neutrons. Oxygen (atomic number 8) has a mass number of 16 because it normally has eight neutrons along with its eight protons.
Electrons	The electron has kinetic energy (energy due to motion) and potential energy (energy due to the electrostatic field). In other words, an electron can orbit only at a certain distance from the nucleus.

It is possible for atoms of the same element (atomic number) to have different numbers of neutrons and, therefore, different mass numbers. Atoms having the same atomic number (number of protons) but different atomic masses are called *isotopes*.

In able to generate X-rays, the following three basic requirements that must be present are:

- Supply electrons.
- Move electrons.
- Impinge electrons onto the target.

Supply electrons

Since all matter is considered to be composed of electrons and other minute particles, electron sources are readily obtainable. Electrons can be supplied by simply raising the temperature of a suitable material. To excite the electron, it is necessary to sufficiently heat the material. As the temperature rises, the electrons become more and more agitated until they finally "escape" the material. The excited electrons will surround the material in the form of an electron cloud (fig. 1–1), commonly known as *thermionic emission*.

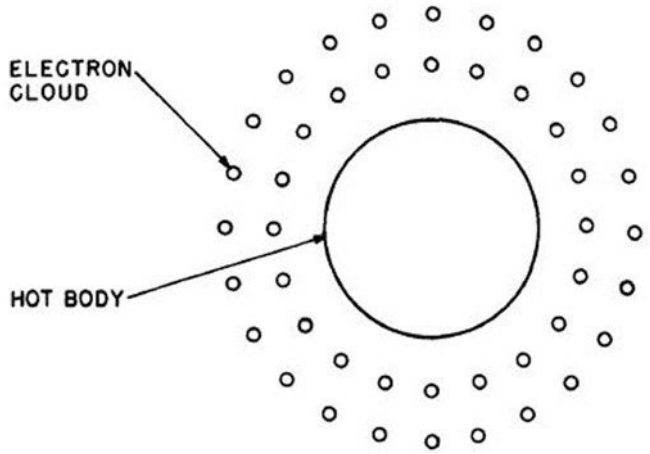


Figure 1–1. Electron cloud.

In an X-ray tube, the heated material is called the *filament*, which is similar to the filament in a light bulb. Just as in a light bulb, the filament is heated by passing electrical current through it. This cloud of electrons simply hovers around and returns to the emitting substance unless some external action or force pulls it away; therefore, electron emission is facilitated by heating a filament, which is incorporated into the cathode. The *cathode* is a negatively biased electrode of an X-ray tube from which the electrons emit and accelerate to the anode. The *anode* is a positive terminal of an X-ray tube. It is a high atomic number, high melting point element, and receives the electron bombardment from the cathode or negative terminal.

Move electrons

As high voltage using direct current is applied between the cathode and the anode, the cathode emits electrons that flow toward the anode. This movement is due to the repelling and attracting forces inherent in an electric circuit. The fundamental law of electrostatics states: "Like charges repel and unlike charges attract." Electrons are negative charges, thus repel each other; however, a stronger attracting force is needed to accelerate the electrons to a higher velocity; therefore, a strong opposite (positive) charge is used to move the electrons from one point to another. This voltage force, which drives electrons from the cathode to the anode, is known as *Kilovoltage* with a unit symbol "kV."

Units of X-Ray	
Name	**Description**
Kilovoltage (kV)	This voltage force drives electrons from the cathode to the anode. It has a unit of electromotive force or potential equal to 1,000 volts.
Milliamperage (mA)	A measure of the current flowing between the cathode and the anode in an X-ray tube, and is a measure of the intensity of the emitted radiation. It is a unit of electrical current equal to one thousandth of an ampere.

It is important this movement is conducted in a good vacuum; otherwise, the electrons collide with air molecules and lose energy through ionization and scattering. In an X-ray tube, the anode is given a positive charge with respect to the filament, which is part of the cathode. A focusing cup in the cathode is used to direct the stream of electrons to the target.

Impinge electrons onto the target

The voltage applied between the cathode and anode is called the *X-ray tube voltage*, and the surface of the anode that is struck by electrons is called the *target*. When the rapidly moving electrons collide with the target stopping their rapid motion, a small portion of their energy transforms into X-rays. The remainder of the energy turns into heat, raising the temperature of the target (anode). Because the target heats to extremely high temperatures, it is made of a high melting point material like tungsten.

The number of electrons emitted from the cathode and the dose of X-rays generated off the target of the anode can be adjusted by changing the filament current of the X-ray tube. When the X-ray tube voltage changes, the speed at which electrons strike the target changes, causing an alteration in the energy level of the X-rays and their wavelength. X-rays which have relatively short wavelengths are called *hard X-rays*, and those with relatively long wavelengths are called *soft X-rays*.

Characteristic radiation

The most distinguishing characteristic of X-rays is their short wavelength. The penetrating ability of X-rays is directly proportional to their energy, which in turn, is inversely proportional to their wavelength. This means that the shorter the wavelength, the higher the energy; on the flip side, the longer the wavelength, the lower the energy.

There are several characteristic spikes in a typical X-ray spectrum. These intensity spikes are caused by interaction between the impinging stream of high-speed electrons and the electrons bound tightly to the atomic nuclei of the target material. If an atom is considered as a planetary system, with the nucleus of protons and neutrons at the center and the electrons moving in orbits around the nucleus, modern physics predicts the orbital electrons near the nucleus will have very well defined energies; conversely, electrons in different orbits will have different energy levels. If an electron from an external beam collides with an orbital electron with sufficient energy, and knocks it from its orbit, an electron from a higher energy level would, after a time, drop down to fill the void and restore atomic stability. When that electron drops to the lower energy level, it gives off a photon with energy equal to the difference in energy levels. Since these energy levels depend strictly upon a particular atom, the radiation emitted is called *characteristic radiation*. The characteristic radiation emitted by the target material is superimposed upon the *continuous spectrum*. Figure 1–2 demonstrates x-ray production.

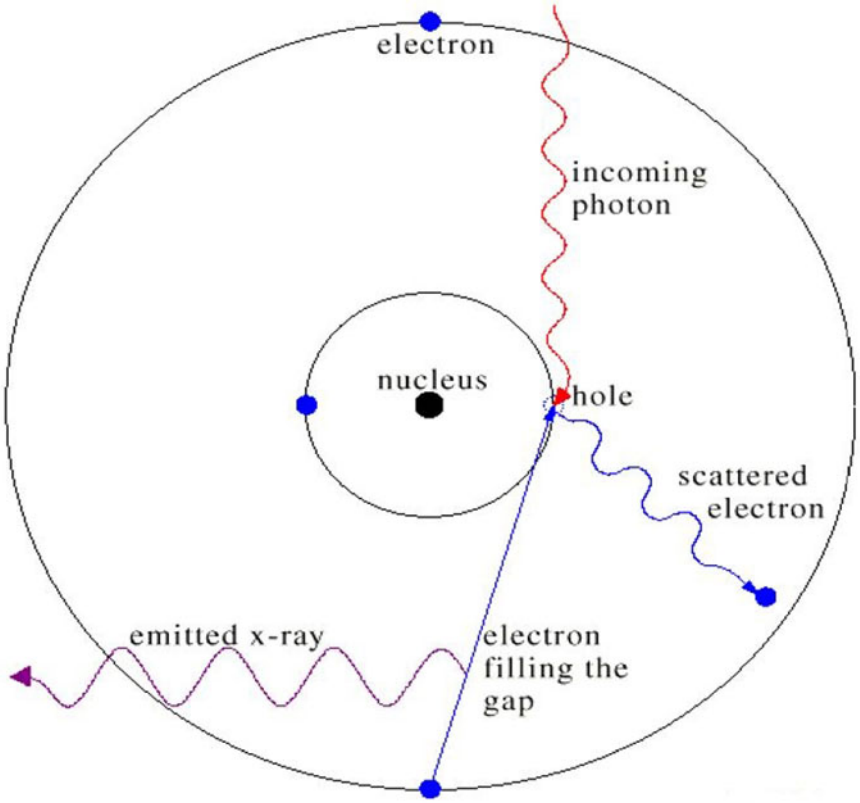


Figure 1–2. X-ray production.

A typical X-ray spectrum of radiation generated by an X-ray tube would appear as in figure 1–3. The K and L series of characteristic radiation designate the radiation emitted from different electron orbits around the nucleus of the atom.

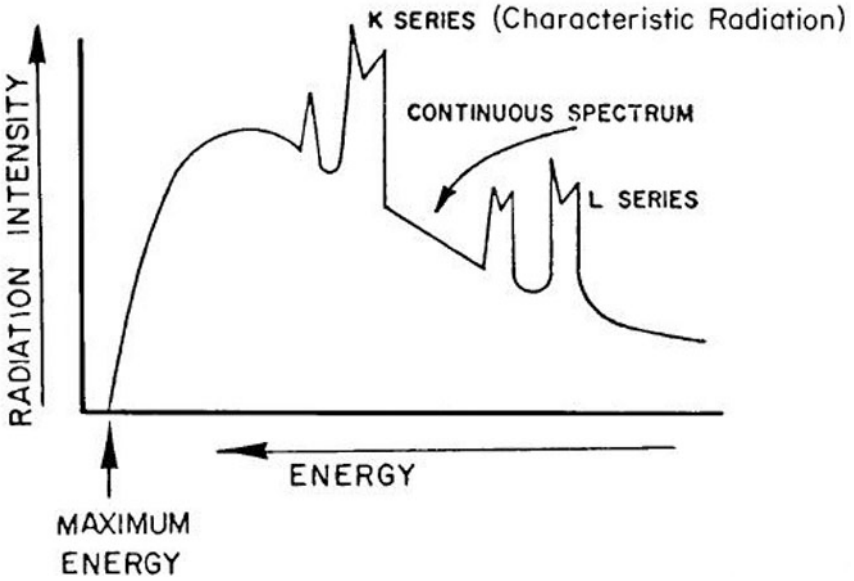


Figure 1–3. X-ray spectrum.

As energy levels increase, electrons are dislodged from the various orbits with the K-series being the closest to the nucleus (fig. 1–4).

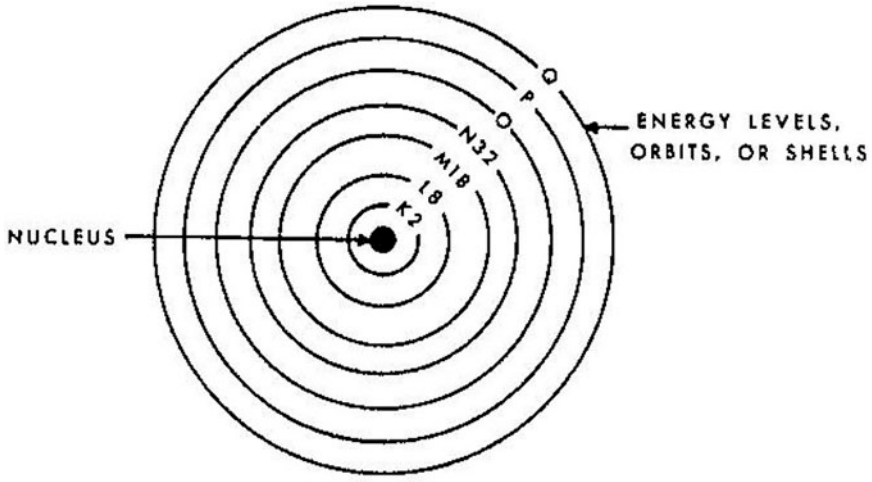


Figure 1–4. Electron shells.

Absorption mechanisms

Absorption of gamma or X-radiation by materials requires detailed consideration. These radiation photons are electromagnetic waves of energy have no mass or electrical charge, and can penetrate the densest of materials. These waves are dimensionally so short they have wavelengths less than the electron spacing in the atoms and therefore have the capability of traveling through the atomic structure. The absorption of the photons is a result of the photon either striking an electron or entering the nuclear field of the atom. The energy lost by a radiation beam as it travels through matter is due to interactions of the photons with matter. In these interactions, the energy of the photon transfers principally through three processes:

1. Photoelectric absorption.
2. Compton effect.
3. Pair production.

Photoelectric absorption

When photons have energies of 100 kiloelectron-volt (keV) or less, they are readily absorbed by the electrons in the orbital shells of the atoms of the absorber. The energy of the photon transfers to the electron, often dislodging it from its orbit, and the remainder of the photon's energy is used to give the electron kinetic energy. These ejected electrons are called *photoelectrons* and the process is known as *photoelectric absorption*. The moving electrons lose their energy through coulombic interactions and can produce ion pairs. This is shown in figure 1–5.

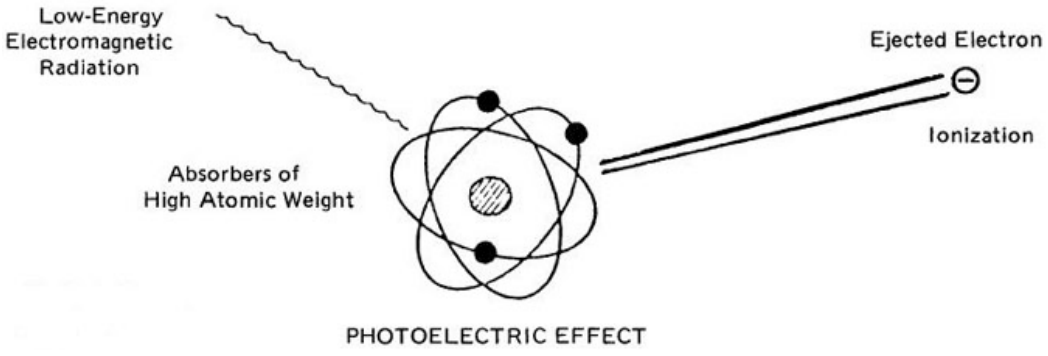


Figure 1–5. Photoelectric absorption.

During this process, the radiation photon has given up all of its energy and no longer exists. This mechanism of absorption has a very high probability for very low energy radiation and accounts for the major absorption of radiation when photon energies are 100 keV and less.

Compton effect (scattering)

When the photon energies are in the 100 keV to 10 miloelectron-volt (MeV) range, not all of the energy is required to dislodge an orbital electron and accelerate it by induction of kinetic energy. In this case, photoabsorption can occur; however, the photon continues at some different path and at a reduced energy level, due to the loss of energy to the electron. By this mechanism of absorption, the path of the photon alters, and its energy decreases. This mechanism of absorption is referred to as Compton effect or Compton scattering. Compton effect accounts for the major absorption of radiation in the energy range between 100 keV and 10 MeV. This is shown in figure 1–6.

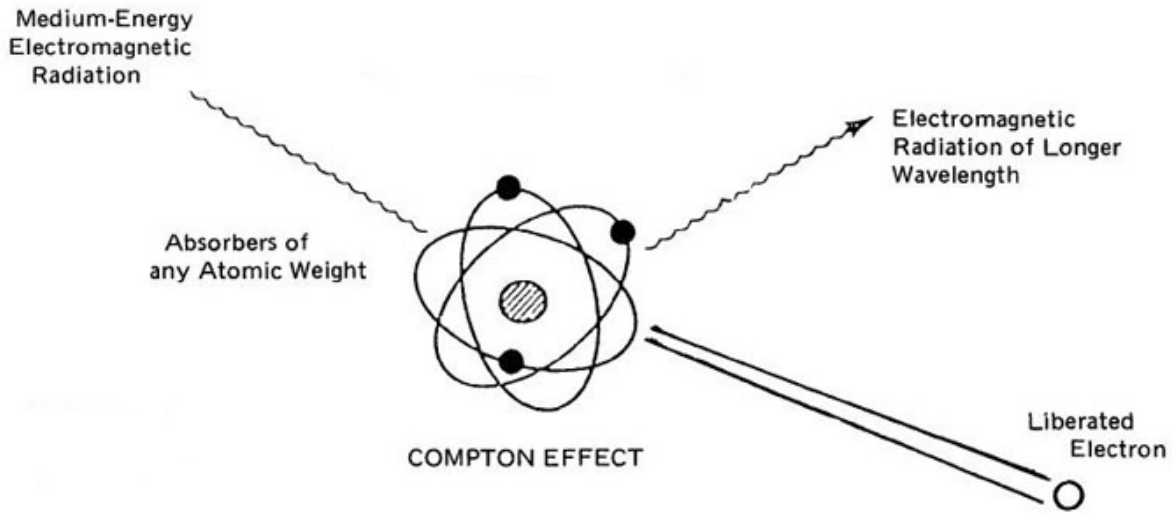


Figure 1–6. Compton effect.

Pair production

When photon energies exceed 1.02 MeV, their energy can cause pair production. In this event, the nuclear field surrounding the nucleus of the atom disintegrates the high-energy photon. The energy of the photon converts into an electron-positron pair. The positron has the same mass as an electron and is of equal, but opposite charge. In this absorption mode, the energy of the massless photon converts to mass. Einstein's equation states energy (measured in volts) equals mass times the square of the velocity of light ($E = mc^2$). If this equation is used, the mass of an electron is equivalent in energy to a 0.51 MeV photon. This explains the requirements for a photon to have energy of at least 1.02 MeV before pair production can occur. Additional energy above the 1.02 MeV causes the pair of particles to have kinetic energy or velocity. The positron may cause ionization or it may combine with an electron, causing annihilation and emission of two gamma photons of 0.51 MeV per photon. These lower energy photons may subsequently interact by either the photoelectric or the Compton effect absorption modes. This is shown in figure 1–7.

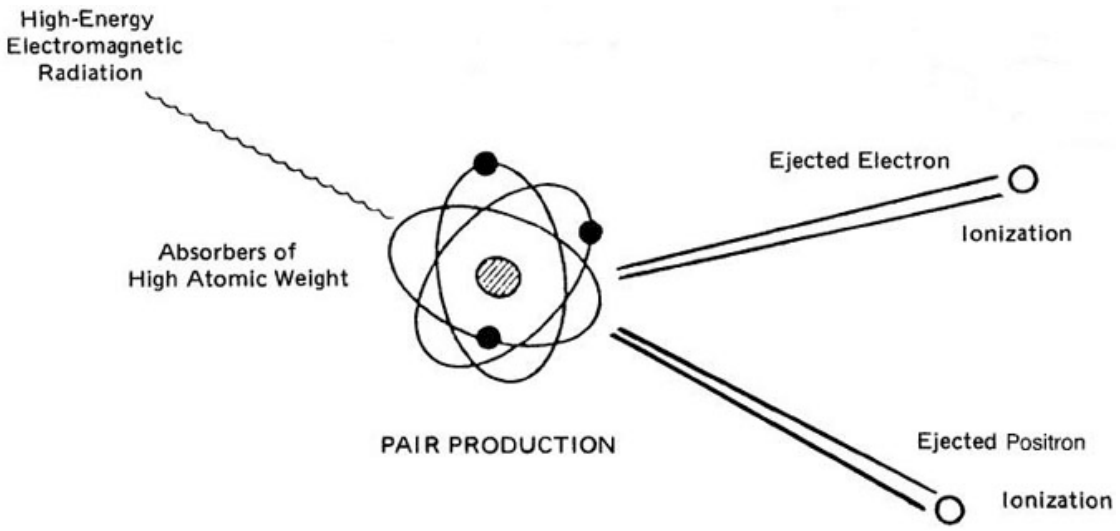


Figure 1–7. Pair production.

Material contrast

The most important variable that the radiographer can control in industrial X-ray inspection is the kilovoltage. The amount of radiation absorbed by the part depends on the atomic number, density, and thickness of the material. The radiographer cannot change these factors, but can change the energy of radiation.

In industrial radiographic applications, the difference in thickness (often due to discontinuities) is the actual parameter from which interpretation is made; therefore, the greater the change in the radiation transmitted due to a particular change in material thickness, the more obvious is the thickness change revealed in the final image. This radiation difference due to material thickness change is called *material contrast*. The material contrast is a function of the absorption characteristics of the part inspected and the radiation energy level. When measurements are made and a numerical value has been established, it is called the *material contrast factor*.

602. Generating X-rays

X-ray generators are fabricated electronic devices designed to produce X-radiation. X-ray generators are commercially obtained and the equipment is either portable or stationary. Portable X-ray generators are for inspection of test objects either impossible or very difficult to transport or safely inspect. Stationary X-ray generators are used in shielded facilities where the objects to be tested can be readily transported to the X-ray equipment.

Now we will look at the generation of X-rays and how they are produced in a radiation tube head.

Radiation produced by a tube head

When the electrons bombard a target, they come to an abrupt halt. Unfortunately, most of the electrons' kinetic energy converts into heat, which dissipates by the target material. Only a small percentage of the energy available in the electron beam converts into X-ray photons, which can have energies ranging from zero to a maximum determined by the original kinetic energy of the electrons and by how rapidly the electrons decelerate.

X-rays are produced regardless of the material bombarded, whether it is a solid, liquid, or gas. In the X-ray tube, a solid material is used for the target. For efficient X-ray production, the target material must have a high atomic number.

Radiation energy

Radiation generated by an X-ray tube contains various energies and therefore referred to as *white radiation*. The X-rays are a continuous spectrum, and the beam is selectively attenuated as it passes through an absorber. The low energy radiation is highly absorbed by the first few layers of the absorber medium, and the spectral distribution is altered by this.

The radiation energy chosen must be compatible with the absorption rate of the subject. For low absorbing subjects, low-energy radiation produces radiographic images with good contrast. Conversely, for inspection of thick, highly absorbing subjects, the radiation must be capable of sufficient penetration to produce an image within a reasonable period. To achieve a high-contrast, the subject should absorb 96–99 percent of the incident radiation.

Radiation quantity

An alteration in the filament current, measured in mA, produces a direct change in the quantity of radiation emitted, but has no effect upon the radiation energy. Additionally, mA and time are usually interchangeable. That is, the product of mA and time is constant for the same photographic effect. This is known as the *reciprocity law*. This law is valid for X- and gamma ray exposures, with or without lead screens, and over the range of radiation intensities and exposure times used in industrial radiography.

For very low or high intensities, the reciprocity law fails because of changes in the efficiency of the response of the film emulsion to unit radiation. If high production radiography were required, a source with a high radiation output would be economical. Usually, the high-output equipment requires a source with a comparatively large focal spot; therefore, rate of radiation output often directly relates to focal spot size. The resulting unsharpness due to geometry can become detrimental to image quality.

Properties of an X-ray tube

The X-ray tube houses the cathode and the anode under a high vacuum. Traditionally, this tube has been a glass envelope with a reduced thickness at the window (the point where the X-rays exit) to reduce X-ray absorption. The high vacuum reduces the problem of the electrons colliding with, and being absorbed by, molecules of air and provides electrical insulation between the cathode and anode. In tube head designs, a beryllium window is incorporated to further reduce absorption of the X-ray beam, particularly the lower energies. The following table explains each component of an X-ray tube head as illustrated in figure 1–8.

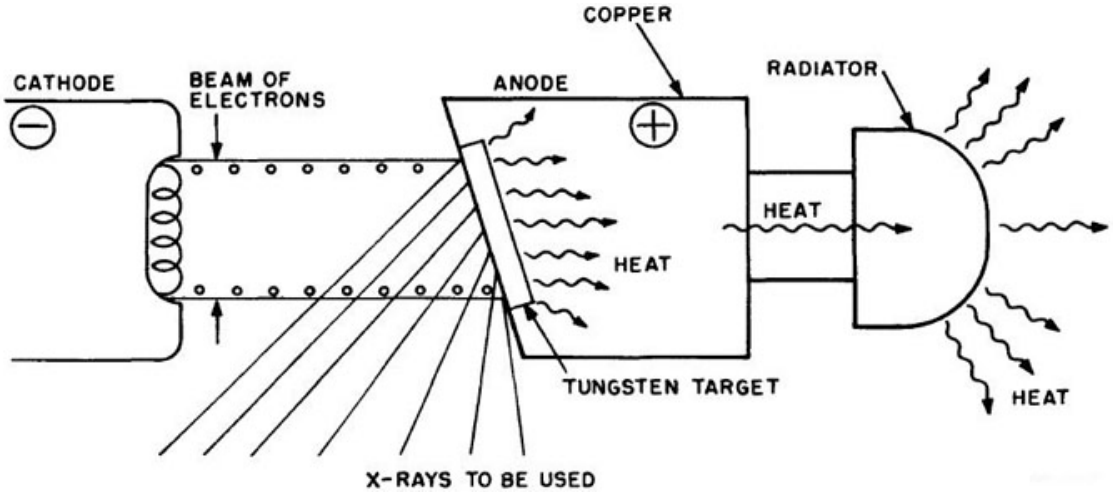


Figure 1–8. Components of an X-ray tube.

Components of a Tube Head	
Name	**Description**
Glass envelope	It is important this movement of electrons conduct a good vacuum; otherwise, the electrons collide with air molecules and lose energy through ionization and scattering. A glass envelope with a strong vacuum is needed to ensure this happens.
Cathode	A filament of thoriated tungsten wire that emits electrons when heated to a high temperature. Since the filament gives off electrons in all directions, some means must be used to focus them on a target. The filament is centered within a “focusing cup” within the cathode structure and serves to focus the electron beam like a light is focused by a flashlight reflector.
Focusing cup	A negatively charged focusing cup is used to direct the stream of electrons toward the anode (target).
Anode	There must be a target for the electron beam to strike before X-rays can produce. In radiographic tubes, the target material is generally made of tungsten. The choice of tungsten as a target for industrial radiography is based on four material characteristics: • High atomic number. • High melting point. • High thermal conductivity. • Low vapor pressure.
Focal spot	The focal spot is the area of the target bombarded by the electrons from the cathode. The focal spot is determined by the shape and size of the focusing cup of the cathode along with the length and diameter of the filament. The size of the focal spot has a very important effect upon the quality of the X-ray image. The smaller the focal spot, the better the detail of the image. The electron stream from the filament is focused as a narrow rectangle on the anode target. The typical target face is made at an angle of about 20 degrees to the cathode. When the rectangular focal spot is viewed from below, in the position of the film, it appears to be more like a small square. Thus, effective area of the focal spot is only a fraction of its actual area (fig. 1–9).

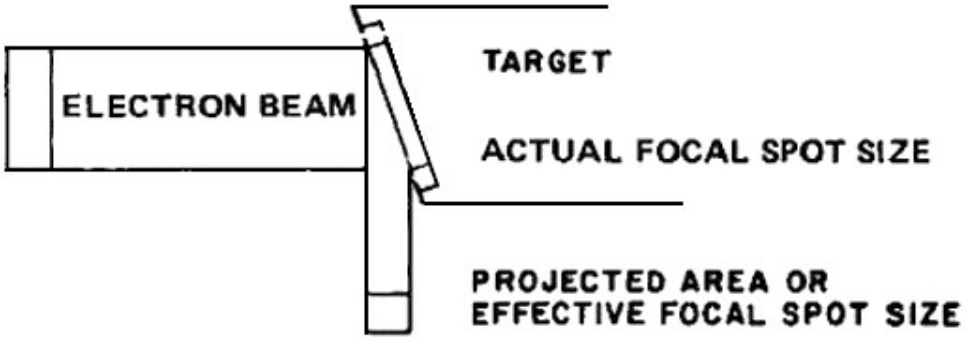


Figure 1–9. Focal spot size.

Inherent filtration

Inherent filtration is the reduction in radiation energy due to absorption by the material necessary to provide the vacuum, the electrical insulation, and mechanical rigidity of the X-ray tube. In construction of some glass X-ray tubes, the port reduces in thickness to provide less inherent filtration. In some other tubes, the port is made of beryllium, which is a light metal of low atomic number and low X-ray absorption. Because of tremendous pressures exerted by the atmosphere on large evacuated containers, X-ray ports must be designed with sufficient thickness to withstand these pressures without implosion.

Cooling requirements

Only a very small amount of energy in an electron beam converts into X-radiation. Most of the other electron beam energy converts into heat. This heat in the X-ray tube target material is one of the limiting factors in the capabilities of the X-ray tube. Thus, it is necessary to remove the heat from the target as rapidly as possible using various techniques.

- In some instances, the target is comparatively thin and requires a suitable oil to be circulated on the back surface.
- In other cases (where the anode is being operated at ground potential), use a water-antifreeze mixture to conduct heat away from the target.
- Most X-ray targets are mounted in copper, which is used as a heat sink.
- Some enclosed tubes depend upon the heat storage capacity of the anode structure to absorb the heat generated during X-ray exposure. This heat dissipates after the unit is turned off. These units usually have a duty cycle limiting the operation. This duty cycle is dependent upon the heat storage capacity of the anode structure and the rate of heat dissipation by thermal radiation.

The rate of heat removal from the X-ray target is the primary limiting factor in X-ray tube operation.

Absorption of radiation

A material discontinuity, such as a void or change in configuration (like in figure 1–10), changes the effective thickness of a material which can change the degree of radiation absorption. Since all radiation not absorbed or scattered within a material is transmitted, the amount of transmitted radiation varies with localized changes in effective material thickness.

If a discontinuity were a foreign material inclusion, it would cause a change in the apparent composition of the material and again result in a change in the transmitted radiation intensity. The degree of this change would be dependent on the relative effects of the test object and the included material on the incident radiation.

Some voids are difficult to detect because they present a very slight change in material thickness to a beam of radiation. An important example of this type of defect is a crack, which represents a tear or rupture within a homogeneous material. If a crack is open, like the one represented in figure 1–11a, it will appear to the radiation beam as a significant change in effective material thickness and is then readily detected. However, if a crack is under compression and is very tight, as illustrated in figure 1–11b, then its detection may become very difficult, if not impossible.

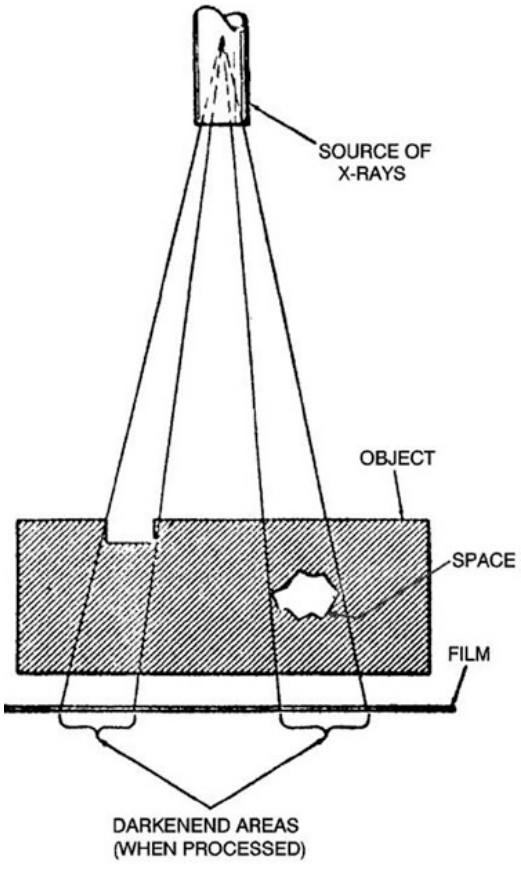


Figure 1–10. Diagram of radiographic exposure.

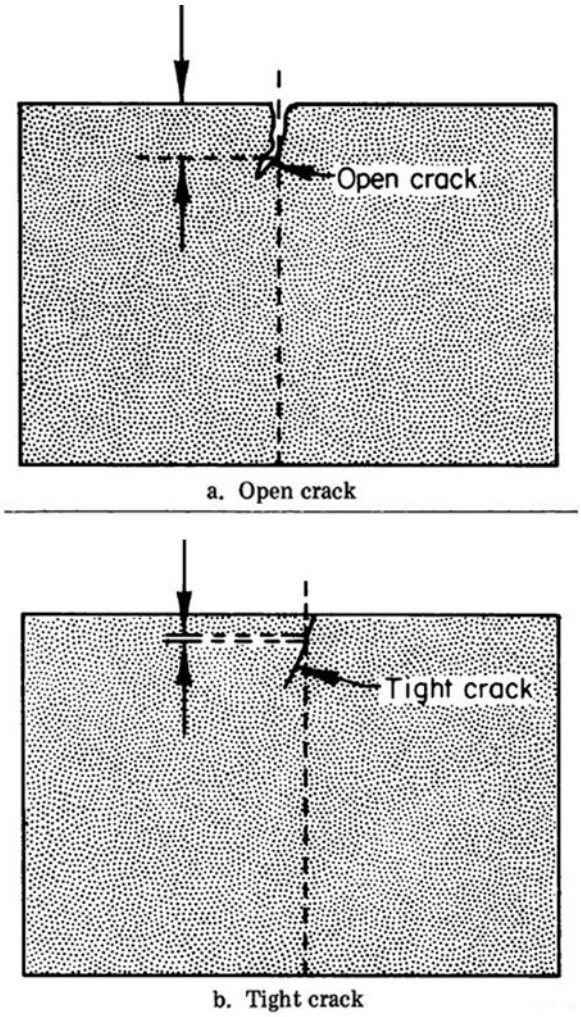


Figure 1–11. Effect of change in thickness cracks.

603. Radiographic film

Films are used as a recording medium because their emulsions are sensitive to the quantity and the energy of electromagnetic radiation over a wide spectral range. In the photographic process, the electromagnetic radiation of the visible spectrum is focused with a lens on the film surface to record the variations of light intensities and form an image. In radiographic applications, the radiation is of such high energies they cannot be focused by a lens. In radiography, recording the variations in radiation quantities caused by absorption and scattering by the test specimen forms a shadowgraph of the test object. After final processing, film exposed with X-rays is called a *radiograph*; film exposed by using a radioisotope might be called a *gammagraph*. Films are an excellent recording medium with a very high signal-to-noise ratio and high amplification. This section describes how films work and responds to radiation.

Structure on industrial film

Industrial X-ray film consists of an emulsion and a blue tinted base of polyester. Film is made up of three different sections.

- Polyester base.
- Emulsion.
- Outer protective layer.

The schematic structure of radiographic films is shown in figure 1–12.

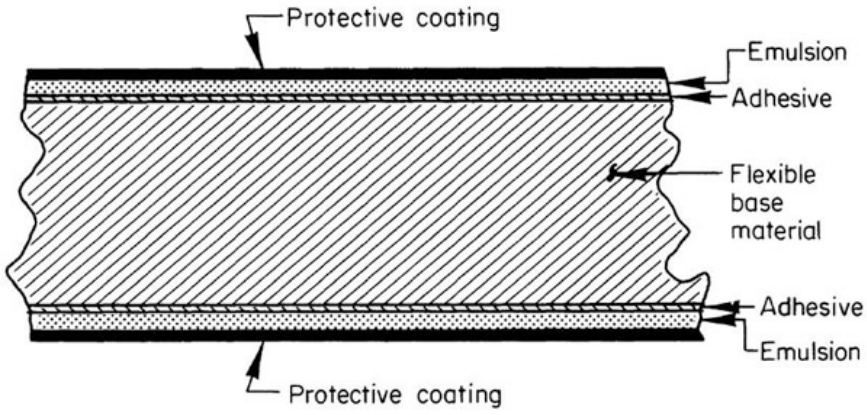


Figure 1–12. Cross section of X-ray film.

Polyester base

Most modern films have a polyester base which is either transparent or has a slightly blue tint. This is very durable, does not absorb water or processing chemicals, is dimensionally stable, dries easily, and will not support combustion. Polyester base materials have advantages because they provide flatness and great strength.

Emulsion

The emulsion consists of silver halide crystals as photosensitive material, plus additives and gelatin. Silver halides form an image when exposed by X-rays, gamma rays, secondary electrons, or fluorescent light. The emulsion in films used for general photography is coated only on one side of the base, whereas it is coated on both sides of most industrial X-ray films.

The absorption of high energy X-rays or gamma rays is increased by using two emulsion layers so the photosensitive silver compound is utilized more effectively for the absorption of radiation and electrons. Furthermore, the two emulsion layers help to increase contrast and image density of radiographs.

Outer protective layer

The emulsion on an outer protective layer may be coated on one or both sides of the base in layers, which can be very thin. Each outer protective layer is approximately .001 inch thick.

Latent image

The latent image forms by interactions of the electromagnetic radiation with the silver bromide crystals. When solid silver bromide is formed in the manufacture of film, the silver atoms give up an orbital electron to a bromine atom.

The silver bromide crystal is a cubical array of silver and bromine ions. The cubical crystalline structure of the silver bromide crystal is not perfect; if it were, the photographic process could not exist. There are also foreign molecules or distortions within the crystal, all of which form latent image sites.

The theory in the formation of latent images is a two-step process. The electromagnetic radiation ejects an electron from the negatively charged bromine ion in the crystalline structure, thus converting the ion into a bromine atom. The free electron can travel within the crystal to a dislocation or other latent image site where it is trapped, establishing a negative electrical charge at that point. This negative electrical charge attracts one of the positively charged interstitial silver ions to the latent image site. When the silver ion reaches the image site, the negative electron counteracts its positive charge and it becomes neutralized and exists as a silver atom. The latent image site is now electrically neutral.

Development of film

The developing agent selectively reduces those crystals containing latent images into black metallic silver, but has a much smaller effect on those crystals not exposed. The metallic silver is opaque and forms the radiographic image.

The purpose of the developing solution or developer is threefold, as explained in the following table.

Film Development Steps	
Step	**Description**
Step 1	First, it blackens those parts of the emulsion exposed (e.g., when a crystal of the film's silver bromide emulsion has been exposed to X-ray radiation and is put into a developing solution, the developer takes the bromide away from the silver and leaves black metallic silver in the gelatin). Where full exposure has occurred, a maximum number of crystals are affected and almost all of them are reduced by the developing solution to metallic silver.
Step 2	Second, it produces various shades of gray where the film has been only partially exposed. These grays are the result of partial removal of bromide. The concentration of black metallic silver per unit area of the film is dependent upon the amount of exposure received, and determines the factor known as film density. The image of the object radiographed consists of varying densities spread over the film, corresponding to the varying amounts of exposure received by the film.
Step 3	Third, is its effect on those parts of the film, which have received no exposure. Since no crystals are affected, the developer should leave these parts unchanged. Thus, a developing solution removes the bromide from the film emulsion where exposure has occurred, but should not produce effects on unexposed areas of the film.

Image quality

Microscopic variations in the response of film to the incident radiation produce effects of considerable practical significance. The number of sites where the silver atoms can respond to the radiation vary in location throughout the emulsion and are inversely proportional to the size of the silver bromide grains. Thus, after exposure to radiation, the density of the image will vary. The larger the number of sites activated by radiation, the larger the number of silver atoms per unit area; as a result, the smaller the density variations, statistically. The following are two practical factors:

- Graininess.
- Signal-to-noise ratio.

Graininess

The graininess of the film is the visual impression of non-uniformity of density in a radiographic image. Graininess increases with increasing film speed and with increasing energy of the radiation. Apart from the visual appearance of graininess, the effect may be subjected to physical measurements. This measured property is referred to as *granularity*.

Signal-to-noise ratio

The accidental variation in image density makes it more difficult to identify the deliberate variation in image density resulting from the use of film. The relationship between the two density variations is known as the signal-to-noise ratio. The ratio for threshold visibility of detail shall be at least five.

Image density

In photographic usage, density is a measure of the degree of blackening of the processed film caused by exposure to radiation. A typical density used in practical radiography is 2.0 and represents 1 percent transmittance.

Density is measured in terms of visible light transmission with test strips. The accepted scale of film density measurement is the logarithm of the reciprocal of the fraction of incident light to transmitted light as given by the following equation:

Formula and Variables
$D = \log \frac{I_0}{I_t}$ $\frac{T_2}{(D_2)^2} = \frac{T_1}{(D_1)^2} T_2 = T_1 \left(\frac{D_2}{D_1}\right)^2$
Where the following variables are represented: • D = Film image density. • I_0 = Original light intensity falling upon one surface of film. • I_t = Light intensity transmitted through the film.

For example, an increase in the amount of blackening from one area of a particular film to another, reduces the proportion of the incident light transmitted from 50–25 percent would cause the film density to change from 0.3–0.6.

Image distortion

For the best radiograph, the source beam should be aligned perpendicular to the part and the film located on the same plane as the part. This positioning projects the image of the part upon the film in the true shape of the object with minimal distortion. Any deviation from these relative positions of source, object, and film will produce an image with some degree of distortion. This alignment is particularly critical for crack detection.

Since their shape usually identifies discontinuities revealed in radiographic images, images free of distortion are very important in interpretation. Where complex structures are encountered in aircraft inspection, it is often impossible to locate the various parts in the most desirable positions, and sometimes an inspection may be facilitated by planned distortions. Interpretation of distorted images is not impossible. The film reader must mentally visualize the geometry of the object under evaluation and understand how the exposure would project the distorted image onto the film. This ability requires practice and experience.

Image unsharpness

This term implies that there will always be unsharpness of the image to some degree, and perfect image sharpness is unattainable. The amount of geometric image unsharpness is due to size of the source of radiation and relative distances, as shown in figure 1–13. The distance on the film over which an edge is spread is known as the geometrical unsharpness.

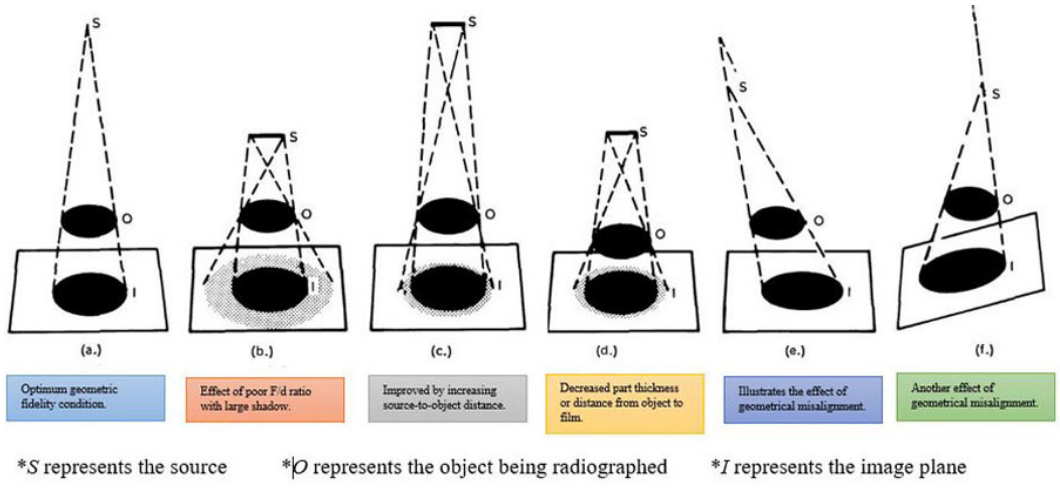


Figure 1–13. Image distortions.

NOTE: F/D (fig. 1–13) means focal spot (F) and distance (D).

Characteristic curve

The characteristic curve is the response of a type of film to radiation of a particular energy. It is obtained by plotting the correlation between the film-image density against the logarithm of relative exposure. Since density is a logarithm, log-log scales are used for the plot.

At low exposures, a large change in exposure is needed to produce a significant change in density (fig. 1–14). As relative exposure increases, the film emulsion becomes more sensitive and the same exposure change produces a greater density difference. The gradient (slope) of the curve increases with increasing exposure. At very high values, the gradient may start to decrease and the film becomes less sensitive. The term used to refer to the gradient of the characteristic curve is *film contrast*.

A characteristic curve provides information about speed, contrast, and fog of X-ray film. It is significant because it demonstrates that dense films are more sensitive to small variations in exposure than light film; therefore, the dense film is better to show small changes in subject contrast due to discontinuities and geometric changes in parts. Characteristic curves can also calculate exposure changes needed to optimize a technique when altering film type or desired density.

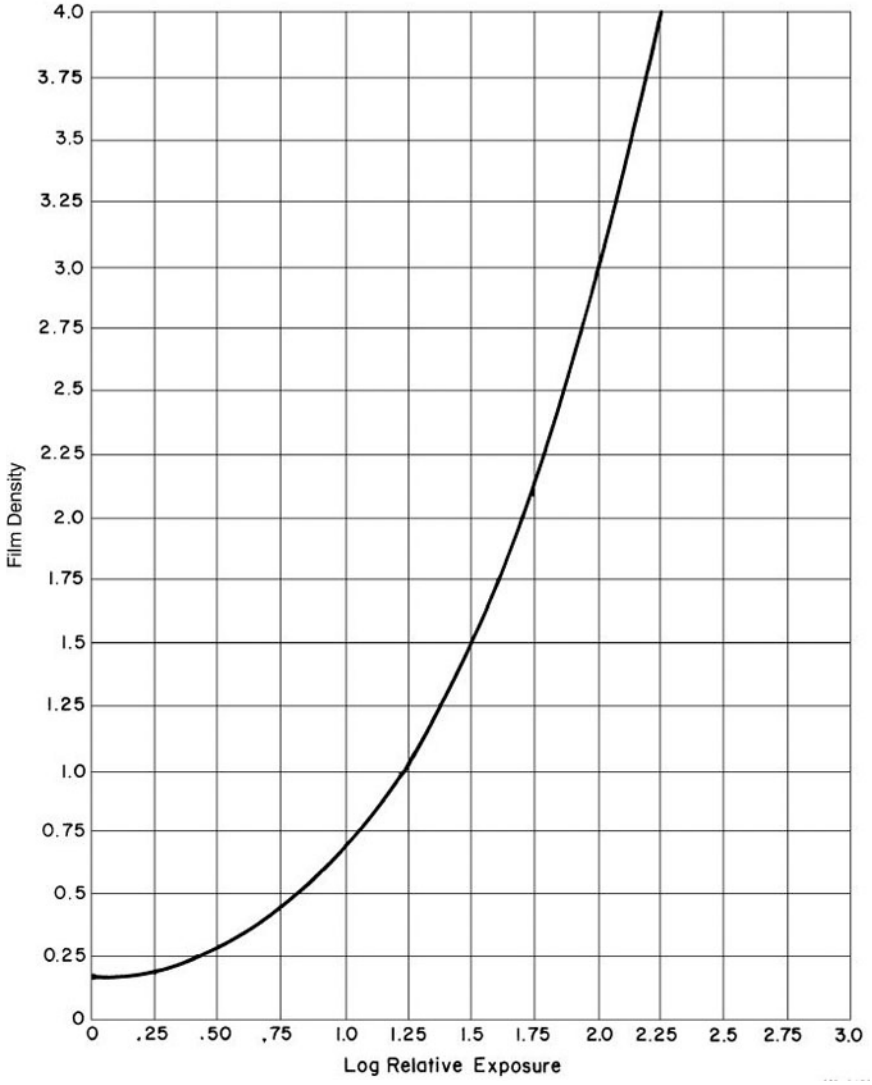


Figure 1–14. Characteristic curve.

Classes of radiographic film

Film varies in signal-to-noise ratio, speed of response to radiation, and graininess. It is most appropriate to classify X-ray film in relation to the signal-to-noise ratios. Very fine-grain films with a very high signal-to-noise ratio require comparatively large quantities of radiation for exposure and produce images with excellent resolution of detail. In the choice of a particular film, a trade-off must be made between resolution and speed of exposure. The criticality of an inspection will determine this tradeoff. Commonly used X-ray film classes are listed in the following table.

Film Classes	
Class Type	**Signal-to-noise ratio**
Class 1	Highest. **NOTE:** These are high detail resolution films and should be employed when the most sensitive radiograph is desired.
Class 2	High.
Class 3	Moderate.
Class 4	Low.

Figure 1–15 illustrates a bar chart reflecting the relationships of signal-to-noise ratio rather than film speed. Each manufacturer has a particular designation for films. Small variations may be noted in film speed and contrast of the films made by the different manufacturers within a particular class.

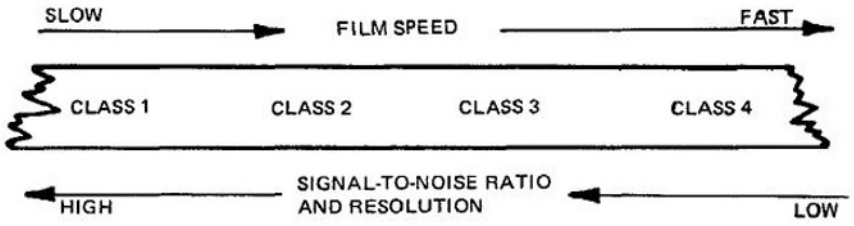


Figure 1–15. Film bar chart.

Film speed

Film speed is a factor in determining the amount of radiation a film must receive to obtain a given density. Generally, film speed varies with film grain size. The larger grain film is faster and the smaller grain film is slower. While film speed is sometimes an important consideration for economy, normally the prime consideration is resolution of the details. High-speed films (e.g., films with low signal-to-noise ratios), should only be used when they are capable of meeting the resolution requirements of the inspection. Where high-detail resolution is required, the slower, higher signal-to noise ratio films need to be used without exception.

Film contrast

Film contrast is a measure of the difference in film density due to exposure to different amounts of radiation. When exposed beneath a step wedge, a film with low contrast would show only minor changes in image density between one-step and another. A high-contrast film, exposed under identical conditions, would show sharp graduated changes in image density between steps.

The efficiency with which the emulsion responds to an increment in exposure varies with the absolute value of the exposure. If a radiograph has high contrast, small differences in light transmission are high and readily discerned by the eye. Thus, the image will reveal small discontinuities in the subject. As a result, a dense image on the film makes small discontinuities on the specimen more visible.

Image densities of 2.0 or more are recommended for high sensitivity to discontinuities in critical areas of parts. Film contrast is distinguished carefully from subject contrast (a flat sheet specimen will give negligible contrast with any film). Subject contrast is affected by X-ray kilovoltage or gamma-ray characteristics. In summary, the overall image contrast with any given specimen will depend upon the following:

- Kilovoltage of the X-ray beam or characteristics of gamma radiation.
- Type of screens used.
- Image density.
- Processing conditions.
- Film contrast.

Film latitude

The film latitude is the reverse of film contrast, the higher the contrast, the smaller the latitude; the lower the contrast, the greater the latitude. Therefore, latitude is the range of radiation intensities a film is capable of recording. Latitude is also the term used to indicate the range of material thicknesses that can be visualized in the final image. Often in the radiography of castings or circular rods, where it is necessary to visualize a large range of thicknesses, wide latitude is desirable.

Radiographic contrast

Contrast in a radiograph is the difference in the resultant density, produced for a given change of X-ray absorption. This affects many factors, some of which must be compromised; thus, operator judgment becomes important. The choice of X-ray equipment is one of the most important considerations. The shorter the effective wavelength of X-rays, the greater the penetrating power. Also, consider the higher the kilovoltage used, the shorter the effective wavelength of the generated radiation. As a result, the higher the X-ray tube voltage, the greater the penetrating power of X-rays generated.

Subject contrast

The radiographer should consider subject or object contrast. At X-ray voltages from 30 kV–5 MeV, aluminum has a lower absorption rate per unit thickness than steel; therefore, it takes a greater thickness change of aluminum to cause the same given change you would notice with steel. Hence, aluminum has less object contrast than steel.

During the radiographic process, differences in object contrast are partially compensated because of lower energy radiation (longer wavelength) and can be used to examine a given thickness of aluminum compared to the same thickness of steel. Object contrast is a somewhat limiting factor in light metals and material with both low density and atomic number.

To improve radiographic contrast and sensitivity we must look at two quality indicators, contrast and detail sensitivity.

Contrast sensitivity

A *penetrameter* is a device employed to obtain evidence on a radiograph that the technique used was satisfactory. It is not intended for judging the size of discontinuities nor for establishing acceptance limits for materials or products. A picture of a penetrameter is shown in figure 1–16 and discussed further in the next section.

Figure 1–16. Penetrameter.

The penetrameter material thickness is added to the thickness of the test object. This increase in thickness causes more radiation to be absorbed, and a penetrameter outline that viewed on the final image has a less dense area. This change in film density due to the additional radiation absorption is a measure of the image contrast.

Detail sensitivity

Detail sensitivity of the radiographic image is revealed by the capability of visualizing the penetrameter holes. When the two percent penetrameter is used on the test object, it usually requires the 2T (thickness) penetrameter hole that is visible on the radiograph. The thickness of the penetrameter is a known percent of the test object thickness. If the 2T hole can be seen, the image is said to have two percent radiographic sensitivity. The film reader can then assume the capability of seeing any discontinuity that represents a two percent dimensional change of the object total thickness. The 1T hole *does not* represent one percent image sensitivity because the thickness of the penetrameter has not been reduced to one percent of the test object thickness. Calculations reveal visualization of the 1T hole in a two percent penetrameter actually reveals 1.4 percent image sensitivity. Resolution of the holes in the penetrameter is a combined measure of image sharpness and contrast, and is thus a measure of the image quality. However, note the regular and expected outline of the holes is more readily seen than a crack line.

Do not place the penetrameter over an area of interest because the penetrameter or the lead identification numbers could hide discontinuities. In some cases, the penetrameter cannot be placed on the actual test specimen. In these instances, it is acceptable to place the penetrameter on a separate block of the same material and of the same thickness as the specimen.

Exposure and images

The exposure factor is a quantity that combines mA with time and distance. Radiographic techniques are sometimes given in terms of kV and exposure factor, or radioactive isotope and exposure factor.

The geometrical setup used to produce a radiographic image is an important factor that contributes to final image quality. Geometrical relationships affect the image sharpness and help control image distortion.

Film placement

After the film and film holder have been chosen, consider placement of film in relation to the test part. For small parts, this could be a simple matter of laying the part on the film. With complex structures involved, film positioning is not quite as simple. The following rules can be of assistance in such inspection situations:

- Always position the film as close as possible to the area of interest.
- Attempt to locate the film so the plane of the area of interest and the film are perpendicular to the radiation beam. This is to prevent distortion in the final image.

NOTE: The part undergoing inspection will always be between the source and the film. This is demonstrated in figure 1–17.

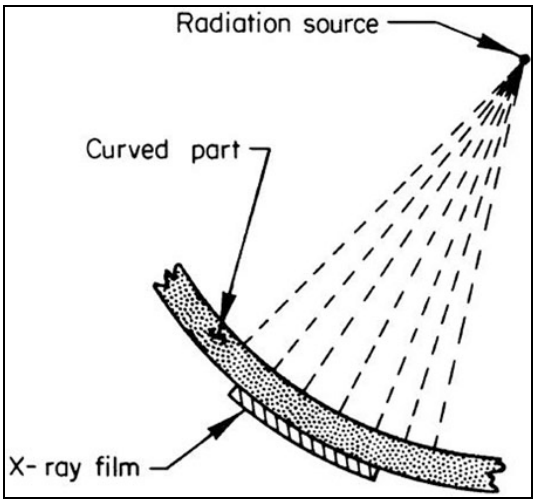


Figure 1–17. Film placement with a curved part.

Focal spot size

The ideal focal spot would have a pinpoint source of radiation. The actual size of the focal spot is determined by the electron bombardment pattern on the target. The minimum size of this area is limited by the melting point of the target material and the concentration of the bombarding electrons per unit area. To reduce the apparent size, the X-ray target is positioned at a small angle; from the position of the X-ray film, this area appears as the projection of this *focal spot* on the film plane. Focal spot sizes must increase with an increasing kV rating to prevent melting of the target material. Radiation is emitted from the entire area of the effective focal spot. It projects at different angles through the test object and spreads the image of a sharp edge over a finite distance on the film. Refer back to figure 1–13b to view examples of the formation of shadow projections.

Source-to-film distance

The sharpest image forms by having a source-to-film distance (SFD) so great that the radiation would be parallel at the film plane. However, since radiation intensity or quantity is diminished in relationship to the inverse square of the distance, the radiation quantity available to expose the film would be very small, and exposure times would become impractical. Due to this, consider economics and practicability when producing a radiographic image. It is recommended the longest practical SFD be used for critical exposures to improve image sharpness.

If the SFD is changed, a formula can be used to correct the exposure, measured in milliamperes seconds (MAS). Because an increase in distance causes a decrease in beam intensity, only the intensity is changed. The kilovoltage *should not* be changed when correcting for SFD changes, as presented in the following equation.

Formula and Variables
$\frac{T_2}{(D_2)^2} = \frac{T_1}{(D_1)^2} \qquad T_2 = T_1\left(\frac{D_2}{D_1}\right)^2$
Where the following variables are represented:
T_1 = Original exposure (MAS).
T_2 = New exposure (MAS).
D_1 = Original distance (SFD).
D_2 = New distance (SFD).

Inverse square law

When the X-ray tube output is held constant, or when a particular radioactive source is used, the radiation intensity reaching the specimen is governed by the distance between the tube (source) and the specimen, varying inversely with the square of this distance. The following explanation is in terms of X-rays and visible light. Since X-rays conform to the laws of light, they diverge when they are emitted from the anode, and cover an increasing larger area with lessened intensity as they travel from their source. This principle is illustrated by figure 1–18.

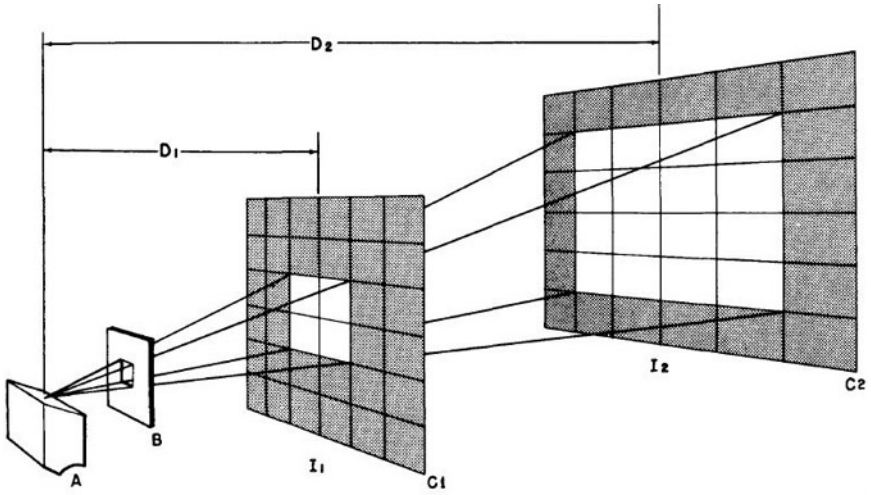


Figure 1–18. Inverse square law diagram.

Source/Defect orientation

Radiography is quite reliable when detecting cracks, provided certain stringent criterion is met. It is very easy to produce an apparently high quality radiograph that does not show an existing crack, or that has a crack indication so faint that it can barely be seen. The resolution of a crack depends upon total density change, and film/subject contrast.

Several factors produce density changes on X-ray film. The primary factor in the case of crack detection is the change in thickness or mass between the cracks and part inspected. A general rule is cracks must be at least two percent of the part's thickness if it is to produce a readable indication. This rule has variables that influence film density changes; in some cases, a change of as little as a one percent thickness will produce a visible indication. In other instances, a crack exceeding five percent of the part thickness may not produce a readable change in density. Regardless of total density change across an indication, if the contrast is not high, crack indications can be missed.

Scatter radiation

Whenever X-rays interact with material, absorption, scattering, or penetration will occur. In industrial radiography, scatter radiation can present a problem since it has the ability to expose the X-ray film without contributing to image information. Exposure of the film from scatter radiation is referred to as *fog*, and substantially reduces image contrast. Scatter radiation (fig. 1–19) can have the following three different sources:

- Reflected scatter.
- Back scatter.
- Forward scatter.

Reflected scatter

Reflected scatter comes from the area around any objects that might be in the radiation beam (e.g., the part under test, tube head stand, or a wall).

Back scatter

Back scatter is scatter radiation, which comes from objects behind the film (e.g., the floor).

Forward scatter

Forward scatter is the third source of scatter radiation, and is caused by the test object itself. This scatter can obliterate an object's edges on the film, referred to as *undercutting*.

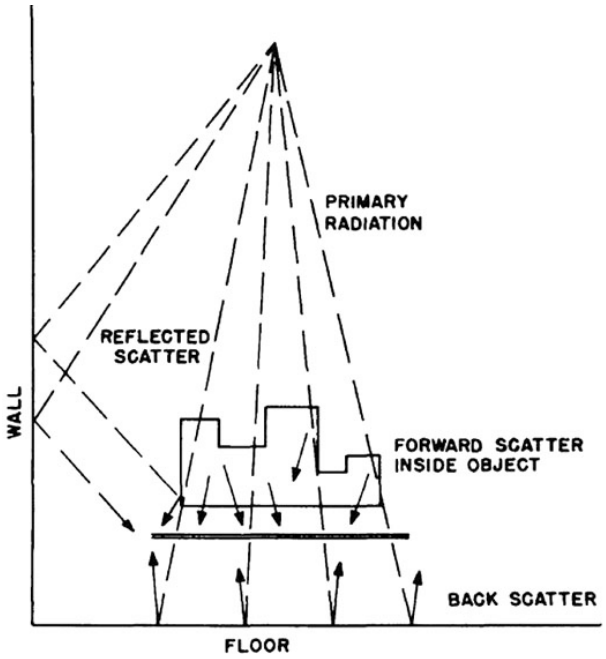


Figure 1–19. Sources of scatter radiation.

Scatter radiation and atomic numbers

The amount of scatter radiation affects the radiation energy and the atomic number of the element causing the scatter. The lower the atomic number of a material, the greater the degree of scatter radiation. Materials with a high atomic number will cause less scatter.

Reducing scatter radiation

Of several techniques that can be used to reduce scatter radiation, the following are just a few.

- Radiographic masks made of lead or other high absorbing materials will reduce the radiation area to only the area necessary for exposure.
- Lead in many different forms can be placed behind the X-ray film and test object to reduce excessive backscatter.
- Lead foil can be placed between the test object and the X-ray film to absorb some of the scatter radiation before the film is exposed.

NOTE: Filters in this position will reduce subject contrast.

Processing effects

Processing variables, especially development time, also affect density and film contrast through their effect upon the slope of the characteristic curve. Relative exposure needs to produce a standard density and increase as development time decreases.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

601. Understanding X-rays

1. What are high-energy photons that are produced when electrons make transitions from one atomic orbit to another?

2. What is referred to as quantum of light?

3. What three primary subatomic building blocks make up atoms of all elements?

4. What are atoms that have the same atomic number but different atomic masses called?

5. What must be done in order to excite an electron?

6. What is a negatively biased electrode of an X-ray tube from which the electrons emit and accelerate to the anode called?

7. What voltage force drives electrons from the cathode to the anode and has a unit of electromotive force equal to 1,000 volts?

8. What type of wavelengths do hard X-rays have?

9. Which series of characteristic radiation designates the radiation emitted from different electron orbits around the nucleus of the atom?

10. During which process will the radiation photon have given up all of its energy and will no longer exist?

11. During which process will a photon continue at a different path with reduced energy level, so that the path of the photon is altered and its energy decreases?

12. What are the energy requirements for a photon before pair production can occur?

13. The amount of radiation absorbed by the part being inspected depends on what three items?

602. Generating X-rays

1. What must a target material have for efficient X-ray production?

2. What houses the cathode and the anode under a high vacuum?

3. What is incorporated to further reduce absorption of the X-ray beam, particularly the lower energies?

4. What is negatively charged and is used to direct the stream of electrons toward the anode?

5. List the four material characteristics that the choice of a target for industrial radiography is based upon.

6. What is the reduction in radiation energy due to absorption by the material necessary to provide the vacuum, the electrical insulation, and mechanical rigidity of the X-ray tube?

7. What is used to conduct heat away from a target where the anode is being operated at ground potential?

603. Radiographic film

1. What is a film exposed by using a radioisotope called?

2. What does industrial X-ray film consist of?

3. What does the emulsion of a film consists of?

4. The absorption of high energy X-rays or gamma rays increase by using how many emulsion layers?

5. What selectively reduces crystals containing latent images into black metallic silver?

6. What is the second step in the developer solution process?

7. What will vary on an image after exposure to radiation?

8. What is the typical density used in practical radiography?

9. How should the source beam be aligned for the best radiograph?

10. What is the term used to refer to the gradient of the characteristic curve?

11. Very fine-grain films with a very high signal-to-noise ratio require comparatively large quantities of radiation for exposure and produce what type of images?

12. What does film speed vary with?

13. What is a measure of the difference in film density due to exposure to different amounts of radiation?

14. What is the range of radiation intensities a film is capable of recording?

15. What in a radiograph is the difference in the resultant density, produced for a given change of X-ray absorption?

16. What device is used to obtain evidence on a radiograph to verify that a technique was satisfactory?

17. How is the actual size of the focal spot determined with an active source of radiation?

18. What depends upon total density change, and film/subject contrast on a radiograph?

19. What is a general rule for readable indications when looking for cracks on X-ray film?

20. What type of radiation property results from the area surrounding objects within a radiation beam?

1–2. Radiographic Equipment and Safety

Even though there are several different types of X-ray generators used in NDI, only one is used in today's Air Force. In this section, we will discuss our career field's radiographic equipment, as well as its safety. For example, X-ray generators are not only safe to use, but must also protect against damage from inadvertent misuse. To accomplish this objective, X-ray equipment has protective devices that are used for both shielded and unshielded operations. Lastly, we will turn our attention to process control inspection.

604. Radiographic equipment

This lesson focuses primarily on radiographic equipment which is used to inspect a variety of materials. The vast majority of radiography concerns the testing of welds and aircraft parts. It is used to find cracks, water, foreign objects, and other types of defects.

Portable industrial X-ray unit

The Lorad portable X-ray unit is an air or water-cooled X-ray unit with an operating potential of up to 160 kV and a tube current of up to 5 mA. The tube head is insulated with sulfur hexafluoride gas, and pressurized to 50 pounds per square inch, gauge (psig) at 70° F. It is end grounded and has a 0.063-inch thick beryllium window (for beam filtration) located approximately 2 inches from the end of the tube. The system is equipped with a tube head, cooler, control unit and their connecting cables.

X-ray film

X-ray film is sensitive to the cosmic radiation that exists everywhere. This radiation will cause fogging. *Fog* is the darkening of the radiograph by scattered radiation, exposure to light, or pre-exposure to radiation. It can also be caused by overdevelopment or aging. Fog brings no information to the film and merely creates a high background that reduces contrast and image visibility. Very high-speed films are more sensitive to exposure, and are more susceptible to fogging than the slower emulsions.

Any films in containers sealed by the manufacturer and not opened will be stored with the film on edge to avoid container damage and possible film damage. Storage temperature should be between 40 and 75° F at a relative humidity range of 30–60 percent. When storage temperatures exceed 90° F for 30 days or more, a fog test should be performed with a limit of 0.30 density. Regardless of storage temperatures, stabilize films at room temperature before opening containers.

Film storage is important when it comes time to X-raying aircraft and their parts. We will now look at film expiration and identification.

Film expiration

The expiration date is marked on the film box at the time of manufacture. Order film in quantities so long-term storage is not necessary in order to avoid exceeding the expiration date. The inventory of film will be rotated so that older film is used first. Film that exceeds its "shelf life" date should *not* be put in salvage, the usability will be verified by:

1. Processing an unexposed sheet to determine clearing and fog level, the density should not exceed 0.30.
2. If the clearing and fog level are satisfactory, make a radiograph of a step-wedge and penetrameter to determine the sensitivity and contrast of the film in question, a 1.4 percent sensitivity (2–1T) is recommended.
3. If these limits are acceptable, extend the shelf life by six months and continue using the film.

Document the verification results and at the end of the extended period, verify the film using the aforementioned procedure.

Film identification

To properly apply information learned through radiography, the material inspected must also be accurately identified with respect to the object radiographed. In the absence of engineering direction in a specific weapons system technical order, the required method of film identification is lead numbers and letters, lead tape, or lead labels. The following items are required for identification:

- Aircraft tail numbers or part name.
- Serial number if not an aircraft item.
- Julian date.
- Inspection procedure.
- Shot number.
- Employee number of radiographer-in-charge.
- Organization.

When film size does not allow identification on the film, it will be placed in an acceptable film file pouch and the information typed or written legibly on the film file. When the X-ray film interpreter is not the radiographer-in-charge, the interpreter's employee number will be written on the X-ray film with an appropriate marker (e.g., grease pencil) or on the film pouch when film size is an issue.

Image quality indicators

Wide ranges of penetrameters are specified for use by various industries as image quality indicators (IQI). Wire penetrameters are particularly useful for weld inspection. A common form of penetrameters is a small plaque, fabricated of the same material radiographed. The thickness of the penetrameter is a known percent of the test object thickness. Holes in the penetrameter are of diameters 1T, 2T, and 4T, where the T equals penetrameter thickness. Thickness visualization of these holes can be related to the sensitivity of the radiographic image. A typical penetrameter breakdown is shown in figure 1–20.

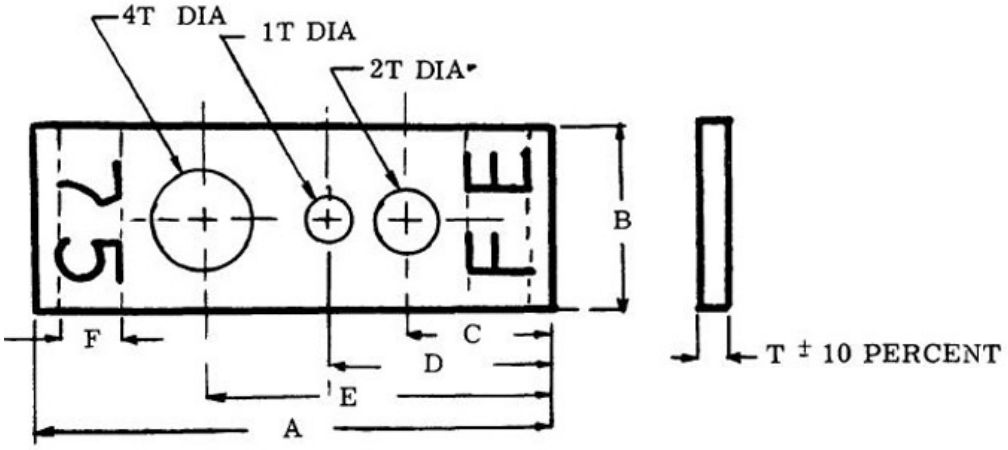


Figure 1–20. Penetrameter breakdown.

Screens

Radiation reaching film may be caused by the use of intensifying screens to reduce exposure time. The intensification factor for lead or calcium tungstate screens depends on the energy converted to either electrons or light to which the screen is sensitive. This factor varies with kV and type of film. Select the film that achieves the highest efficiency of energy conversion from the screens used.

The following table describes three types of screens used to intensify images.

Types of Screens	
Type	**Description**
Lead Screens	Certain materials emit electrons when struck by high energy X-rays or gamma rays; these electrons are called secondary electrons. X-ray film is not only sensitive to light, but to these secondary electrons. The material of choice is lead foil, usually 0.001 inch–0.040 inch thick, and bonded to a flexible support. Lead screens in direct contact with film have the following two effects: • *Intensify incident radiation* – incident radiation with energies above 88 keV eject photoelectrons from the atoms of lead. These photoelectrons act on the emulsion in the same way as the primary radiation beam. • *Improve clarity* – They improve clarity by absorbing scattered radiation of longer wavelengths.
Fluorescent Screens	Due to visible light dispersion, fluorescent screens render images less sharp than those obtained with direct exposure. Their use is normally limited to those situations where exposure speed is more important than image quality, or where the radiation quantity available is inadequate to perform the task. Fluorescent screens consist of a phosphor like calcium tungstate coated on a flexible support. Whenever there is a need to perform a radiographic inspection using a combination of screens and film, they should be of the same plane dimensions and in close contact with each other during exposure.
Fluorometallic Screens	These screens consist of calcium tungstate phosphor coated on lead foil, which in turn is coated on a suitable, flexible support. When used in appropriate applications, the combination of fluorescent phosphor and lead foil results in substantial intensification with radiographic images having improved contrast.

Illuminators and viewers

The illuminator must provide sufficient light to transmit adequate light for the observer to distinguish areas easily. Since the human eye has greater visual acuity and contrast visualization at given levels of light, the illuminator must provide control of light levels to adjust for optimum visual response of observer. The contrast sensitivity of the human eye is greatest when light reaching the eye comes from one source; therefore, radiographs should be read in areas of subdued light to avoid reflection and glare.

Densitometer

Measure radiographic densities with electronic direct-reading type densitometers. The electronic direct-reading type densitometer is more accurate than the visual type. This densitometer is capable of measuring light transmitted through a radiograph with a film density up to 4.0 with a density unit resolution of 0.02. When film densities greater than 4.0 are required to perform a radiographic inspection, a densitometer for film densities up to maximum density is necessary.

Monitoring devices

Radiation is extremely dangerous in our career field; therefore, several monitoring devices are needed to ensure the safety of you and your lab. The following devices are required equipment for X-ray inspection.

- Thermoluminescent dosimeter (TLD) badge.
- Electronic personnel dosimeter (EPD).
- Digital alarm dosimeter (DAD).
- Survey instruments.

Thermoluminescent dosimeter badge

TLDs are well suited for personnel and environmental monitoring of X-ray and gamma radiation. TLDs are special materials which, when exposed to ionizing radiation, results in raising the electrons of the detector material to temporary higher energy states. When these materials are later heated, the

electrons fall back to their normal energy states and in the process emit light. The amount of light emitted is directly related to the amount of radiation dose the TLD received. By measuring this light, the dose received by the individual wearing the dosimeter can be assessed. Although a number of materials can be used as TLDs, lithium fluoride, lithium borate, and calcium sulfate are the most commonly used materials for personnel dosimetry.

TLDs are primary dosimetry devices, which have replaced film badges as the legal record of radiation exposure in the Army and Air Force. Personnel should verify the following for each personal alarming dosimeter/alarm meter:

- Check to ensure that alarm functions (sounds) at the start of each shift.
- Alarm signals must be given a preset dose rate of not more than 500 mR/hr (in which R is a roentgen, and mR is one-thousandth of a roentgen).
- Require special means to change the preset alarm function.

Electronic personnel dosimeter

An EPD is a device that measures gamma and X-ray radiation, and provides readout of both skin and deep dose equivalent ranges of 0.1–1000 roentgen equivalent man (REM). The radiation is detected by three silicon diode detectors, which save data to secure memory every few minutes and provide visible and audible alarms if either the accumulated dose or dose rates exceed specified levels. Doses should be checked periodically throughout the day when performing radiography, and are recorded in the dosimetry log at the beginning and end of each operation for future comparison with TLD results. When EPDs are submitted for calibration, long-term dose memory is reset to zero. They are used in the same manner as TLDs.

Digital alarm dosimeter

The DAD is a solid-state dosimeter that uses a halogen-quenched, filtered Geiger-Mueller (GM) tube for detecting and measuring radioactivity. The GM tube converts the radiation detected into pulses, which are fed to an amplifier and then to a pulse-division circuit which produces an output to the digital display counter whenever pulses equivalent to one dose increment have been accrued. At the same time, the division circuit output actuates the audible system and emits a “chirp” for each dose increment.

The alarm dosimeter has a case usually constructed from aluminum or high impact plastic. The DAD is lightweight (8 ounces or less), has a corrosion-resistant surface coating and operates on a 9-volt alkaline battery for up to 6 months of normal use.

Operation is very simple, as shown in the following steps:

1. Turn the unit on (some units reset the display each time the unit is turned on; others require resetting the display with a reset switch or button).
2. A memory is available on some models, which allows the unit to be turned off without losing the stored dose. This feature permits a single daily recording of the wearer’s exposure dose because the dosimeter will continue to monitor exposure to the radiation without having to record each exposure dose if operations stop and resume several times a day.
3. It will be worn between the neck and waist on an outer garment or on a belt provided the DAD securing clip is designed for attachment to a belt.
4. Any time a DAD is used by a different radiographer, it should be reset to zero prior to use.

Survey meters

Radiation exposure, at the energies used for industrial radiography, is most accurately measured with ionization chamber type survey instruments. These survey meters or detectors use an air-filled chamber, across which an electric field is applied. When X-ray or gamma radiation interacts with the air in the chamber, it creates positive and negative ions that drift apart under the influence of the electric field. As the ions are collected on the electrodes within the chamber, a small current is

generated which is measured by the instrument and directly related to the radiation exposure rate in air. Several types may be used in the Air Force so get familiar with the one used in your shop.

Radiographic processing equipment

Radiographic processing involves two basic modes, manual and automatic processing. A third mode, digital will be discussed in a later section.

Manual processing

In the case of manual processing, chemistry is placed in tanks of a suitable material. Films are affixed to corrosion resistant metal hangers, which are submerged in the chemistry during processing. Chemistry temperature needs to be controlled, and in some instances, is accomplished with an incoming water mixing valve. A separate electrical dryer unit is employed to dry the processed film.

Automatic processing

Automatic dry-to-dry machine processing is in wide use today because it affords increased processing stability and results in significantly shorter total processing time. Most automatic processors incorporate equally driven transport rollers. All of the rollers in the four processing stages of development, fix, wash, and dry are driven at the same speed, and therefore, turn together as the film is being transported between them.

605. Radiation safety

This lesson serves as a training guide for the safe use of X-ray sources for industrial radiographic purposes. It will provide information on biological effects from radiation to the body and guidance to those who use X-ray sources by recommending operational procedures, personnel controls, and radiation protection practices. These will assist in eliminating needless exposure to ionizing radiation.

Biological effects of radiation

After the discovery of X-rays and radioactivity, it became increasingly apparent that an element of danger was associated with exposure to ionizing radiation. The harmful effects of radiation appear to be caused by ionization and excitation produced in the cells of living tissue. Because of ionization, some structures essential to the normal functioning of the cells are altered or destroyed. The effect of ionizing radiation on the body depends on the dose rate, total absorbed dose, and area of the body irradiated.

Dose rate and total absorbed dose

The dose rate at which radiation delivers is most important from a biological standpoint. In general, the effects of a given absorbed dose decrease as the rate of exposure decreases.

A certain total absorbed dose of radiation received by an individual within a few hours could cause harm. The same total dose spread over a period of years could produce no noticeable effect. The smaller the total absorbed dose and the dose rate are, the less the injury. This is based on the ability of the exposed tissue or cell to recover partially from the damaging effects of radiation. Following radiation exposure, some damage heals and some does not. If time allows for healing between exposures, larger exposures are required to produce the same effect as a smaller single exposure.

Acute exposure

In general, the biological effects resulting from radiation exposure are classified according to the duration of the exposure. An acute exposure is the absorption of large amounts of radiation in a short time. This type of exposure is not probable under normal operational conditions.

Chronic exposure

A chronic exposure is the absorption of relatively small amounts of radiation over a long time. To prevent injury, radiation protection guides have been established for chronic exposures that result from occupational exposure to ionizing radiation.

Medical exposure

Radiation exposures resulting from necessary medical and dental diagnostic or therapeutic X-ray procedures should *not* be included in the determination of the radiation exposure status of the individual concerned. The benefit received from such procedures is more beneficial than the damage that might be incurred by the additional radiation. Occupationally exposed personnel should *not* wear their film badges while undergoing medical or dental X-ray procedures.

Area of the body irradiated

The extent of injury to the body depends on the total area irradiated. Limited portions of the body could receive large doses of radiation resulting in local injury to the irradiated area, but the overall health of the individual is not seriously affected. One reason for this is that when the exposed area is small, the unexposed portions of the body can contribute to the recovery of the injured area. On the other hand, exposure of the whole body or to a large portion of the body to the same amount of radiation might well be fatal since many organs are affected, making recovery much more difficult.

Different portions of the body show different sensitivities to ionizing radiation. In general, the most sensitive parts include the lymphoid tissue, bone marrow, spleen, organs of reproduction, and gastrointestinal tract. Of intermediate sensitivity are the skin, lungs, and liver. Muscles, nerves, and bones are the least sensitive to radiation.

Acute overexposure of the whole body to penetrating radiation can result in serious injury. This could lead to the development of anemia, leukemia, malignant tumors, or cataracts and increase the average rate of genetic mutation. If the dose received is sufficiently large, there is early nausea and vomiting, decreased blood cell count, loss of hair, loss of appetite, general discomfort, and diarrhea.

Although there are individual variations, these symptoms can be expected after a whole body exposure of 100 roentgens or more are received within a period of a few hours to one day. At the time of onset, the severity and duration of these symptoms depend on the total absorbed dose. It is best to avoid all unnecessary exposure to ionizing radiation.

Units of radiation dose measurement

All radiation possesses energy as in the case of electromagnetic radiation such as X, gamma, or particulate radiation, such as alpha, beta, neutron, or proton radiation. Absorption of radiation is the process of transferring this energy to atoms of the medium through which the radiation is passing.

The harmful effects of ionizing radiation to a living organism are due to the energy absorbed by the cells and tissues of the organism. This absorbed energy or dose produces chemical decomposition of the molecules present in the living cells. The decomposition appears to be related to ionization and reactions between the radiation and atoms within the tissue. The amount of ionization or the number of ion pairs produced in the cells or tissues provides a measure of the biological damage that might be expected from a given quantity or dose. Since the amount cannot be measured directly, a practical basis for radiation dose measurement is the number of ion pairs produced within the cells or tissues. The following are three units of radiation dose measurement you are concerned with:

1. Roentgen.
2. Radiation absorbed dose (rad).
3. Roentgen equivalent man (rem).

Roentgen

The unit used for expressing the exposure to X-ray or gamma radiation is the roentgen. The roentgen is defined as the special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to absorbed dose in rads multiplied by the quality factor. In this definition, roentgen is a unit of exposure based on ionization in air; it is not a unit of absorbed dose in the air. The roentgen applies only to X-ray and gamma radiation. It can be subdivided into the smaller unit

mR, which we referred to in the previous lesson. In standard measures of energy, one roentgen of X-ray or gamma radiation is equal to the absorption of 87 ergs of energy per gram of air.

Radiation absorbed dose

The rad is the amount of absorbed dose of any kind of ionizing radiation. In other words, ionizing radiation imparts energy to matter; the amount of this energy is determined by the mass of the matter (or irradiated material). The unit of absorbed dose is the rad. One rad is equal to the absorption of 100 ergs per gram of any material. It should be emphasized that although the roentgen unit is applicable only to X-ray or gamma radiation, the rad is a measure of absorbed dose from any kind of ionizing radiation in any medium. Radiation absorbed dose can be subdivided into a smaller unit called the millirad (mrad), which is 1/1000 of a rad.

Roentgen equivalent man

Rem refers to all ionizing radiation, which is capable of producing similar biological effects. The absorbed dose producing a specific biological effect varies from one type of radiation to another. The difference in behavior is expressed by a quality factor (QF), also called relative biological effectiveness, which is assigned to the particular type of radiation. The QF is simply a factor to convert the energy measurements in rads into estimates of the biological effect expected from the different types of radiation.

The product of the absorbed dose and a suitable QF expresses the irradiation with a common scale for all ionizing radiation. This product is called the dose equivalent, the unit of which is the rem. The rem is subdivided into a smaller unit called the millirem (mrem) and is 1/1000 of a rem.

The industrial radiographer's primary concern with the rem is with radiation exposure records and protection guides. Report results of personnel monitoring evaluations in rems.

As low as reasonably achievable

Exposure to radiation, even at very low dose rates, is permissible only when the benefit derived from such exposure exceeds the risk incurred. Each individual should strive at all times to maintain all radiation exposures *as low as reasonably achievable* (ALARA). Individuals will not ever knowingly expose themselves, or cause others to be unnecessarily exposed to radiation.

The annual peacetime ionizing radiation dose received by occupationally exposed adults should not exceed the following annual limit:

- The total effective dose equivalent (TEDE) of 5 rem.
- The sum of the deep dose equivalent from external sources and the committed dose equivalent to any individual organ or tissue, other than the lens of the eye, of 50 rem.

Radiation safety officer

The NDI laboratory supervisor will normally be delegated the responsibility for administering all industrial radiography operations and ensuring compliance with all aspects of the radiation protection program. The unit commander or maintenance chief normally appoints the section radiation safety officer (RSO). The following are the responsibilities of the RSO:

- Determine the competency of industrial radiographers.
- Maintain control of all industrial radiographic equipment.
- Provide initial radiation safety training to newly assigned workers and ensure all others receive annual refresher training.
- Develop and maintain current radiological safety operating and emergency procedures approved by the RSO.

Maintain a copy of the radiological safety operating and emergency procedures approved by the RSO with the radiation equipment during all operations. The emergency procedures should specify the following:

- Individuals to contact in the event of a suspected overexposure.
- Forms to be completed.
- Where to take the individual for treatment/observation.
- How to approximate the degree of exposure.
- What to do with direct reading dosimeters/TLDs.

Forms and documentation

Documenting and maintaining logbooks are an important part in keeping your section safe. Your lab will need to maintain, as a minimum, two separate utilization log books; one for shielded areas and the other for unshielded areas (a book is not required for those areas not utilized). The unshielded log should be subdivided to clearly identify each unshielded area and include its own set of utilization forms, such as the Air Force Technical Order (AFTO) Form 125, Industrial Radiography Utilization Log; AFTO Form 125A, Industrial Radiography Utilization Log Facility Survey Drawing; and AFTO Form 115, Digital Alarm Dosimeter Results Log.

Air Force Technical Order Form 125

Complete the AFTO Form 125 for all shielded and unshielded inspections, and suspected overexposures of personnel. Maintain these files for three years. If a suspected overexposure occurs, any other documents generated during the subsequent investigation will be filed with the respective utilization log. When a log is completed, the radiography supervisor (lab chief) will sign it and ensure it is properly completed.

Air Force Technical Order Form 115

Read and record direct reading dosimeters daily in the utilization log, then store them in your record management file plan. Air Force units will document dosimeter readings on AFTO Form 115. All doses will be stored in a central database for corresponding TLD doses and dose reporting's. Web-based real-time environmental monitoring system (WebREMS) may be used in lieu of the AFTO Form 115.

Emergency situations

An exposure above occupational limits shall be suspected an emergency during the following:

- A direct reading dosimeter registers 500 mrem or more, or any individuals' direct reading pocket dosimeters exceed maximum scale.
- The radiography supervisor, regardless of dosimeter readings, believes either an overexposure has occurred to another radiographer or any one not directly involved in the radiographic operation.

If an exposure above occupational limits is suspected, an emergency situation exists. The actions in the following table must be taken:

Step	Emergency Actions Taken Due to Radiation Overexposure
1	Immediately cease all radiography operations and report the incident to the immediate supervisor.
2	Obtain the name, social security number, and organization of all personnel suspected of overexposure.
3	Notify the installation RSO or bioenvironmental engineering services of the suspected overexposure. Prepare to turn in the affected individual's TLD badge and the control badge for immediate processing, as directed. The occupational health physician in consultation with the RSO will determine the need for medical treatment.
4	Read and record direct reading dosimeters.
5	Determine and record exact position and duration of exposure.
6	Update the industrial utilization log as needed. Make sure the detailed sketch of the area includes the positions of personnel suspected of being overexposed. Record all other pertinent data about the incident (x-ray apparatus position, kV, mA, and direction of primary beam).

Step	Emergency Actions Taken Due to Radiation Overexposure
7	Obtain a signed statement from the exposed individual(s) of actions resulting in (or contributing to) the exposure.
8	After completion of the above phase of the investigation, and in the case of non-monitored personnel being exposed, this procedure can be used by the RSO or radiographers to quantify personnel exposure.
9	The NDI laboratory supervisor and the unit RSO with signed statements should prepare a complete report of the incident from all operators and personnel exposed with their concurrence of the report. A copy of this report is to be provided to the installation radiation safety officer for review and filing in the industrial workplace file plan.

Safety and warning devices

Inspect all interlock, beam control mechanisms, safety and warning devices, remote monitoring systems, etc., for proper operation, initial operation, and on each shift when X-ray equipment is used. Maintain a log initialed by the person making these inspections with the utilization log. For units who do not use their facilities on a regular basis, interlocks are subjected to detailed operational testing at intervals not to exceed six months.

Personnel radiation monitoring requirements

Use of personnel monitoring devices is mandatory for each individual who may be exposed to ionizing radiation during the normal course of their duties or occupation according to the following criteria:

- Occupationally exposed adults who may reasonably be expected to receive an annual dose in excess of 100 mrem.
- Occupationally exposed adults entering any high or very high radiation area (regardless of the anticipated magnitude of exposure).
- TLD badges are the primary dosimetry device used in the Air Force and have generally replaced other film badges as the legal record of radiation exposure.
- Declared pregnant women are to be monitored for the entire period of pregnancy.
- Other individuals needed for effective management of the ALARA program. This includes radiation safety monitors supporting unshielded radiography operations who do not otherwise require dosimetry devices, will be provided with dosimetry devices to include TLDs if their radiation dose would reasonably be expected to exceed the general public exposure limit of 100 mrem TEDE per year or 2 mrem in one hour.

606. Shielded and unshielded safety requirements

As used in this section, radiation protection survey means an evaluation of potential radiation hazards associated with the use of industrial X-ray and gamma equipment, under specified conditions, when used in shielded and unshielded installations. When appropriate, such evaluation includes inspection of equipment, examination of its location with reference to controlled and uncontrolled areas in the immediate environment, and measurements of exposure levels.

Surveys and reports

A radiation protection survey of all new shielded and unshielded installations or new equipment are completed and retained by the local bioenvironmental engineering services and the NDI supervisor. This survey expresses actions taken, and recommendations regarding the survey.

Radiation assessments are made by the installation RSO as an integral part of the annual quality assurance audit of the radiation protection program. Assessments verify the adequacy of operating procedures, the presence and proper use of radiation warning signs/signals, and other necessary equipment. Further, the assessments verify the annual ALARA training and assessment of worker dose to radiation.

Shielded installations

Shielded installations are designed with sufficient shielding to meet exposure limit requirements. The Air Force describes a shielded installation as any enclosed radiographic facility designed to limit exposures on the outside of the facility to less than 2 mrem in any one hour and less than 100 mrem in a year. The shielding design incorporates the energy of the X- or gamma ray source to be used, as well as the expected workload, use factors, and occupancy factors of installation. Use at least one calibrated and operable radiation survey instrument.

An installation is classified as shielded when it conforms to all of the following mandatory requirements:

- No person, either within the controlled area of a shielded installation will receive radiation exposures exceeding the total effective dose equivalent limits for members of the public.
- The radiation source and all objects to be exposed are within a permanent enclosure, and no person is permitted to remain within during irradiation.
- Each entrance used for personnel access to the enclosure/high-radiation area will have both visible and audible warning signals. These signals include warning signs, beacons, interlock systems, and audible alarms.

The shielded facility *is not* used for excessive storage. All radiation warning signs and shut-off switches are positioned at eye level with no obstructions. Excessive clutter may interfere with accurate survey measurements and cause an unsafe condition should an emergency shut-off become necessary.

Warning signs

The interior of the exposure room will have posted “Caution, High Radiation Area”, “Danger, High Radiation Area”, or “Grave Danger, Very High Radiation Area” signs visible from any location. The interior of a cabinet installation should have an identical sign that is visible with the access door open.

The entrance to the exposure room, or cabinet for cabinet type installations, housing X-ray equipment will have posted radiation signs, either “Caution, Radiation Area”, “Danger, High Radiation Area” or “Grave Danger, Very High Radiation Area,” as applicable. In addition, gamma radiography sources and cabinet type installations containing a radioactive source will also have a “Caution, Radioactive Materials” sign attached to the outside. A label or sign “Caution, Produces X-rays when energized” (or equivalent) will be affixed to the X-ray tube head.

Radiation Area Definitions	
Area	**Definition**
Radiation Area	An area where an individual located one foot from any source of radiation that could receive greater than 5 mrem in one hour.
High Radiation Area	An area where an individual located one foot from any source of radiation that could receive greater than 100 mrem in one hour.
Very High Radiation Area	An area where an individual is located 3.3 feet from any source of radiation that could receive greater than 500 rads in one hour.

Beacons

Rotating or flashing strobe-type visible warning beacons are used at all entrances to the enclosure. These must be activated at least 20 seconds before irradiation starts (simultaneously with audible alarm). These beacons will be located so they are visible to an individual entering, or already inside of the facility, and will be operational when X-rays are being produced. Display an adequate sign near the lights to explain their function.

Red warning beacons are located within the enclosure and outside all entrances to the enclosure. *Do not* use low intensity, flashing warning lights unless special circumstances occur. The installation RSO is the only approval authority for these special circumstances.

Interlock systems

The visible and audible warning beacons/signals will be tied to an interlock system. The interlock system should be placed on each door to interrupt power to the control box/tube head, stopping the irradiation process when unauthorized access is attempted. In the event of a warning beacon/signal malfunction (i.e. bulb burns out), the interlock should terminate power to the x-ray tube.

A time delay/interlock may be locally fabricated or purchased in order to meet requirements. The wiring harnesses are similar to the harnesses used with X-ray interlock assembly. All time delay interlock systems installed should be compatible with all X-ray units commonly available.

Audible Alarms

A pre-exposure audible alarm will be used within the enclosure and must be actuated at least 20-seconds before irradiation starts. Audible alarms cease when radiation is started, but the visible warning signal remains actuated during irradiation. The audible signal is capable of producing a sound pressure level so it can be heard over background noise that may be present.

Audible alarms are not required if the enclosure is so small it cannot be entered by an individual. An example of such an enclosure is a cabinet X-ray system that has a small opening into which the part to be radiographed is placed, but into which an individual could not walk or even crawl without difficulty.

Unshielded installations

Radiographers will actively survey unshielded installations during each subsequent operation. Initial surveys include radiation exposure measurements to establish, or verify safe operating conditions as established by the applicable standard operating procedures. Unshielded applies where fixed shielding cannot be used (e.g., flight line, open hangars make-shift buildings, etc.). Whenever radiographic operations are performed, at least two operable radiation survey instruments will be available at unshielded installations.

An installation is classified as unshielded if operational requirements cannot be provided with the inherent degree of protection specified for Air Force shielded installations. Such installations include fenced or roped-off areas located either in the open, or inside buildings such as hangar bays. Unshielded installations conform to all of the following requirements:

- Compliance with radiation dose limits applicable to the general public and to occasionally exposed individuals require that access to areas in which radiation doses could exceed 2 mrem in any one hour or 100 mrem in a year is restricted. Radiation area postings are extended out from the X-ray tube or alternative arrangements are made to restrict access to this area.
- When radiographic operations are conducted without benefit of shielding, it is often necessary to erect a rope barrier around the X-ray tube head at a distance of 230 feet or more for vertical beam orientation.
- If the beam orientation or technique factors change between exposures, reestablish and verify radiation area boundaries. These areas include warning signs, beacons, interlock systems, and safety monitors.

Warning signs

If the unshielded installation is in a remote area, and if entry into the enclosed area can be absolutely prevented during irradiation, the source and all objects exposed will be within a posted perimeter. This perimeter will limit the area in which the exposure can exceed 100 mR/hr in an hour provided:

- Post the perimeter with a sufficient number of “Caution, Radiation Area” signs from any direction of approach.
- The boundary of the restricted area can be determined where applicable.

Beacons

Red, rotating, or flashing strobe-type visible warning beacons are used on the perimeter and positioned at the X-ray source (low-intensity flashing warning lights *will not* be used). The beacon positioned at the source will be rotating/flashing only when the source is energized.

Interlock system

Place an X-ray interlock between the control unit and the rotating/flashing strobe-type "X-ray on" beacon. The interlock assembly enables electrical power to the "X-ray on" power circuits only after the rotating/flashing strobe warning beacon is attached. Radiographers each day and prior to use will verify proper operation of X-ray equipment by inspecting radiography interlocks.

The interlock is tested every six-months by verifying it does indeed de-energize the X-ray tube head when the exposure is complete, the circuit is tripped, or it is manually shut off by the operator.

Safety monitors

Instead of an audible alarm system that is used for shielded operations, unshielded uses safety monitors. Bioenvironmental radiation surveys for unshielded locations are used for set-up instructions and manning requirements. Deviations from set-up procedures or location and number of radiographers, safety monitors, or safety monitor assistants will be approved by the RSO prior to X-ray operations. If the perimeter is too large or is arranged so that the operator cannot readily determine whether the radiation area is unoccupied, a sufficient number of radiographers or radiation safety monitors will be strategically located to provide adequate visual surveillance over the entire area. These personnel will all have adequate and properly calibrated survey meters. If the following conditions are met, the requirement for additional monitors may not be necessary:

- The radiographic procedures are to be accomplished fenced-in, or in a locked area to which access is controlled by the radiographer.
- There *will not* be less than one radiation safety monitor.
- X-ray and gamma ray controls will be placed so all monitors, for the entire perimeter of the barrier, can be seen and heard by the radiographer-in-charge. If this is not possible, a hand held battery powered communication device is used.

Measuring exposure

Radiation exposure, at the energies used for industrial radiography, is most accurately measured with ionization chamber type survey instruments. These detectors use an air-filled chamber across which an electric field is applied. When X-ray or gamma radiation interacts with the air in the chamber, it creates positive and negative ions that drift apart under the influence of the electric field. As the ions are collected on the electrodes within the chamber, a small current is generated which is measured by the instrument and directly related to the radiation exposure rate in air.

All survey instruments used for industrial radiography will be capable of measuring a range from 2 mrem/hr through 1 rem/hr, as a minimum. The SM–400, although having a maximum range of 300 mrem/hr, is authorized for X-ray NDI use provided an instrument meeting the requirements stated above is readily available. The following are the three common types of survey meter instruments used in the Air Force.

- Victoreen model 440.
- Nuclear Research Corporation SM400.
- Heat pipe model VR–10.

Due to the response time of electrical components, survey meters will not instantly indicate the maximum exposure rate. Typically, survey meters have a response time ranging from 2–15-seconds, with longer response times being required for lower dose rates. Therefore, prior to use, turn survey meters on for several minutes, and allow them to stabilize.

607. Process control inspections

Process control of radiography is based on variables involving materials, equipment, personnel, and documentation that are well defined and maintained. For the most part, process controls of these variables are dependent on the radiographer and care the inspector uses in setting up all these features. Good record keeping of the entire process is important in maintaining reliability.

This section provides process control inspection procedures needed to maintain radiographic inspections.

Process control frequency

It is intended that general practice be performed to practice and establish the minimum requirements for all film radiographic equipment and materials. The following table outlines the frequency for film radiography process controls.

Process Control Frequency	
Test	**Interval**
Safe Light Fog Evaluation	Initial install, when replaced, and annually.
Safe Light Filter Check	Monthly.
Interlock Functional Check	Prior to X-ray operation.
Interlock System Inspection	180 days.
Fixer Control	Recommended by manufacturer's instructions.
Development Process	Weekly.
Survey Meter Operational Check	14 days, or recommended by manufacturer's instructions and prior to use.
Densitometer Calibration Check	Prior to use.

Safelight check

The darkroom is completely protected against radiation and visible light for efficiency and reducing the possibility of damaging radiographic film. For this reason, individual safelight testing should be performed if any of the following exist:

- New safelights are installed.
- Changes to existing lights such as replacing entire units, bulbs, filters, or position changed (e.g. reflecting versus direct lighting).
- Filters are faded or damaged (e.g. scratches and cracks).
- Safelight showed unsatisfactory test results.
- Producing excessive safelight fog.

Periodic collective safelight filters deteriorate during use. This rate of deterioration is dependent on their age, amount of use, and amount of heat generated by the bulb; therefore, a periodic schedule should be established to collectively test safelights to prevent film fog dependent upon their use.

The procedures in the following table are recommended for the individual safelight check.

Individual Safelight Check	
Step	**Description**
1	X-ray a piece of 14x17 class 4 (or fastest film speed used in lab). X-ray film until a 1.5 ± 0.2 density is achieved. Use initial settings of 25 kV, 2 mA at 8 seconds.
2	Turn off, disconnect, or remove all safe lights from the dark room except the one to be tested.
3	Turn off remaining safelight and open the exposed film in complete darkness.

Individual Safelight Check	
Step	**Description**
4	Cover the entire sheet of film with cardboard or other like type of material; place it in the working area at least four feet under the safelight.
5	Uncover 2.5 inch section of film, turn on the safelight and expose it to the safelight for 6 minutes. After 6 minutes, uncover another 2.5 inch and expose for 3 minutes. Repeat the procedure for 1 minute, 30 seconds, and 15 seconds. Be sure to leave the last section covered and completely unexposed.
6	Turn off safelight and develop the film in complete darkness.
7	Take density reading for all the sections on the X-ray film and compare to the last, unexposed section. The section with the least amount of measurable density change is the maximum allowable time undeveloped film may be exposed to this safelight. If that time is less than 4 minutes and 45 seconds, the safelight does not meet minimum requirements.

Interlock operational check

An inspection of the X-ray interlock system is required daily if the X-ray facility is used every day. For facilities not used every day, a prior to use inspection is required. The interlock operational check is performed at least every six months. The AFTO Form 135, Industrial Radiography Safety Checklist, may be used to document the interlock operational check. The operational check will include as a minimum the following checklist items:

- Do all interlock door switches stop X-ray production when the door is opened?
- Are all rotating beacons operational?
- Does the audible alarm sound for 20 seconds prior to X-ray emission?
- Are all emergency stop buttons unobstructed and operational?
- Is the shielded radiation utilization log current? Does it include a facility survey, local operating procedures, emergency procedures, and ORMs within arm's reach of the console?
- Do all personnel involved with X-ray operations have a TLD and an EPD, or equivalent approved direct reading dosimeter affixed to the trunk of the body and outside of their clothing?
- Does the shielded facility have legible and unobstructed warning signs inside and outside?
- Is at least one calibrated and operable survey meter ready for X-ray operations?
- Has the AFTO Form 140, Radiac Equipment Maintenance Record, been documented for the survey meter battery and operational check?

Developer testing

A major variable in the radiographic process is the processing of the film. The chemical concentrations, contaminants, and temperature are important variables, which affect the process. A method of monitoring changes during film processing involves periodically processing many control-exposed films to detect changes in film density and contrast. The last strip in the control exposure should be processed with the control film of the new batch to maintain continued control from month to month.

To ensure you are completing the most up to date and accurate procedure, refer to work package (WP) 106–00 within TO 33B–1–2, *Nondestructive Inspection General Procedures and Process Controls.* The following steps are required for developer testing.

Developer Test	
Step	**Description**
1	Expose a piece of film and a step wedge to X-rays. Five sheets of X-ray film

Developer Test	
Step	**Description**
	may be exposed at the same time when using a steel wedge and three sheets when an aluminum wedge is used. Expose film sufficiently to present the whole range of densities from the step wedge. Pre-manufactured control strips are authorized to be used for this test.
2	Cut the film into thin strips and seal securely to prevent exposure to light.
3	Process the first strip with fresh developer. Save the strip to use as a reference.
4	Once a week during the life of the developer, process another strip and compare the resulting density reading with the reference strip.
5	If a variation in excess of 0.3 density units occurs, replace the developer.
6	Repeat the process each time the developer is changed.

Fixer control

Fixer control is a measurement of the replenishment rate of an automatic processor. Follow the instructions in the owner's manual for making this measurement. Generally, a graduated cylinder is used to capture the fixer being pumped into the tank while processing one piece of 14x17 film. The amount should measure between 170 and 190 milliliters (ml).

An exhausted fixer solution will produce adverse effects relative to the permanency of radiographs. It is necessary to check the fixer solution for exhaustion once per month, or when regular processor maintenance is performed. Fresh chemicals are metered into the processor as film is processed and it is this replenishment that keeps the solution active. While checking the replenishment rate, circulation in the fixer should also be verified; if the processor has a fixer filter, it should also be checked and cleaned.

Survey meter operational checks

The survey meter is checked by the user with a radiation check source prior to the first monitoring operation of the day, and at two-week intervals, or as specified by manufacturer's instructions for instruments not in daily use.

Nuclear Research Corporation SM–400

The Nuclear Research Corporation SM–400 (fig. 1–21) is one radiation measurement instrument used in the Air Force. It is a low energy ion chamber survey meter capable of measuring alpha, beta, gamma, and X-ray radiation. The ion chamber has a very thin Mylar window that permits detection of low energy radiation. A meter calibrated in mR/hr indicates the intensity of radiation.

Front panel

Front panel controls include a seven-position selector switch. The OFF position removes battery power. The BAT position checks the battery condition. The five sensitivity positions of 300, 100, 30, 10, and 3 mR/hr are used to select full-scale meter sensitivities from 300 mR/hr down to 3 mR/hr. Also on the front panel is a ZERO ADJ control that adjusts the meter to zero when no radiation is present. The SM–400 is calibrated (by a precision measurement equipment laboratory—[PMEL]) by removing a front panel screw to gain access to the internal calibration potentiometer.

End cap

The end cap serves the following three main functions when installed:

- Protects the thin Mylar window on the chamber from damage.
- Prevents alpha, beta, and low energy gamma or X-ray radiation from being detected.
- Holds the built-in Thorium (Th)–232 check source used for the operational check.

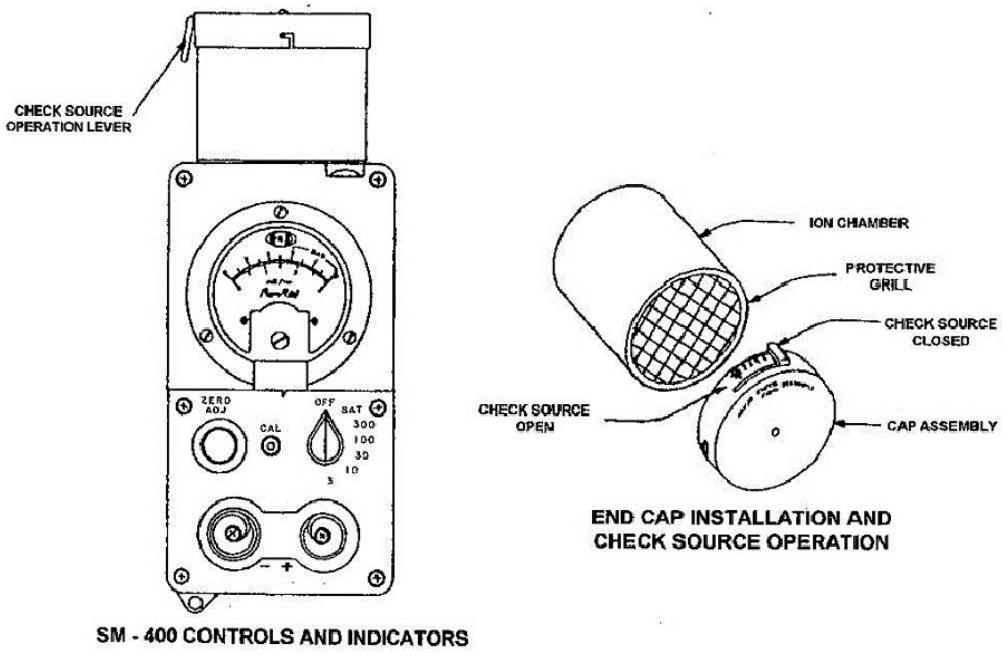


Figure 1–21. SM–400 survey meter.

Victoreen Model 450P survey meter

Another type of alarm dosimeter used in the Air Force is called the Victoreen Model 450P survey meter. It is a lightweight portable survey meter designed to measure X-ray above 25 keV. It has a five decade operating range from 0–5 mR/hr on the lowest scale to 0–5 R/hr on the highest scale and has a programmable "flash alarm" which causes the display to pulsate at a rate of once per second when the measured dose rate exceeds a preset limit. The detector is a 300-cc (cubic centimeter) ionization chamber pressurized to six atmospheres. For maximum sensitivity, the model 450P survey meter should be perpendicular to the ground plane when making measurements rather than being parallel to the ground. It is also considered hazardous when shipping because of the pressurized ion chamber and must be shipped to test, measurement & diagnostic equipment (TMDE) accordingly.

Victoreen operational check

The Victoreen survey meter procedures are provided in the following table:

Operation Check for Victoreen Survey Meter	
Step	**Description**
1	Turn on instrument and allow it to warm up as required.
2	Locate white dot on right side of instrument.
3	Place radioactive source material (rod or disc) as close as possible to white dot. (The same source material should be used every time check is accomplished.)
4	Maximize reading on screen and document readings. Ensure readings are within ±20 percent of the base line value obtained after TMDE calibration. Document reading on the AFTO Form 140.

SM–400 operational check

The operational check consists of the battery check, zero adjust check, and radiation measurement check. It is accomplished in the order of the following paragraphs:

Battery

Rotate the selector switch to the BAT position to check the condition of the two size D batteries. If the meter does not read in the "good" area, replace the batteries.

Zero adjust

The zero adjust switch has a lock to prevent accidental movement after adjustments are made. Check and adjust the zero reading of the SM–400 in a radiation free area.

1. First, set the selector switch to the 300 mR/hr position and place the check source in the CLOSED position. Warm up the unit for at least 2 minutes.
2. Next, rotate the selector switch clockwise, stopping at each step to let the meter needle settle down and see if it reads zero. If the meter doesn't read between 0 and 0.2 mR/hr on the 3 mR/hr range, unlock the ZERO ADJ control, and adjust the needle till it does.
3. After the adjustment is made, lock the control.

Radiation measurement check

The Th–232 check source that is incorporated in the end cap assembly is used to perform the radiation measurement check and to check the overall operation of the SM–400.

1 . Place the range selector switch in the 3 position (or the 10 position if the reading is greater than 3 mR/hr), and open the check source.
2. The meter reading may fluctuate during the source check, so use an average reading. The meter reading must increase by between 0.5 and 5 mR/hr. If the instrument does not meet this requirement, recalibration by a PMEL is required.
3. Place the check source in the CLOSED position and the SM–400 is ready for use.

Radiation detection and measurement

To detect and measure radiation, place the selector switch in the 300 position. If the meter indicates less than 20 percent of full scale, proceed to the next lower range until you reach the lowest range where the meter reads less than 20 percent of full scale. Leave the cap on the SM–400 until just prior to the X-ray operation. The cap protects the thin Mylar film that covers the ion chamber from getting accidentally damaged.

CAUTION: *Do not* touch the Mylar window; if it is damaged, the SM–400 won't work. In addition, the SM–400 is sensitive to RF radiation, such as that produced by an X-ray unit control box or handheld radios. RF energy can cause inaccurate readings.

Densitometer calibration check

The general procedure in the following table is intended for densitometers similar to the one shown in figure 1–22. For other styles of densitometers, commercial manufacturer's instructions will be used to perform the densitometer calibration check.

Densitometer Calibration Check.

Step	Description
1	Turn on the instrument and allow it to warm up for at least 2 minutes.
2	Without the calibration step tablet in reader, press the READ button and hold it in contact with the reading surface.
3	While holding the READ button in contact with the reading surface, press the NULL button. The display should read 0.00.
4	Release the READ button.
5	Press the READ button. If the instrument is correctly nulled, the display will read 0.00. If the display does not read 0.00, repeat steps 2 and 3.
6	Release the READ button.

Densitometer Calibration Check.	
Step	**Description**
7	Select three steps on the National Institute of Standards and Technology (NIST)-traceable step tablet; the steps selected should have densities above, below, and near the midpoint of the range that is required in the part-specific procedure.
8	Independently measure the density values for each of the three steps selected in step 7 by centering the film area directly over the light under the reading head, and then pressing the READ button.
9	Compare the measured densities with the actual density values of the step tablet and ensure that the measured values do not vary from the actual density values more than ± 0.05 density units.

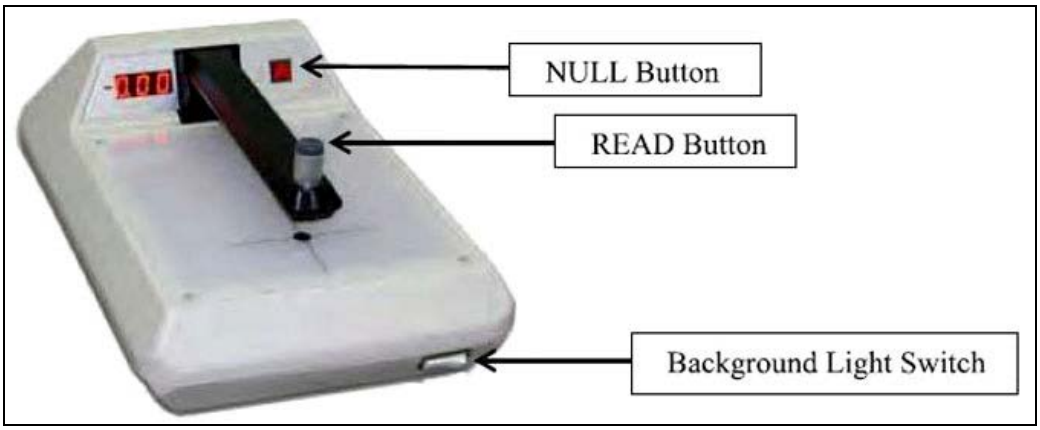


Figure 1–22. Densitometer.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

604. Radiographic equipment

1. What is the Lorad portable X-ray tube head insulated with?

2. How will film sealed by the manufacturer and not opened be stored at your lab?

3. When testing for expired film, and the clearing and fog level are satisfactory, what should you do next?

4. How should film be marked when the film size does not allow for its identification?

5. What is an example of an IQI?

6. What screens consist of calcium tungstate phosphor coated on lead foil, which in turn is coated on a suitable, flexible support?

7. How is density of a radiograph measured?

8. What monitoring devices are required for X-ray inspection?

9. How is radiation detected with an EPD device?

10. What is a solid-state dosimeter that uses a halogen-quenched, filtered GM tube for detecting and measuring radioactivity?

11. What type of detectors use an air-filled chamber, across which an electric field is applied?

605. Radiation safety

1. Harmful effects of radiation are caused by what?

2. What is the absorption of large amounts of radiation in a short time?

3. What are the most sensitive parts of the body when exposed to radiation?

4. What are the three units of radiation dose measurement that you will be concerned with?

5. What is the unit used for expressing the exposure to X-ray or gamma radiation?

6. What is the energy imparted to matter by ionizing radiation per unit mass of irradiated material?

7. The results of personnel monitoring evaluations are reported in which radiation measurement?

8. During peacetime, what should be the annual maximum ionizing radiation dosage received by occupationally exposed adults?

9. What procedures, approved by the RSO, state where to take an individual for treatment and observation if possible exposure has occurred?

10. After viewing dosimeter readings, on what form should you daily record them?

11. When will all interlock, beam control mechanisms, safety and warning devices, remote monitoring systems, etc., be inspected for proper operation?

606. Shielded and unshielded safety requirements

1. Who retains a completed radiation protection survey of all new shielded and unshielded installations, or when the survey pertains to new equipment?

2. Describe an Air Force shielded installation.

3. What should the interior of a shielded exposure room have?

4. Rotating or flashing strobe-type visible warning beacons are used at all entrances and must be activated at least how long before irradiation starts?

5. What are visible and audible warning beacons or signals tied to during an X-ray procedure?

6. What type of locations may require the use of unshielded X-ray procedures when fixed shielding procedures cannot be used?

7. What type of visible warning beacons are *not* used during unshielded operations?

8. When is the interlock tested?

9. Instead of an audible alarm system that is used for shielded operations, what is used for unshielded X-ray operations?

10. All survey instruments used for industrial radiography will be capable of measuring from what range?

607. Process control inspections

1. What types of variables involved are process controls of radiography based upon?

2. How often is the safe light filter check completed?

3. What is the first step when performing the individual safelight check?

4. If a NDI facility does not perform X-rays every day, how often should the interlock operational check be completed?

5. How many sheets of X-ray film may be exposed at the same time when a steel wedge is used for developer testing?

6. On what form is the Victoreen survey meter operational check documented?

7. What has a lock to prevent accidental movement after adjustments are made?

8. How long is the SM–400 warm up during the zero adjust check?

1–3. Processing and Interpreting Radiographic Film

In this section, you will study a typical darkroom, the use of automatic processing chemicals and equipment, as well as the silver recovery system.

608. Processing radiographic film

Automatic processing chemicals protect film against mechanical pressure and roller stains. The developing solution contains a hardener to inhibit excessive softening of the emulsion, which would otherwise interfere with the transport of the film through the processor. These chemicals are specially designed for use at high temperatures and are supplied in concentrated liquid form.

Most NDI laboratories process their radiographic film using automatic film processing equipment. In this lesson, you will learn how automatic film processing is accomplished by the use of chemicals and the silver recovery system.

Although the entire X-ray process must be closely controlled to produce the expected results, this requirement centers on film processing. The novice might think X-ray is a cure all; however, to the informed, it is a very costly and sometimes an inaccurate NDI method. X-ray procedures should be followed precisely because they are critical. These procedures include proper beam alignment, correct film, source focal spot size, and correct exposure parameters. This radiographic process has many factors that affect the quality of the final product.

Darkroom

Darkroom design is critical toward controlling the radiographic process. The darkroom should be completely protected against radiation and visible light. For efficiency and reducing the possibility of damaging radiographic film, two distinct areas should be established within the darkroom; these include the *dry area* and the *wet area*.

Dry area

The dry area is where film is prepared to be loaded in the automatic film processor, loaded in cassettes, or cut to support special inspections. Liquids or materials that could damage unprotected film should not be allowed in this area.

Wet area

The wet area is where development chemicals are mixed before adding into the automatic processor.

The dry and wet areas should be physically separated to prevent the wet chemicals from being accidentally transferred to the film loading areas, causing spots or other artifacts on the film.

Ventilation and safelights

Darkrooms also require proper ventilation and safelights. Ventilation provides effective circulation of air for the protection of personnel due to the fumes associated with film development. Safelights are used to minimize fogging of undeveloped radiographic film.

Ventilation

Suitable ventilation of the darkroom is determined by bioenvironmental. The circulation of clean fresh air will reduce fatigue and provide a healthier atmosphere for personnel. Light-tight ventilators are installed and the number will depend on the size of the darkroom. Ventilators keep the air moving from the dry side to the wet side of the room and out of the building.

Safelights

To minimize the fogging of undeveloped radiographic film by the safelights in the darkroom, the following provisions apply:

- General illumination should be indirect.

- Safelights should be suspended from the ceiling and be at least four feet from undeveloped/exposed film.
- Only the minimum level of safelights needed to perform darkroom operations are allowed.
- Only safelight filters (model 6B or equivalent) designated for use with industrial radiographic film will be allowed.
- The manufacturer's recommended bulb wattage will not be exceeded.
- The darkroom walls should be painted a light color, which best reflects light from the safelight. The darkroom should have an antechamber type entrance that makes an efficient light trap.
- During the development and preparation of uncovered, undeveloped radiographic film, ambient light should not exist.

Automatic processing

A system of rollers is generally employed as the transport mechanism in automatic processors, as shown in one manufacturer's sectional view (fig. 1–23).

Reduction in processing time and quality variations

Automatic processors decrease processing time from approximately one-hour, in a manual hand tank system, down to 5–13 minutes. Furthermore, the automatic processor reduces variations in radiographic quality; however, the processor alone cannot produce these effects unless combined with suitable film and processing chemicals.

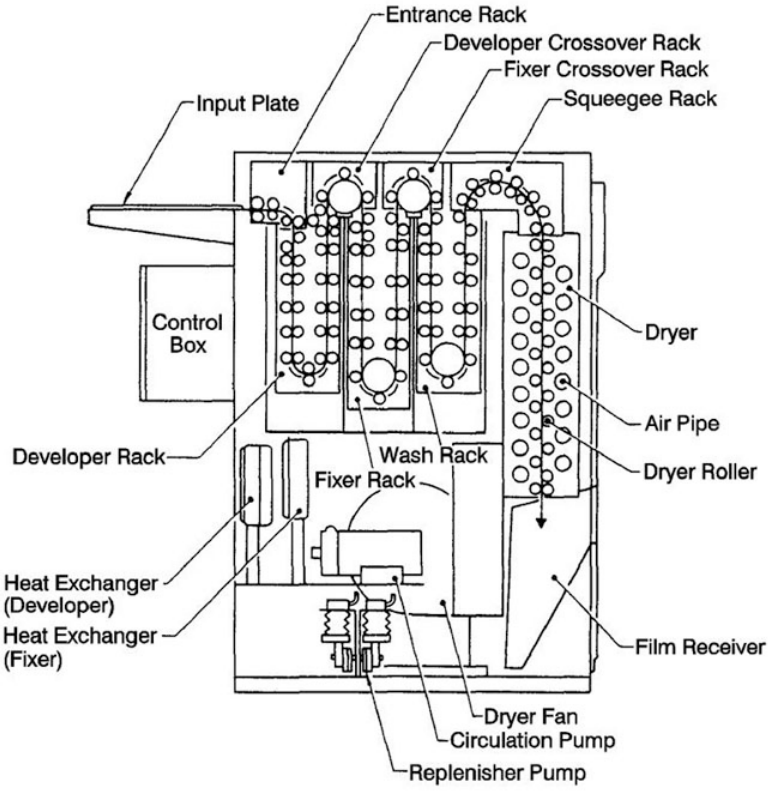


Figure 1–23. Example of an automatic processor.

In the roller transport type automatic processors for industrial X-ray films, processing solutions are used at high temperatures in order to speed the process. Many transport rollers are used to squeegee the film and remove the exhausted solutions from the surfaces.

Automatic film processing cycle

A typical complete automatic film processing cycle consists of the following four steps through which the film is automatically conveyed by the equipment:

1. Developing.
2. Fixing.
3. Washing.
4. Drying.

Developer

Developers used in automatic processors are specifically formulated to be suitable for processing at high temperatures and include special chemicals which adjust the contrast and fog. A hardener is included to harden the emulsion, thus providing sufficient resistance to the forced roller squeegee effect.

The activity level of the developer solution used in automatic processing is kept constant by the addition of replenisher. The degree of exhaustion of the active components may differ from case-to-case, depending on the type of processor, the average density of the radiographs, and the water quality, even if the quantities of film processed remain constant.

Process the film lengthwise to avoid losing the film in the rollers. When a new batch of developer is added, one or more strips are processed and preserved as the standard for comparison throughout the useful life of the developer. Thereafter, to compare the usefulness of the developer, a strip should be processed or checked after every 50 of 14x17-inch films or the equivalent processed, or 5 gallons of developer. If the densities of the test strip are less than those of the strip processed in the fresh solution, the rate of addition of replenisher should be increased. On the other hand, if the densities of the test strips are too high, the rate of addition of replenisher should be decreased.

Fixer

Developer tank transport rollers reduce the amount of developer carryover to the fixer. This extends the life of the fixer although the primary function of the rollers is to move the film through the processor.

An exhausted fixer solution will produce adverse effects relative to the permanency of radiographs. It is necessary to check the fixer solution for exhaustion once per month, or when regular processor maintenance is performed. Fresh chemicals are metered into the processor as film is processed and it is this replenishment that keeps the solution active. The normal replenishment rates for auto-fixer are 170–190 ml per 14x17 film processed. While checking replenishment rate, circulation in the fixer should also be verified and if the processor has a fixer filter, it should also be checked and cleaned.

Silver recovery

The value and scarcity of silver makes recovery of it economically feasible. Approximately 80 percent of the silver in the film emulsion is transferred to the fixer solution; the remaining 20 percent forms the radiographic image. Here we will discuss methods used to recover the silver from both the fixer and the film.

The unexposed and undeveloped silver halides in the film emulsion are removed by the fixer solution; therefore, the exhausted fixer becomes rich in silver content. There are three basic methods of silver recovery from the fixer solution, as presented in the following table.

Basic Silver Recovery Methods	
Type	**Description**
Electrolysis	When electric current is passed between two electrodes immersed in the silver bearing fixer, the silver is electronically deposited upon the cathode. This silver can be stripped from the cathode and refined. This method permits re-use of the fixer.
Metallic replacement	This method consists of replacing the metallic silver with a less valuable base metal such as iron, zinc, or copper. As an example, if steel wool is inserted into the exhausted fixer

Basic Silver Recovery Methods	
Type	**Description**
	solution, the silver in solution is replaced by the iron, and the silver accumulates on the bottom of the container in the form of sludge. The sludge is removed and refined to reclaim the silver. The fixer should be discarded after silver recovery by this method.
Chemical precipitation	Silver can be reclaimed from fixer by the addition of certain chemicals to the exhausted fixer. The silver is precipitated out of the solution in the form of a sludge that can be recovered and refined. The chemical reaction generates obnoxious fumes and odors, and separate facilities are recommended for this method of silver recovery. The fixer should be discarded after silver recovery by this method.

Maintenance of automatic processors

Periodic inspection, maintenance, and lubrication of radiographic film processing equipment is required by the technical manual governing its operation. It is imperative the prescribed daily, biweekly, and monthly requirements be strictly followed to ensure proper operation of equipment and to support quality radiographic inspection results. With appropriate maintenance, automatic processors give reliable and repeatable service for long periods of time.

609. Interpreting radiographic film

Interpretation of radiographic images cannot be translated into mathematical formulas or routine procedures. The wide variety of test objects and the various fabrication processes by which they have been made makes radiographic interpretation a complex subject. Radiographic inspection is conducted to assure a material or part has the required integrity to reliably perform the function for which it was designed. The effects of discontinuities or manufacturing deviations must be correlated with the function of the part. Specifications are usually used to spell out the discontinuities that could be considered detrimental to the function of the part and the acceptable magnitudes of the discontinuities.

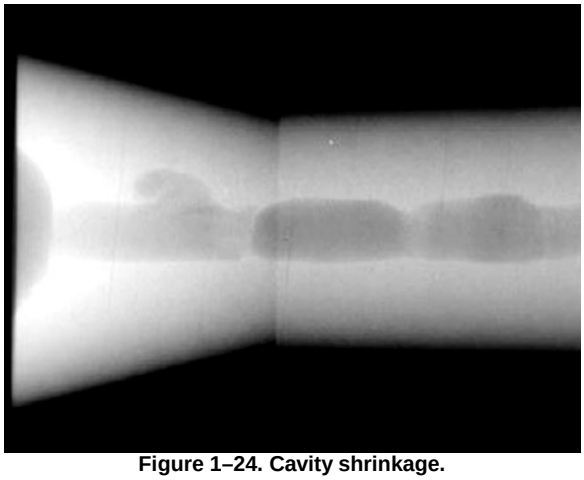
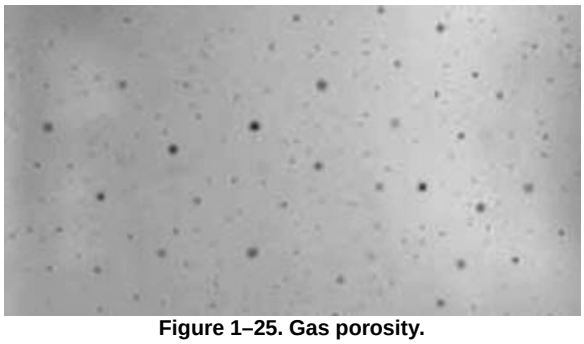
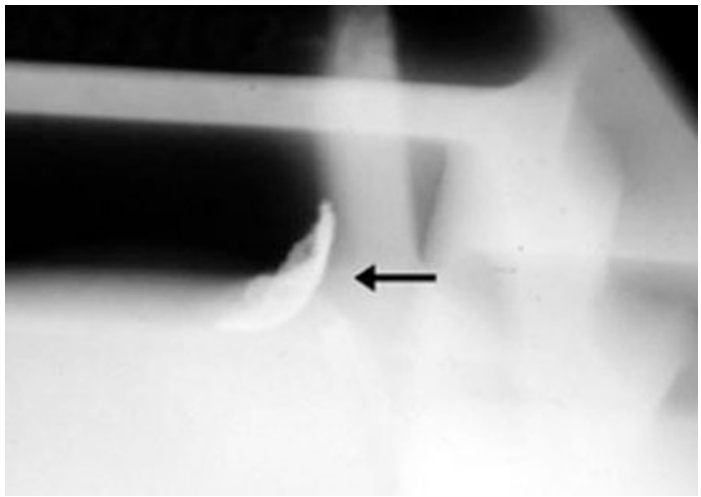
The inspector reading radiographs need to be acquainted with the exposure technique used, material radiographed, conditions of processing, and the geometry of the exposure setup. In this way, they can judge more accurately the radiographs produced and interpret the discontinuities more accurately. To determine if the part is rejectable or acceptable, they will generally consult with the structural or design engineer unless standards have been established. This section outlines the different defects that can be found while interpreting film.

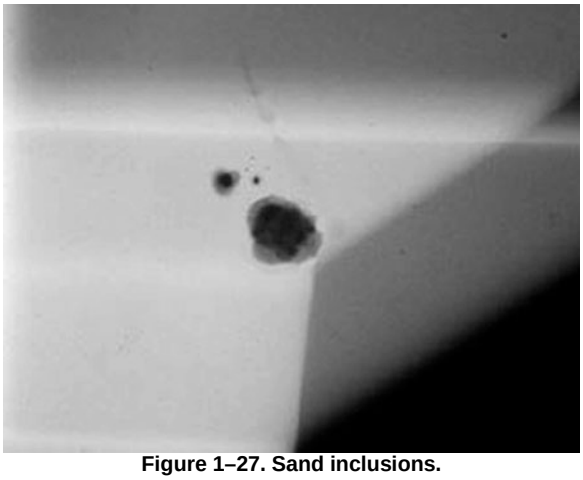
Castings

Radiographic examination is ideally suited to the inspection of castings because, the most common casting discontinuities are three-dimensional and are, therefore, almost independent of angle of inspection. Exceptions in some cases include fine cracks, cold shuts, unfused chills, and chaplets. To reveal these, the radiation must be at or near the same parallel plane as the discontinuity. Hairline surface cracks such as those produced by grinding are seldom, if ever, revealed by radiography.

Correct radiographic procedures require the selection of the lowest voltage to do the job in a reasonable exposure time. Where many castings are examined, a convenient technique is to establish a reasonable exposure time, and select the voltage required for the thickness of the particular section. Good practice normally requires exposures to be longer than 1 minute. When castings with great differences in thickness must be radiographed in one exposure, an increase in voltage will provide wider latitude, as well as shorter exposure time; however, contrast is reduced. If other factors remain constant, the most desirable combinations of voltage and exposure time for a specific part being examined may be governed largely by the acceptable radiographic sensitivity.

Casting defects are included in the following table.

Type of defect	Description
Shrinkage	A form of discontinuity that appears as dark spots. It assumes various forms, but it occurs because molten metal contracts as it solidifies in all portions of the final casting. Shrinkage can be recognized in a number of characteristics by varying appearances.  **Figure 1–24. Cavity shrinkage.**
Gas porosity	Caused by accumulated air or gas trapped in metal, these discontinuities are usually smooth-walled rounded cavities of a spherical, elongated or flattened shape.  **Figure 1–25. Gas porosity.**
Inclusions	Nonmetallic materials in a solid metallic matrix. They may be less or more dense than the matrix alloy and will appear as a darker or lighter indication.  **Figure 1–26. Inclusions.**

Type of defect	Description
Sand inclusions	Nonmetallic oxides appearing as irregular dark blotches. These come from disintegrated portions of mold or core walls and from oxides, which have not been skimmed off prior to introduction of the metal into the mold gates.  **Figure 1–27. Sand inclusions.**
Cracks	Thin (straight or jagged) linearly discontinuities that occur after the melt has solidified. They generally appear singly and originate at casting surfaces.
Cold shuts	Appear on or near a surface of cast metal as a result of two streams of liquid meeting and failing to unite. They look like cracks or seams with smooth or rounded edges.
Hot tears	Linearly disposed indications that represent fractures formed in a metal during solidification because of hindered contraction. The latter may occur due to overly hard mold or core walls. The effect of hot tears, as a stress concentration, is similar to that of an ordinary crack.

Welds

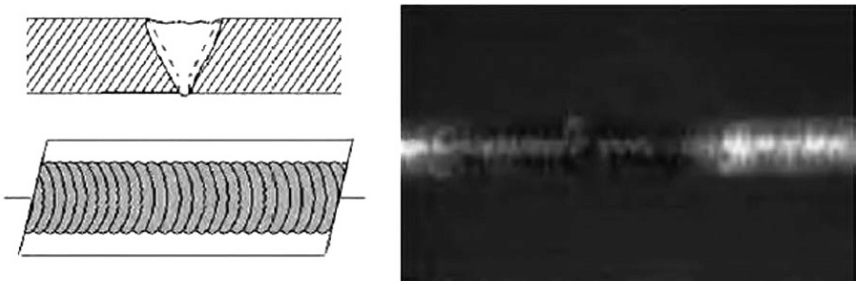
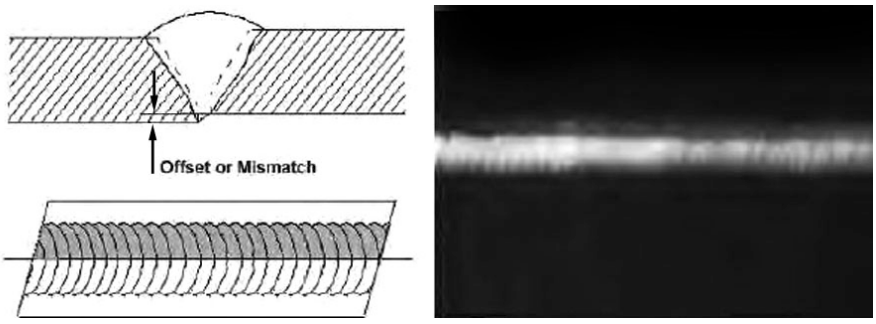
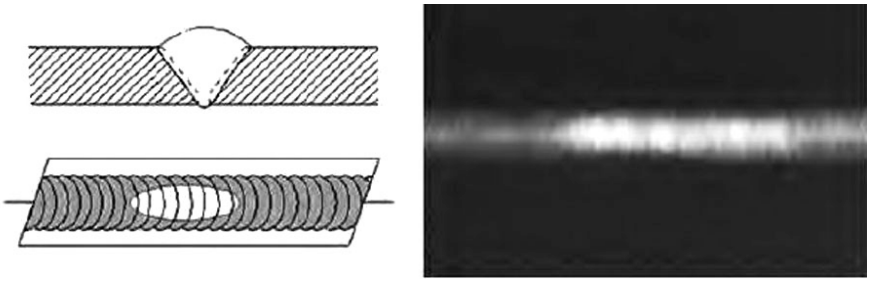
Metal may be joined together by welding to form many shapes and structures required in aircraft. This fabrication procedure, when carefully controlled, will provide a joint equal in strength to the parent materials. There must be just enough heat to produce fusion and adequate penetration, but not too much, which would cause porosity, cracks, or undercutting.

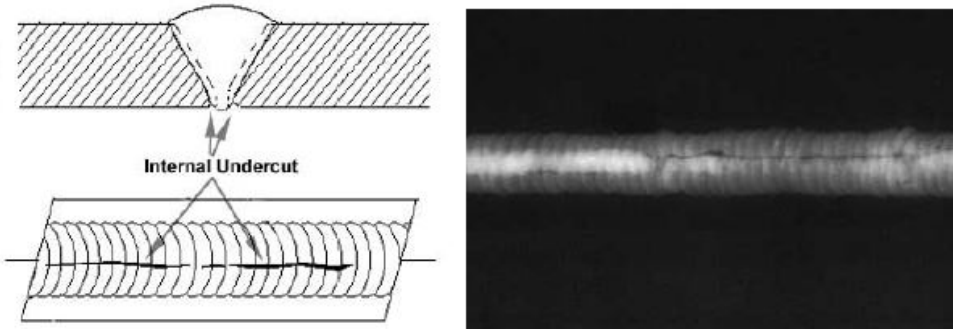
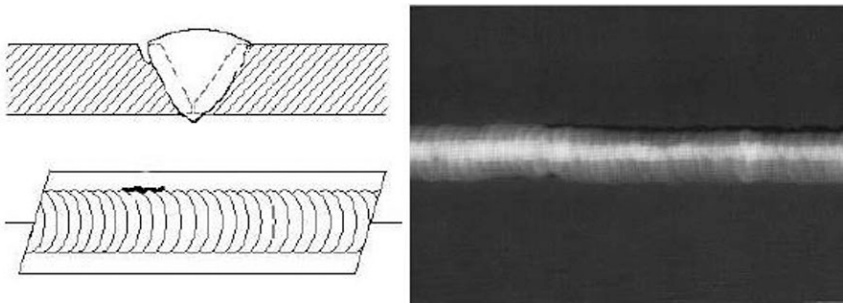
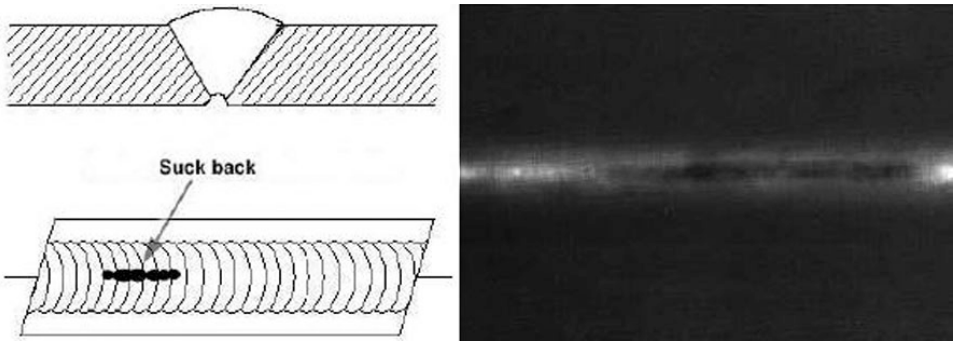
Most weld discontinuities can be readily detected by radiographic inspection since they consist of a change in material homogeneity. Cracks in welds are often detectable since they will usually occur in the direction of the thickness of the plate and will be parallel to the X-ray beam.

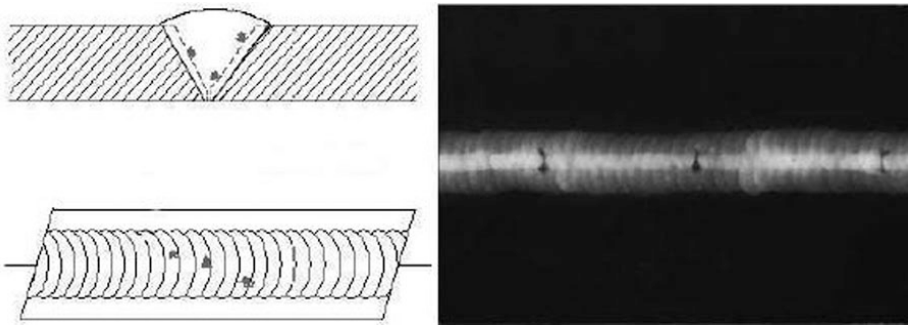
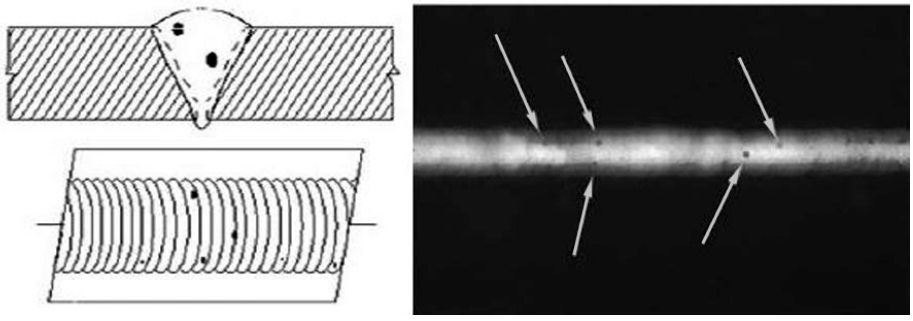
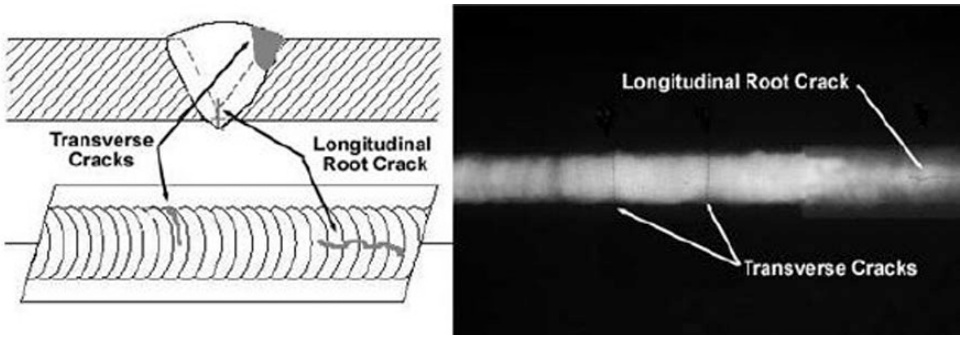
Welding defects and conditions

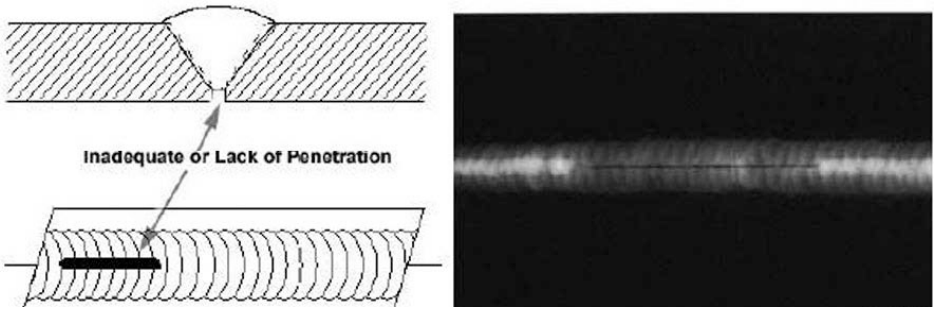
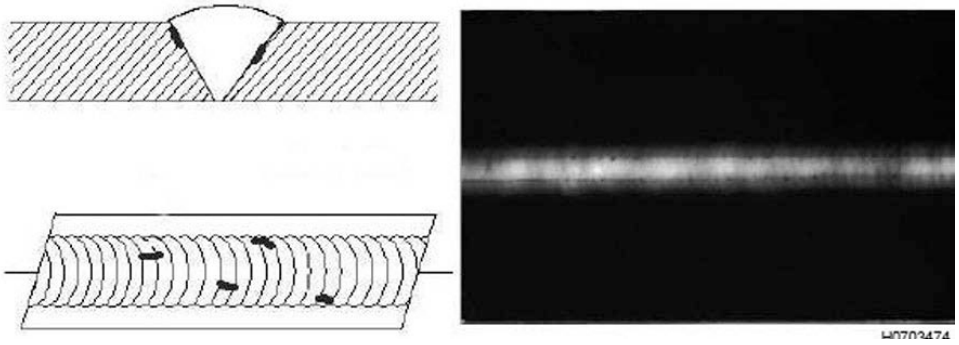
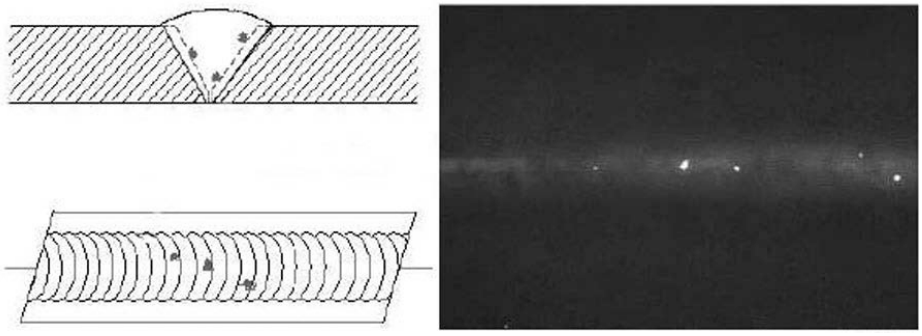
Foreign material whose density is approximately the same as the weld metal may not be detected. In the inspection of weldments, radiography is an indispensable tool for the location of internal discontinuities. It is the oldest and best known nondestructive means for this purpose. It is used to establish welding procedures, to qualify welders, to inspect welded fabrications, and for quality control. The following table describes welding defects.

Welding Defects	
Type of Defect	**Description**
Inadequate weld reinforcement	An area where the thickness of the weld metal is less than the thickness of the base material. The image density will be darker than the image density of the surrounding base material.

Welding Defects	
Type of Defect	**Description**
	 **Figure 1–28. Inadequate weld reinforcement.**
Offset (Mismatch)	A term associated with a condition where two pieces being welded together are not properly aligned. It shows a noticeable difference in density between the two pieces. This is caused by the difference in material thickness. The dark, straight line in the weld failed to fuse with the land area.  **Figure 1–29. Offset.**
Excess weld reinforcement	The appearance on a radiograph is a localized, lighter area in the weld. A visual inspection will easily be determined if the reinforcement is in excess of that specified by the engineering requirements.  **Figure 1–30. Inclusions.**
Internal undercutting	An erosion of the base metal next to the root of the weld. It appears as a dark irregular line offset from the centerline of the weldment. Undercutting is not as straight edged as lack of penetration because it does not follow a ground edge.

Welding Defects	
Type of Defect	**Description**
	 **Figure 1–31. Internal undercutting.**
External undercutting	An erosion of the base metal next to the crown of the weld. It appears as a dark irregular line along the outside edge of the weld area.  **Figure 1–32. External undercutting.**
Suck back	Is a condition where the weld metal contracted as it cooled and has been drawn up into the root of the weld. It looks similar to lack of penetration, but the line has irregular edges and is often quite wide in the center of the weld image.  **Figure 1–33. Suck back.**
Slag	These are nonmetallic solid material entrapped in weld metal or between weld and base metal. It has dark, jagged asymmetrical shapes within the weld or along the weld joint areas.

Welding Defects	
Type of Defect	**Description**
	 **Figure 1–34. Slag.**
Porosity	A result of gas entrapment in the solidifying metal. It can take many shapes on a radiograph but often appears as dark round or irregular spots appearing singularly, in clusters or rows. Sometimes porosity is elongated and may have the appearance of having a tail. This is the result of gas attempting to escape while the metal is still in a liquid state and is called *wormhole* porosity.  **Figure 1–35. Porosity.**
Cracks	Can be detected in an image only when they are propagating in a direction that produces a change in thickness that is parallel to the X-ray beam. Cracks will appear as jagged and often very faint irregular lines.  **Figure 1–36. Cracks.**
Incomplete penetration	This may occur in a fillet weld showing as dark lines along one side of a weld image.

Welding Defects	
Type of Defect	**Description**
	 **Figure 1–37. Incomplete penetration.**
Lack of fusion	A condition where the weld filler metal does not properly fuse with the base metal. It appears as a dark line oriented in the direction of the weld seam along the joining area.  **Figure 1–38. Lack of fusion.**
Tungsten Inclusions	Tungsten is a brittle and inherently dense material used in the electrode in tungsten inert gas welding. If improper welding procedures are used, it may be entrapped in the weld. Tungsten is denser than aluminum or steel; therefore, it shows as a lighter area with a distinct outline on the radiograph.  **Figure 1–39. Tungsten inclusion.**
Burn-through	This results when too much heat causes excessive weld metal to penetrate the weld zone. Often lumps of metal sag through the weld creating a thick globular condition on the back of the weld. These globs are referred to as *icicles*. It appears as dark spots, which are often surrounded by light globular areas.

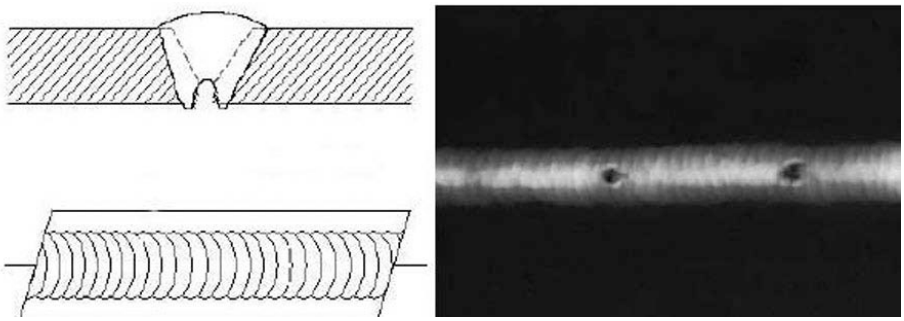
Welding Defects	
Type of Defect	**Description**
	

Figure 1–40. Burn-through.

In-service inspections

When materials are utilized fully as required in the design of modern aircraft, there is occasional failure due to fatigue. These result because of over-stress of the material due to unusual operating conditions such as the following:

- Wear.
- Corrosion.
- Cracks or crack like discontinuities.
- Water in honeycomb.
- Foreign objects.
- Assembly issues.

This type of material change may be the most difficult to detect due to the very nature of the changes and the inaccessibility of the areas in which these changes are most likely to occur in an aircraft. Radiography has been used to detect these conditions when they occur in inaccessible areas and are not available for visual inspection.

Wear

Rivets and bolts may wear the skin, spar, and frame holes so there is not a correct fit in the holes for adequate strength in joints or attachments of a wing section. This can occur due to continued flexing of components from use or because of severe stress due to unusual operating conditions in turbulent weather or an adverse landing. This condition may also result in radial cracks from bolt holes. This type of failure is extremely difficult to detect by radiography.

Corrosion

Corrosion may occur in aircraft materials, which reduces its strength and expedites the possible failure. This deterioration of the metal may be due to electrolytic action, moisture, chemicals, or gases, which attack the metals, intergranular action due to improper heat treatment at the time of manufacture, or other factors. This condition usually occurs on internal surfaces of such components as tubular supports or housings. Since corrosion represents a change of material and occurs in all directions, it is easily detected by a proper radiographic exposure. If corrosion has proceeded to this point, the support is appreciably reduced in strength and may experience failure.

Cracks or crack like discontinuities

Cracks and other crack-like discontinuities are found in numerous parts and structures. This is particularly true where structures are subjected to vibration or fatigue loading, due to propagation of

these crack-like discontinuities. Cracks are very dangerous discontinuities and are the most difficult service type failure to detect by radiography. Crack-like discontinuities will appear in a radiograph as very straight and sharply outlined dark or black lines. They may also appear as diffused jagged lines; in some cases, they have a tree-like pattern.

Crack-like discontinuities oriented at any angle other than 90 degrees to the X-ray film and not parallel with the X-ray beam, produce very little change to the radiation transmission and may not be visible in the radiographic image. Radiography can only be depended on to reveal crack-like discontinuities that are aligned within approximately 7 degrees of the X-ray beam. This depends on the thickness and width of the crack. Normally cracks that are easily detectable by X-ray are visible to the naked eye. Radiography may be used to determine the extent of cracks or other conditions detected visually, or by magnetic particle or penetrant methods of inspection.

Water in honeycomb

A typical condition that occurs in honeycomb structures is the formation of water in the cores. Entrapped water causes corrosion of both face sheet and core material. This entrapped water will also freeze and expand at high altitudes. This expansion distorts the cells and can break the bonds between core and facing sheets. When this condition exists, vibration of the face sheet can occur, causing failure of adjacent bonds and propagation of bond failure.

Radiographic inspection is conducted to evaluate core damage and water content as a maintenance inspection. Entrapped water in honeycomb cells usually appears as a smooth, consistent, light density area that does not have a grainy or porous appearance. The lightest area (more dense substance) indicates greater amounts of water.

Epoxy in honeycomb cells appears grainy, non-homogeneous. If the cell is not spotty and completely filled, the epoxy will be located around the periphery of each cell.

Foreign objects

Radiography is an excellent method to locate and evaluate foreign objects. Foreign objects may be free rivets, bolts, or other objects that could be detrimental to the function of the part or assembly.

Assembly issues

Radiography has found wide use in the reevaluation of various assemblies to determine status or condition. If the use of the assembly produces changes in it, which are recordable by an X-ray beam, then radiography may be useful in supplying confirming evidence of the suspected condition.

Triangulation technique

In some cases, it is desirable to know the location of a given discontinuity relative to one of the plane surfaces of the object. If repairs are to be made, it is desirable to know from which surface the repair should be started. A single radiograph may not reveal this information. This information can be obtained by making a double exposure with suitable markers placed on the object. These markers are placed on both the source side and on the film side. Either two exposures can be made on one film where discontinuity is very prominent; or two separate films can be used and later be superimposed. This is a triangulation technique, whose radiographs can be used for measurement purposes to obtain the desired information.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

608. Processing radiographic film

1. What two distinct areas should be established within a darkroom, which enables efficiency and reduces the possibility of damaging radiographic film?

2. How are ventilation and safelights used in a darkroom?

3. What is an automatic processor processing time?

4. A typical complete automatic film processing cycle consists of what four steps?

5. What are used in automatic processors that are suitable for processing at high temperatures and include special chemicals, which adjust the contrast and fog?

6. Approximately what percent of the silver in the film emulsion is transferred to the fixer solution?

7. What method of silver recovery consists of replacing metallic silver with a less valuable base metal such as iron, zinc, or copper?

609. Interpreting radiographic film

1. Radiographic examination is most common for the inspection of what?

2. What type of casting defect appears as dark spots and assumes various forms but occurs because the molten metal contracts as it solidifies?

3. What type of casting defect is straight or jagged and occurs after the melt has solidified, usually appearing singly and originating at casting surfaces?

4. What type of welding defect has two pieces of metal being welded together that are not properly aligned?

5. What type of welding defect is a nonmetallic solid material entrapped in weld metal with dark, jagged asymmetrical shapes?

6. What type of in-service inspection may affect rivets and bolts on skin, spars, and frame holes?

7. What can orient at any angle other than 90 degrees to the X-ray film and not parallel with the X-ray beam and may not be visible on the radiographic image?

8. What condition exists in which vibration of the face sheet may occur, causing failure of adjacent bonds and propagation of bond failure?

9. What can find the location of a given discontinuity relative to one of the plane surfaces of an object?

Answers to Self-Test Questions

601

1. X-rays.
2. Photon.
3. Protons, neutrons, and electrons.
4. Isotopes.
5. Sufficiently heat the material.
6. The cathode.
7. Kilovoltage.
8. Short.
9. The K and L series.
10. Photoelectric absorption.
11. Compton Effect.
12. At least 1.02 MeV.
13. The atomic number, density, and thickness of the material.

602

1. A high atomic number.
2. The X-ray tube.
3. A beryllium window.
4. Focusing cup.
5. High atomic number, high melting point, high thermal conductivity, and low vapor pressure.
6. Inherent filtration.
7. A water-antifreeze mixture.

603

1. A gammagraph.
2. An emulsion and a blue tinted base of polyester.
3. Silver halide crystals as photosensitive material, plus additives and gelatin.
4. Two.
5. The developing agent.
6. It produces various shades of gray where the film has been only partially exposed.
7. Density.

8. 2.0.
9. Perpendicular to the part and the film located on the same plane as the part.
10. Film contrast.
11. Images with excellent resolution of detail.
12. Film grain size.
13. Film contrast.
14. Latitude.
15. Contrast.
16. A penetrameter.
17. The electron bombardment pattern on the target.
18. The resolution of a crack.
19. Cracks must be at least two-percent of the part's thickness in order to have a readable indication.
20. Reflected scatter.

604

1. Sulfur hexafluoride gas.
2. With the film on edge to avoid container damage and possible film damage.
3. Make a radiograph of a step-wedge and penetrameter to determine the sensitivity and contrast of the film in question, a 1.4 percent sensitivity (2–1T).
4. It will be placed in an acceptable film file pouch and the information typed or written legibly on the film file.
5. A wide range of penetrameters.
6. Fluorometallic Screens.
7. Through the use of electronic direct-reading type densitometers.
8. TLD badge, EPD, DAD, and survey instruments.
9. By three silicon diode detectors, which save data to secure memory every few minutes and provide visible and audible alarms if either the accumulated dose or dose rates exceed specified levels.
10. DAD.
11. Survey meters.

605

1. Ionization and excitation produced in the cells of living tissue.
2. An acute exposure.
3. The lymphoid tissue, bone marrow, spleen, organs of reproduction, and gastrointestinal tract.
4. Roentgen, rad, and rem.
5. Roentgen.
6. Rad.
7. Rem.
8. The TEDE of 5 rem and the sum of the deep dose equivalent from external sources and the committed dose equivalent to any individual organ or tissue, other than the lens of the eye, of 50 rem.
9. The radiological safety operating and emergency procedures.
10. AFTO Form 115.
11. At initial operation, and on each shift when X-ray equipment is used.

606

1. The local bioenvironmental engineering services and the NDI supervisor.
2. Any enclosed radiographic facility designed to limit exposures on the outside of the facility to less than 2 mrem in any one-hour and less than 100 mrem in a year.

3. Posted “Caution, High Radiation Area”, “Danger, High Radiation Area”, or “Grave Danger, Very High Radiation Area” signs visible from any location.
4. Twenty seconds.
5. An interlock system.
6. Flight line, open hangars make-shift buildings.
7. Low-intensity flashing warning lights.
8. Every six months.
9. Safety monitors.
10. Two mrem/hr through 1 rem/hr, as a minimum.

607

1. Materials, equipment, personnel, and documentation that are well defined and maintained.
2. Monthly.
3. X-ray a piece of 14x17 Class 4 (or fastest film speed used in lab). X-ray film until a 1.5 ± 0.2 density is achieved. Use initial settings of 25 kV, 2 mA at 8 seconds.
4. Prior to use.
5. Five.
6. AFTO Form 140.
7. The zero adjust switch.
8. Two minutes.

608

1. Dry and wet areas.
2. Ventilation provides effective circulation of air for the protection of personnel due to the fumes associated with film development. Safelights are used to minimize fogging of undeveloped radiographic film.
3. Five to 13 minutes.
4. Developing, fixing, washing, and drying.
5. Developers.
6. Eighty percent.
7. Metallic replacement.

609

1. Castings.
2. Shrinkage.
3. Cracks.
4. Offset.
5. Slag.
6. Wear.
7. Crack-like discontinuities.
8. Water in honeycomb.
9. Triangulation technique

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (601) Excited electrons will surround a material in the form of an electron cloud commonly known as
   a. isotopes.
   b. fluorescence.
   c. thermionic emission.
   d. electromagnetic radiation.

2. (601) What is the positive terminal of an X-ray tube?
   a. Anode.
   b. Cathode.
   c. Electron.
   d. Filament.

3. (601) The type of process for when photons have energies of 100 kiloelectron-volt (keV) or less, and are readily absorbed by the electrons in the orbital shells of the atoms of the absorber, is referred to as
   a. compton effect.
   b. pair production.
   c. characteristic radiation.
   d. photoelectric absorption.

4. (602) How much incident radiation should a subject being X-rayed absorb in order to achieve a high-contrast?
   a. 90–94 percent.
   b. 96–99 percent.
   c. 96–100 percent.
   d. 90–100 percent.

5. (602) What has a very important effect upon the quality of an X-ray image?
   a. Strong vacuum.
   b. Target material.
   c. Size of the focal spot.
   d. Diameter of a filament.

6. (602) To the radiation beam, an open crack appears as
   a. variations of light on an image.
   b. a significant change in material thickness.
   c. shadows created by absorption by the test specimen.
   d. a change in the apparent composition of the material.

7. (603) What can be used as a recording medium because their emulsions are sensitive to the quantity and the energy of electromagnetic radiation over a wide spectral range?
   a. Films.
   b. Screens.
   c. Photograph.
   d. Gammagraph.

8. (603) What makes up the formation of latent images by interactions to electromagnetic radiation?
   a. Polyester.
   b. Black metallic silver.
   c. Silver halide crystals.
   d. Silver bromide crystals.

9. (603) Which class of radiographic film has a moderate signal-to-noise-ratio?
   a. Class 1.
   b. Class 2.
   c. Class 3.
   d. Class 4.

10. (603) How is detail sensitivity of a radiographic image visually revealed?
   a. Densitometer.
   b. Penetrameter holes.
   c. Signal-to-noise ratio.
   d. Inverse square law diagram.

11. (603) What is exposure of film from scatter radiation called?
   a. Fog.
   b. Back scatter.
   c. Forward scatter.
   d. Image distortion.

12. (604) Which of these materials *cannot* be used for thermoluminescent dosimeter (TLD) badges?
   a. Silicon diode.
   b. Lithium borate.
   c. Calcium sulfate.
   d. Lithium fluoride.

13. (604) What should you do when a digital alarm dosimeter (DAD) is used by a different radiographer?
   a. Sign it out.
   b. Calibrate it.
   c. Reset it to zero.
   d. Make sure there is available memory.

14. (605) When the effects of a given absorbed dose decreases, the rate of exposure
   a. doubles.
   b. increases.
   c. decreases.
   d. stays the same.

15. (605) Symptoms can be expected if the whole body is exposed to how much radiation?
   a. 10 roentgen equivalent mans (rem).
   b. 100 radiation absorbed doses (rad).
   c. 1000 millirad (mrad).
   d. 100 roentgens.

16. (605) A radiation safety officer (RSO) is normally appointed by whom?
   a. Supervisor.
   b. Flight chief.
   c. Unit commander.
   d. Maintenance officer.

17. (605) What form will be completed for all overexposures, shielded, and unshielded inspections?
    a. Air Force Technical Order (AFTO) Form 115, Digital Alarm Dosimeter Results log.
    b. AFTO Form 125A, Industrial radiography Utilization Log Facility Survey Drawing.
    c. Department of Defense (DD) Form, Request for Movements Improvement Study.
    d. AFTO Form 125, Industrial Radiography Utilization Log.

18. (606) An area that is considered to be very high in radiation, measured in radiation absorbed dosages (rad), is an area where an individual is
    a. 3.3 feet from any source of radiation that could receive greater than 500 rads in one hour.
    b. 2.5 feet from any source of radiation that could receive greater than 100 rads in one hour.
    c. 3 feet from any source of radiation that could receive greater than 500 rads in one year.
    d. 1 foot from any source of radiation that could receive greater than 100 rads in one year.

19. (606) When unshielded radiographic operations are conducted for vertical beam orientation, you should erect a rope barrier around the X-ray tube head at what distance?
    a. 230 feet.
    b. 250 feet.
    c. 275 feet.
    d. 300 feet.

20. (606) When should radiographers verify proper operation of radiography interlocks?
    a. Bi-weekly.
    b. Prior to use only.
    c. Every six months.
    d. Daily and prior to use.

21. (607) When is the survey meter operational check performed?
    a. Monthly and prior to use.
    b.Weekly and recommended by manufacturer.
    c. Every 14 days or as recommended by manufacturer only.
    d. Every 14 days or as recommended by manufacturer, and prior to use.

22. (607) In order for a safelight to meet or exceed minimum requirements, the density change must be at least
    a. 4 minutes and 45 seconds.
    b. 4 minutes and 25 seconds.
    c. 2 minutes and 45 seconds.
    d. 2 minutes and 25 seconds.

23. (607) How do you go about completing an operational check on the Victoreen survey meter?
    a. Set selector switch to the 300 milliroentgen (mr)/hour (hr) position and place the check source in the open position.
    b. Place a radioactive source material as close as possible to the white dot and maximize reading.
    c. Set selector switch to the 300 mr/hr position and place the check source in the closed position.
    d. If the instrument is correctly nulled, the display will read 0.00.

24. (608) What type of safelight filter is the only model designated for use with industrial radiographic film?
    a. 2A or equivalent.
    b. 4B or equivalent.
    c. 6B or equivalent.
    d. 8C or equivalent.

25. (608) When a new batch of developer is added, a strip of film should be checked after how many 14x17 inch pieces of film have been processed to compare the usefulness of the developer?
    a. 20.
    b. 50.
    c. 100.
    d. 150.

26. (608) Which type of silver recovery system sends electric current to the silver bearing fixer and the silver is electronically deposited upon the cathode and can be refined?
    a. Electrolysis.
    b. Electro replacement.
    c. Metallic replacement.
    d. Chemical precipitation.

27. (609) What type of casting defect may be less or more dense than the matrix alloy and will appear as a darker or lighter indication?
    a. Cold shut.
    b. Shrinkage.
    c. Inclusions.
    d. Sand inclusions.

28. (609) What are often detectable in the direction of the thickness of a plate and will be parallel to the X-ray beam?
    a. External undercutting.
    b. Cracks in welds.
    c. Lack of fusion.
    d. Seams.

29. (609) What type of welding defect does not properly fuse with the base metal and appears as a dark line oriented in the direction of the weld seam?
    a. Burn-through.
    b. Lack of fusion.
    c. Tungsten inclusion.
    d. Incomplete penetration.

30. (609) How does water in honeycomb cells usually appear on a radiograph?
    a. Dark and grainy.
    b. Grainy and non-homogeneous.
    c. Spotty and completely filled with light appearance.
    d. Smooth, consistent with a light density area and no grainy appearance.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Digital Radiographic Inspection

COMPUTED RADIOGRAPHY (CR) HAS EMERGED AS A leading environmentally safe technology for recording radiographic images similar to the way film radiography has been practiced for decades. CR offers many advantages over conventional film-based radiography. The most prominent advantages are the increase in productivity, ease of archiving and retrieving images, use of powerful image processing tools to qualitatively improve images, greater thickness latitude with same or better contrast sensitivity and in many applications, a lower X-ray dose to inspect the object. CR enhances productivity as image processing is accomplished in a very short time without the dependence of chemicals or water.

In this unit you will gain a basic understanding of digital radiography and the equipment used. Computed radiography improves productivity and uses new technology to enhance images by the use of lasers which will also be discussed. Lastly, you will learn several different process control tests that are needed to ensure the longevity of your lab's equipment, as well as the ability to perform CR.

2–1. Fundamentals of Digital Radiography

Digitization of continuous variables is a common practice. Digital imaging techniques allow us to retrieve information electronically for easy and accurate manipulation or analysis by computers. Digital images vary from traditional images in the way the image information is represented. In this section, you will learn about fundamentals of digital radiography, CR systems, and their process control procedures.

610. Computed radiography

CR is similar to film-based radiography as it utilizes the same radiation source; however, it differs in how the image is captured and processed. Rather than using conventional radiographic film, CR uses a flexible phosphor imaging plate (IP), which is exposed in the same manner as film, but is processed using a CR reader or scanner. This lesson introduces the basic understanding of CR and how it works.

Understanding computed radiography

CR (photo stimulated luminescence method) can be described in simple terms as a two-step radiographic imaging process:

1. First, a storage phosphor IP is exposed to ionizing radiation, both X-ray and gamma rays.
2. Second, the luminescence from the IP's photo stimulable luminescent phosphor is detected, digitized, and presented via a high-resolution display monitor. This is displayed in figure 2–1.

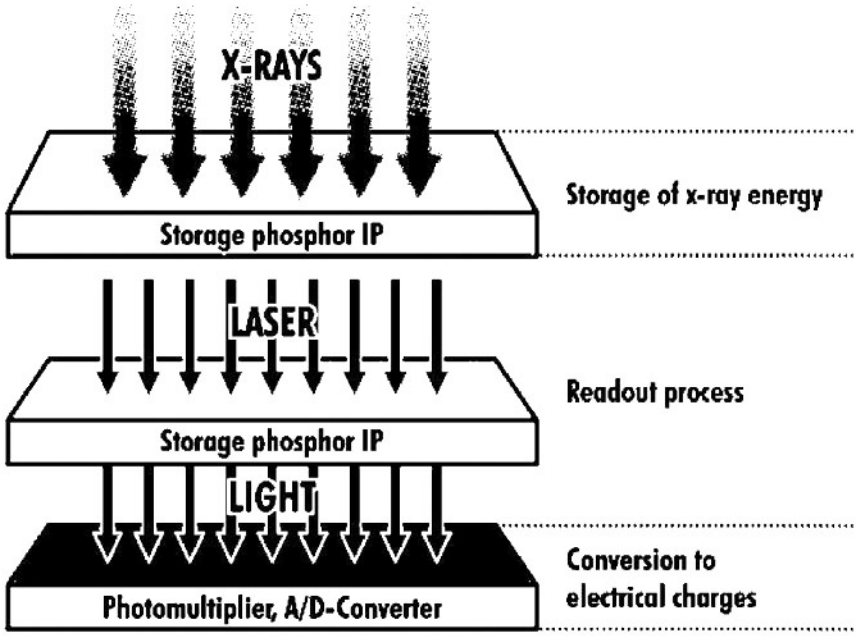


Figure 2–1. Computed radiography.

In simpler terms, a reader uses a laser to convert energy recorded in an IP phosphor into light, and the light output converts into a digital image, which is evaluated using each manufacturer's unique CR software.

Most Department of Defense (DOD) aerospace inspections are low energy applications that fall into two general categories. These can each be performed with the following:

- Low spatial resolution/low signal-to-noise ratio (SNR) (e.g., foreign objects, water, and honeycomb).
- High spatial resolution/high SNR (e.g., airframe cracks and welds).

Conventional film vs digital images

Compared to conventional radiographic film, CR typically can produce improved contrast sensitivity as well as increase the image latitude, being able to image a wider range of densities in one exposure as compared to film; however, conventional high-resolution film is still considered to have superior spatial resolution than CR. This is primarily because film contains silver halide grains, while state-of the-art CR systems typically sample data at a resolution of 25−100 microns (pixel size). Although CR pixels are relatively larger than film grains, detection of fine defects (e.g., cracks, microporosity) is dependent on the combination of spatial resolution, contrast sensitivity, and SNR.

The sensitive layer of IPs consists of small crystals of a barium fluorobromide that absorbs energy from incident X-rays and stores that energy in excited states of the crystal structure. The CR crystals are typically much larger than the silver halide grains in industrial films. This allows for greater thickness of the sensitive layer and consequently improves X-ray absorption efficiency. The thickness of the sensitive layer and the crystal size can be tuned to adjust the speed and resolution of the IP. At the kV ranges used in many common inspections, the thickness and composition of the sensitive layer can make IPs somewhat more sensitive to scattered radiation than typical films; thus, in some inspections, a slightly lower kV setting, increased part-IP distance, or additional front screens are needed to compensate.

Digital images

Image types could be classified as *continuous* and *discrete*. Discrete images are described as being distinct from each other while continuous image variables flow into each other and are considered to be similar to regular film. These definitions are the basic definitions in any mathematics or scientific discipline. Continuous can be converted to discrete variables.

Digital imaging techniques allow us to retrieve information electronically for easy and accurate manipulation or analysis by computer. Digital images vary from traditional images in the way the image information is represented.

Traditional images, like the image that appears on an industrial radiographic film, are made up of continuous tones. We can get an electronic representation of the continuous tones with an analog waveform generated by some measuring device. Sampling discrete sections of the waveform and storing the sampled value as strings of ones and zeros (the only digits used in modem computing equipment) produce digital images.

Two types of resolution that make up a digital image quality include brightness and spatial resolution.

Brightness resolution

The brightness resolution is also referred to as the grayscale or color range of an individual pixel. Brightness resolution is defined in a digital image by the pixel it represents. The value can be made of one or more *bits*. The more bits actually used to define the brightness levels in a digital image, the higher the brightness resolution and quality of the image. Brightness resolution is also known as *pixel depth.*

Spatial resolution

Spatial resolution is the number of pixels horizontally and vertically in a digital image. Spatial resolution of a digital image determines the actual size of the pixel in real units, and thus, is determined by the sampling interval of the original digitization operation. A longer interval produces lower spatial resolution images, while a shorter interval produces higher spatial resolution. The term resolution when not preceded by spatial or brightness generally refers to spatial resolution.

Capture

Digital radiographic images are captured in many different ways in industrial radiography. Some methods involve the use of standard radiographic film (film based capture), or film designed with digitization in mind. Other methods bypass using film altogether, and use direct or indirect capture methods (filmless capture). All rely on taking an analog signal and converting it to a sampled digital form using sensors and photo-multiplier tubes for the analog signal.

Laser scanners

Laser scanners utilize a laser beam that passes through the film, and the resulting light is converted to a voltage signal by a photomultiplier tube. The voltage values are sampled over time to produce a digital image with brightness values calibrated to optical density values.

Phosphor screens

Phosphor screen based systems are the most like traditional film based radiography. A special capture system X-ray sensitive screen (or plates) captures radiographic information and is then placed in a reader to convert the information into a digital image. The plates can be either rigid or flexible depending upon the hardware used, and are reusable. Phosphor filmless imaging is a very popular method of digital radiography because of the ease of use, as well as the film like nature of the process.

Digital image quality factors

Image quality of a scanned image is dependent upon pixel size, spatial resolution, and the pixel depth. The sampling time for a given area is generally proportional to the spatial resolution and to the brightness resolution. Generally, digital capture systems and scanners allow you to set these values up

to the limit of the hardware. It is not always necessary to do so for all shots. Entrapped water detection, for example, would benefit from the highest brightness resolution, but would not require the highest spatial resolution.

The size of stored images in bytes is directly proportional to the image spatial resolution; so, it does not make sense to perform every capture at the highest possible quality. The procedure and part should dictate the resolution settings to use for digital capture. In addition to the brightness and spatial resolution, other factors that affect the quality of a captured digital image include the following:

- Part noise.
- Dynamic range.
- Artifacts.

Noise

Noise is defined as the data present in a radiological measurement that is not directly correlated with the degree of radiation attenuation by the object being examined. Scatter within the image, variations in the phosphor plate, and electronic induced noise all contribute to the degradation of the image. Noise creeps into a digital radiograph in a couple of ways:

- There is the noise inherent in radiography, and can generally be kept to a minimum by using the proper and prescribed techniques.
- There is also the noise in the digital capture hardware. The modular transfer function (MTF) is used to measure the SNR. This is considered a factor when deciding upon a digital capture system for your particular application.

Dynamic range

Dynamic range is the effectiveness of the scanner or capture hardware in differentiating between differing shades of gray or brightness. It is a measurement of the number of bits used to represent each pixel in a digital image. Phosphor plate capturing systems tend to excel in the dynamic range department while film digitizers tend to have a breakdown level toward the higher densities. The greater the dynamic range, the higher the contrast and color/grayscale bit depth.

Artifacts

Artifacts are unwanted images caused by input or output process, that is, hardware or software. Images like films are subject to artifacts created during image capture. Artifacts such as dust and fingerprints can also harm the quality of a digital image. Many times, artifacts are hard to distinguish from actual indications on an image because of the nature of digital imaging. It is important to keep the capturing hardware clean and to cover digitizers and scanners when they are not in use to minimize artifacts.

Basic CR process

The basic steps of the CR process are given in the following table and in figure 2–2.

CR Process		
Step	**Process**	**Description**
1	Exposure of object	Using the approved procedure, the test object is exposed to ionizing radiation.
2	Image capture	An IP, in place of film, is exposed to the ionizing radiation and a latent image is created.
3	Scanning of the IP	Depending on the CR system, the technician will enter pertinent information into the acquisition software before or after the scanning operation. The exposed IP is placed in the reader, often using a hard cassette specific to the system, and the IP is scanned with a laser (red) stimulating light causing photostimulable

CR Process		
Step	**Process**	**Description**
		luminescence (PSL) light to be released from the IP. This light is collected by optics and channeled to one or more photomultiplier tubes (PMT). The computer processes the information received, and the software allows the viewing of the image data.
4	Viewing/Post Processing.	The image is displayed on a high-resolution viewing monitor (typically monochrome). Technicians evaluate the image according to the inspection procedures, and may add appropriate labels or annotations. During this step, contrast and brightness (also known as window and level), as well as magnification, are often adjusted by the technician. In some cases, select post-processing filters may be authorized.
5	Image storage/Filing	The original data file, processed CR image (if required), and any annotations are saved and are retrievable based on archival requirements.

Figure 2–2. CR imaging flowchart.

611. Computed radiography equipment

Like film systems, CR systems can vary in capability. IPs can range from coarse grain to fine grain (like film), and IP readers can sample the data at low or high resolution. In addition, many other CR system variables can significantly influence the image quality. There are many different types of CR systems used in the Air Force; this career development course (CDC) is not specific to any one type. First, we look at the different components included in a typical CR system.

Computed radiography system

The CR system is comprised of several components, each of which affects the inspection process. The primary components include the following:

- Imaging plates.
- CR reader.
- CR eraser.
- Computer workstation.

Imaging plates

A phosphor IP is a flexible two-dimensional area detector in which the latent image of the test part is stored after the test part is exposed to the penetrating radiation. The primary function of the IP is to release the radiation input signal containing part information into a corresponding optical signal while preserving the maximum amount of part information.

IPs in CR systems can range from coarse grain to fine grain (like film), and IP readers can sample the data at low or high resolution. In most cases, a coarse or medium grain IP used with an IP reader with low sampling resolution can produce acceptable images for low spatial resolution/low SNR applications. Conversely, a fine grain IP used with an IP reader with high sampling resolution may be required for high spatial resolution/high SNR applications.

IPs use the same type of polyester plastic substrate as modern X-ray films. They are produced in sizes similar to commonly available films. IPs typically include additional layers to control the emitted light and an outer coating to seal and protect the sensitive layer from moisture and abrasion. Unlike most

X-ray films, IPs are all single-sided, and the thickness of the sensitive layer is greater than for film emulsion layers. Optimum imaging performance is obtained when the sensitive layer faces the X-ray source. Severely degraded image quality and physically inverted images will result if IPs are mistakenly exposed backwards. It is important to know how to handle and take care of the IPs in your lab.

Handling of Image plates

The normal wear-out mechanism for IPs is mechanical damage or abrasion. When the protective layer becomes scratched, the image quality is degraded. Thus, the life obtained varies dramatically with the care and cleanliness used in handling the IPs. Handle only by the edges to prevent skin oils and fingerprints from contacting the active surface. In some applications, where they are never directly handled and remain in rigid cassettes during storage and exposure, they can remain useful for many thousands of uses.

Care of image plates

Particular care should be used to keep all cassettes, screens, and sleeves that come in contact with IPs free of dust and debris. Minor scratching or contamination of the backing surface does not directly affect IP performance or image quality, but can cause the transport of dust and abrasives into cassettes, readers, or erasers. Technicians should use cotton gloves to aid in keeping IPs clean. Only manufacturer-recommended cleaning solutions and procedures should be used on the IPs if removal of surface contaminants is required.

Computed radiography reader

The reader is the component that will take an exposed IP, scan the IP using a laser light, capture the light emitted from the IPs, and provide the necessary information to the computer workstation. Following the exposure to the laser light, the eraser will expose the IP to white light, causing the IP to be returned to a state for future use.

The characteristic time to naturally relax the excited metastable states is typically, many hours at room temperature allowing up to 24 hours in some applications between exposure and readout. However, if a red light photon is absorbed by an excited electron in a metastable state, it can then decay promptly through an alternate decay path, releasing its stored energy in the form of a blue light photon.

This process is at the heart of CR, causing a “tickling” of an electron that was previously excited by an absorbed X-ray with a red laser, emitting a blue light photon. This process is known as PSL, and *photo-stimulable phosphor* (PSP) is a material used with this characteristic. By measuring the amount of blue light emitted, the amount of absorbed X-ray dose is inferred, as shown in Figure 2–3.

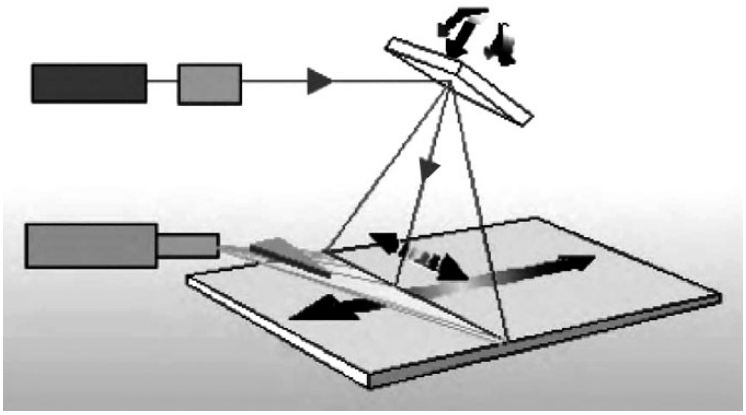


Figure 2–3. Computed radiography reader.

CR reader is not an imaging system like a camera or microscope, and the emitted blue light is not focused to an image receptor. Various readers use different methods to gather or guide the blue

emission light into the PMT; however, none of the readers focus light from points on the IP to an image receptor. Rather, the CR image is formed by sampling the PMT output in time, and associating each measurement with the location of the red laser during that time interval. The PMT views a large area of the IP, so any and all blue light emitted can be gathered and measured.

Computed radiography eraser

In severe cases, defect traps result from CR erasing and can cause residual or *ghost* images that can be very difficult to erase. Ghost equalization is recommended by some IP manufacturers to recondition IPs with residual images, while others recommend exposing affected IPs to wide-spectrum ultraviolet light. Any IPs that exhibit objectionable residual images cannot be used for inspection; therefore, exposure techniques that subject IPs to extreme exposure contrasts should be avoided (e.g., very long exposures at low kV that are sometimes attempted when trying to achieve contrast in both thin and thick regions of small parts that do not fully cover the entire IP).

Residual images are reduced or eliminated with lead masking when the test article does not cover the entire imaging plate. If authorized for the application, pre-filters or screens may also help.

Computer workstation

The workstation typically controls both the acquisition and viewing of the CR image. The following table describes each in more detail.

Computer Workstation Items	
Type	**Description**
Acquisition interface	This allows the user to select pertinent reader settings prior to scanning the IP. The interface controls may be on the reader or within the computer workstation, depending on the CR system manufacturer and model. Selectable reader settings typically include sampling resolution, laser power, and PMT gain. Acquisition software also typically provides data fields for inspection and technique information.
Image viewing interface	Once the reader has scanned the IP and displayed the image on the viewing monitor, controls are provided for viewing and post-processing the image such that the user can interpret the radiograph per specified procedures. These controls typically include the following: • Window/level. • Magnification. • Image filters. • Various other tools. Use of these controls may be regulated by the specific inspection procedure.
Viewing monitors	CR systems may have one or multiple monitors. In most cases, high resolution monitors are monochrome (black and white), but may be in color. When a second monitor is employed, it is typically a low resolution monitor strictly for displaying the user interface. This low resolution monitor should *not* be used to interpret CR images.

Viewing systems

Digital radiographs are viewed on systems primarily designed for digital radiography. The systems differ from ordinary image processing systems for home and photographic use in that they are tailored specifically for radiography.

Hardware for digital radiography is similarly designed with CR in mind. For example, the computer for running the software and the interfaces to the acquisition hardware are all specialized pieces of equipment designed to handle large radiographic images with little chance of data corruption or image alteration.

Storing digital images

Storing digital radiographs range from hard drives to magnetic tape systems. Currently, compact discs (CD) are the media of choice; however, these are quickly being replaced by digital versatile discs (DVD), which hold much more data. Most digital radiographs opt not to compress their images at all and store the original raw data. It is always recommended a backup copy of digital data is kept at all times.

Archiving

Archival and retrieval systems are gaining popularity for radiographers that generate large amounts of digital radiographs. These systems are usually comprised of a database and storage mechanism connected over a network. They make searching for an image easy through database commands at the workstation, and deliver the image to the viewer upon request. The actual storage media used is at times unknown to the radiographer, so he or she need never worry about disk space, etc.

Printing images

Digital images allow for the easy replication of hardcopy data either on film or paper. Some systems use chemicals similar to standard film processors; however, more common printing systems use either dye sublimation or thermal films for the hardcopy output of digital radiographs.

Image filtering

Most software packages provide a number of digital processing filters that can be used to transform the data. Usually, image filters process multiple data points to create a single output point, but without changing the number of image pixels. Thus, filter operations do not change the number of pixels in an image or the total amount of data being displayed.

The use of filtration for final interpretation of CR images for challenging aerospace applications is *not* recommended at this time. Any preliminary interpretation using filtration shall be validated with the unfiltered image to ensure the filtration did not create or eliminate indications of interest. As a result, if filtering is employed, the following two controls should be applied:

- The original unfiltered data should be retained as part of the inspection archive.
- The exact sequence of filter steps should be specified in the inspection technique.

Adding annotations

A number of graphical tools are available in most image review software packages, including measurement tools and annotation tools. These allow the user to add markings to the displayed image showing geometrical measurements (e.g., distances, angles, etc.), or to add captions and arrows pointing to features of interest. These tools can be useful to document inspection results. The majority of software programs for CR add these elements to a displayed view in real-time as a post-processing operation and allow for their removal or repositioning. As a result, they are safe to use as needed.

Analysis

The annotated displays can be archived in the following two ways through the use of most software packages:

- A *recipe* can be stored for the post processing steps (including annotation and analysis).
- Displays may be recreated for documentation or reporting purposes.

However, these recipes may not easily translate from one software package to another; additionally, they are typically unavailable to users of generic image display programs on common computers. Thus, most software programs provide the ability to export displayed views; this is usually accomplished by writing 8-bit pixel values displayed on monitors into a computer file using a common picture file format. These exported views are useful for documentation and reporting. They are inserted as figures into word-processing and presentation files for sharing with non-specialists, but are not usually sufficient for archiving inspection results.

Viewing room ambient light

Subdued lighting in the viewing room is preferred rather than total darkness. Background illumination lighting is arranged such that light reflections do not interfere with review of the images. Background ambient light levels should not exceed 30 lux (the measure of light intensity); light levels shall be measured at the monitor surface, with the monitor off. After entering the viewing area, the interpreter should wait sufficient time before interpreting images.

612. Interpreting computed radiography

Image processing and analysis can help determine the quality of an existing digital image, and provide hints as to correct problems within the image. Additionally, enhancement and processing make digital images easier to interpret than traditional film.

Interpreting indications on a digital image will be very similar to conventional film, except for the enhancing and filtering techniques that may be used on computer graphics to locate defects.

Computer graphics

The two ways computers handle graphic information include vector and raster graphics.

Vector graphics

Vector graphic images remain separate from others. Images are mathematical and not tracked in pixels. These graphics are created in drawing and illustration programs, like clipart in word processing packages. They are stored as a collection of objects described mathematically using shape, line segments, and arcs. Vector graphics are also known as object-oriented graphics because of their use of object models to describe the mathematical shapes that construct images.

Raster graphics

Scanners and digitizers create raster graphics, also known as bit-mapped graphics. Each raster graphic is comprised of a two-dimensional array of discrete pixels (like a computer monitor screen). A *bitmap* is a file that indicates a color for each pixel along the horizontal and vertical axis. Raster and bitmap images are used interchangeably, with both referring to a color format where the images are composed of either black or white pixels.

Working with raster images means working with pixels, not objects or shapes. Each pixel in an image is stored in its own location within computer or storage memory as a number representing color, brightness (and sometimes transparency), or other levels. Because storing formulas for drawing shapes takes less memory in general than actually mapping out the individual pixels of the image, vector graphics tend to be much smaller than raster or bitmapped images.

Brightness resolution

Brightness resolution (pixel depth) in image quality is referred to as the grayscale or color range of an individual pixel. Brightness resolution is defined in a digital image by the pixel it represents. The value can be made of one or more “bits.” The more bits actually used to define the brightness levels in a digital image, the higher the brightness resolution (and hence the quality) of the image.

Spatial resolution

Spatial resolution of an image quality is the number of pixels (horizontally and vertically) in a digital image. It determines the actual size of the pixel in real units, and thus determines the sampling interval of the original digitization operation. A longer interval produces lower spatial resolution images while a shorter interval produces higher spatial resolution. The term *resolution*, when not preceded by the word “brightness,” or the obvious word “spatial,” generally refers to spatial resolution.

Pixels

Pixel depth is the measure of brightness resolution in a digital image. The following table shows common pixel depths and their descriptions of each.

Pixel Depth	
Size	**Description**
1-Bit Pixel	A 1-bit pixel depth image can be made up of only two colors, generally black and white. Each pixel is represented in memory as either a one or a zero. Gray values are simulated by grouping black and white pixels over an area to make it appear brighter or darker. Fax machine printouts, and even black and white newspaper photographs, are examples of 1-bit images.
8-Bit Pixel	An 8-bit pixel image can display 256 colors or grayscale levels at the most. They are comprised of individual pixels made up of eight bits each, yielding two to the eighth (2^8) power brightness (or color) levels. Color images use the brightness information of the pixel as a value to use in a table of color values. Web based images with a graphic interchange format (GIF) extension, and many grayscale computer displays, are examples of 8-bit graphics.
12-bit Pixels	12-bit images are usually grayscale images. The value of the pixel is made up of 12 bits, which equate to 4096 individual gray scale values.
24-bit and Higher	24 bit and higher color images (also known as “true-color” images) group three or more 8 bit bytes of brightness information together. Each byte represents a color channel (or an alpha transparency channel) of brightness. The effect is one of millions of colors, but with the same overall brightness resolution of an 8-bit, grayscale image. There is no difference in a 24-bit grayscale image and an 8-bit grayscale image as far as quality is concerned.

Capture

Digital radiographic images are captured in many different ways in industrial radiography. Some methods involve the use of standard radiographic film called *film based capture* or film designed with digitization in mind. Other methods bypass using film altogether, and use direct or indirect capture methods called *filmless capture*. All rely on taking an analog signal and converting it to a sampled digital form using solid state charged coupled device (CCD) sensors, photovoltaic cells, or photo-multiplier tubes for the analog signal.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

610. Computed radiography

1. How is CR similar to film-based radiography, and how does it differ?

2. The Department of Defense aerospace inspections are low energy applications that fall into what two general categories?

3. What does the sensitive layer of IPs consists of?

4. Into what two types are images classified?

5. What is also referred to as the grayscale or color range of an individual pixel?

6. What is the number of pixels horizontally and vertically in a digital image?

7. Laser scanners utilize a laser beam that passes through film. How is the resulting light converted to a voltage signal?

8. What is a very popular method of digital radiography because of the ease of use, and film like nature of the process?

9. In addition to the brightness and spatial resolution, what other three factors affect the quality of a captured digital image?

10. What is the data present in a radiological measurement which is not directly correlated with the degree of radiation attenuation by the object being examined?

11. What is the effectiveness of the scanner or capture hardware in differentiating between differing shades of gray or brightness?

12. What are unwanted images caused by input or output process, that is, hardware or software?

611. Computed radiography equipment

1. What are the primary components in the CR system?

2. What type of equipment within a CR system can range from coarse grain to fine grain, and can sample the data at low or high resolution?

3. How are image plates handled?

4. What CR equipment component will take an exposed IP, scan using a laser light, capture the light emitted from the IPs, and provide the necessary information to the computer workstation?

5. What types of problems may defect traps result in, which can also be very difficult to erase?

6. Which computer workstation item allows the user to select pertinent reader settings prior to scanning the IP?

7. What type of monitor should not be used to interpret CR images?

8. What do more common CR printing systems use for hardcopy output of digital radiographs prints?

9. What is not recommended at this time for use for final interpretation of CR images for challenging aerospace applications?

10. During analysis, what two ways may be used to archive annotated displays through the use of most software packages?

11. What type of lighting is preferred in a viewing room?

612. Interpreting computed radiography

1. What are the two ways in which computers handle graphic information?

2. What type of graphics are also known as bit-mapped graphics, and are created by scanners and digitizers?

3. What can make up the value of brightness resolution?

4. What type of pixel can be made up of only two colors?

2–2. Lasers and Process Controls

Lasers are an important function of the CR system as well as checking for equipment degradation. It is important to understand their role and how they are used in a typical CR system. Lasers can also be harmful if used incorrectly; so safety also plays a small part in digital radiation and the systems used.

This section focuses on lasers and their use within digital X-ray systems, and the many types of process controls needed to ensure your CR system is in good working condition.

613. Introduction of lasers

A red laser light focuses on a small, roughly circular area called the *focal spot*. The size of the spot varies between readers and influences the smallest image features that can possibly be spatially resolved by a particular reader; however, the actual image resolution limit determines the size of the blue emission spot, *not* the smaller red laser spot.

Laser

The IP contributes a significant degree of additional image unsharpness (or a lack of sharpness). The relatively large size of CR crystals affects the absorption and scattering of visible light during the readout process. The larger crystals absorb less light, reducing optical losses, which allows for the increased thickness of the sensitive layer; however, they also have an increased tendency to scatter visible light, both the red excitation light and the blue emitted light. This material property causes some of the optical light to scatter sideways in the IP (i.e., perpendicular to the incident X-ray beam). Thus, the blue spot is larger than the red spot, causing additional blurring and unsharpness during the readout process.

In addition to the actual focal spot size of the red laser, and the lateral scattering of red and blue optical photons in the IP, a third factor also affects the area of the blue light seen by the PMT at any moment. This is the decay time of the excited metastable states. The emission of blue light is slightly delayed from the absorption of the red stimulation light and the typical delay time is a significant fraction of the PMT sampling time. Thus, the shape of the moving blue emission area exhibits a slight smearing called a *tail*, which is opposite to the direction of motion. These three factors combine to determine an effective readout spot size. Generally, none of these optical blurring factors is adjustable by users, so the limiting spatial resolution is fixed by the selection of reader model and IP type.

Spot size

The effective readout spot size is not inherently round, but tends to be elongated in the fast scan direction of the flying spot motion; however, the final spatial resolution also affects the sampling period. The effective spot moves during the sampling period, adding greater unsharpness to the image. Thus, the image resolution is often better in the slow scan direction than in the fast, requiring CR resolution testing in both vertical and horizontal image directions.

Laser power

Some CR readers have an adjustment for laser power. Since the laser brightness is ordinarily insufficient to stimulate emission from all of the latent image states, the maximum power setting available usually results in optimum SNR performance. Exceptions can occur when high power settings degrade the laser focus; consequently, it’s important to follow the guidance from the reader manufacturer.

Photomultiplier tube gain

Most CR readers have an adjustable gain setting that affects the amount of electric current produced by a given amount of light. If the gain is too low, the dynamic range and stability of the PMT are affected; however, a too high of a gain setting cannot compensate for information loss in noisy low dose images, as it will merely amplify the contrast information and the background signal alike. Thus, the PMT gain setting (sometimes called PMT voltage) should be as low as possible without affecting

stable operation of the PMT. The PMT current is amplified prior to digitization, but the conversion from the output to the displayed result is not always linear. The set of digitized data measurements is stored as an array of digital data in a computer file.

Laser safety

Bioenvironmental engineering will approve all laser pointers prior to use and personnel will be trained. Lasers and laser pointers *will not* be directed above the horizon near the flight line, as this may be dangerous to flight operations. The laser will have a warning affixed to it, and it should only be in the on position when aligning film and off at all other times. Lasers are a dangerous tool and *will not* be pointed at any individual.

614. Process control

A variety of process control checks have to be accomplished on CR systems to ensure they are operating at the required level of performance. This lesson provides general practices used to perform process control checks on CR equipment and materials. Like traditional film radiography, the entire process must closely be controlled with process control tests to produce expected results. The following are the primary concerns for the operating performance of the CR system:

- The IP reader, eraser, and monitor.
- Degradation of the IPs.

NOTE: The intervals of the test and method for performing process controls are published in WP 106 01 of TO 33B–1–2 for different CR systems used.

Process control intervals

The CR process controls are split into the following four tests:

- Display monitor tests.
- System tests.
- IP tests.
- Equivalent penetrameter sensitivity (EPS) test (crack detection and weld certification CR systems only).

For general use CR, the following should use system process control intervals.

Process Control Intervals	
General use CR systems for applications other than crack detection	
Test	**Interval**
Monitor test	90 Days.
System test	90 Days.

For CR systems used for crack detection and weld certification, process control intervals use the following.

Process Control Intervals	
CR systems used for crack detection and welder certifications	
Test	**Interval**
Monitor test	Daily/Prior to use.
System test	Daily/Prior to use.

System tests are laid out with an initial test setup/data capture procedure that applies to all tests, followed by individual evaluation procedures so that any one test can be performed individually if

necessary. System specific software procedures are detailed for each manufacturer's CR systems in the manufacturer guidance (e.g., Fuji, General Electric [GE], and vendor managed inventory [VMI]).

Computed radiography standard

The Society of Motion Pictures and Television Engineers (SMPTE) have produced a standard SMPTE recommended practice (RP)–133 that contains an electronic image for evaluating display parameters. Process control tests require visual evaluation of the pattern to evaluate the contrast, brightness, spatial resolution, and overall performance of the monitor. This standard looks like the one shown in figure 2–4.

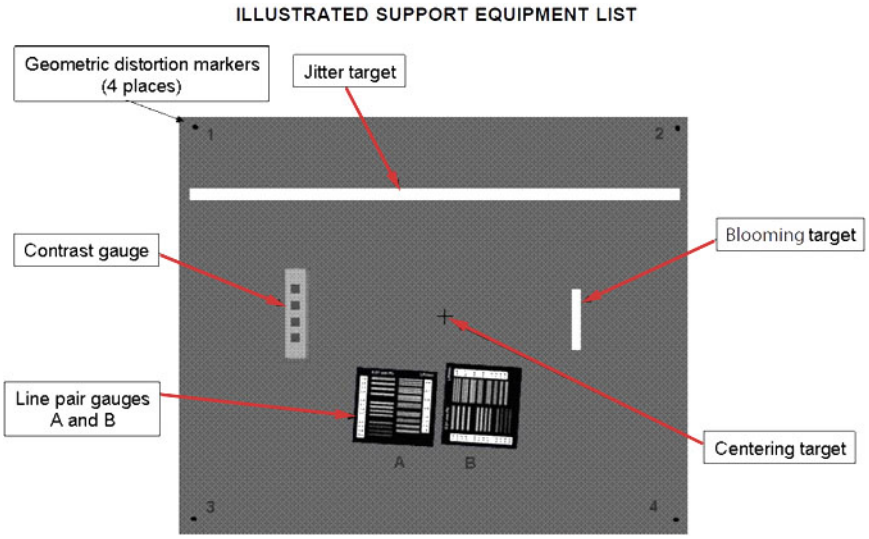


Figure 2–4. SMPTE RP–133 standard for CR process control.

Equivalent penetrameter sensitivity test standard

The EPS test standard consists of a 0.75-inch-thick aluminum absorber, and two (5 and 8 mil, in which mil = 0.001 on an inch, or one thousandth of an inch) or four (5, 8, 10, and 15 mil) EPS plaques. The plaques are placed on the absorber and centered, with approximately 1inch spacing between the plaques to allow securing with tape (fig.2–5). *Do not* cover the holes in the plaques with tape, and make sure that the plaques are flat once secured to the absorber.

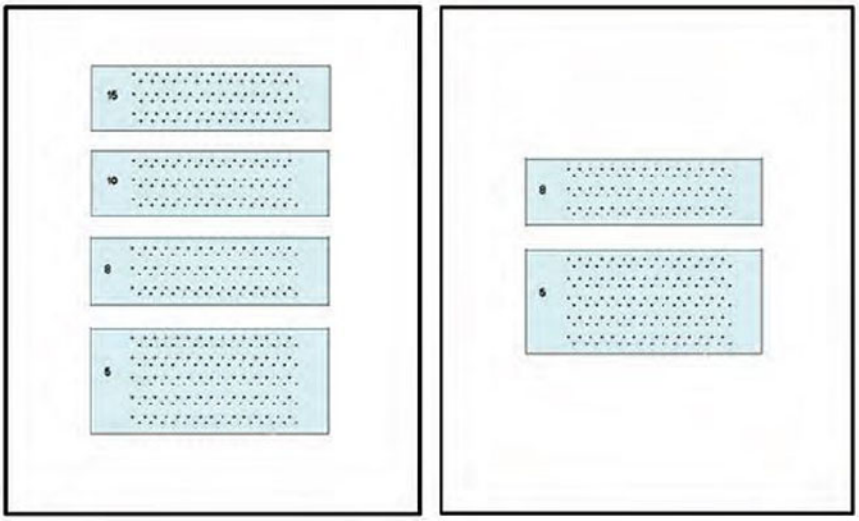


Figure 2–5. EPS test standard.

Display monitor process control test

Load the test pattern (fig. 2–6) onto the high-resolution monochromatic display monitor.

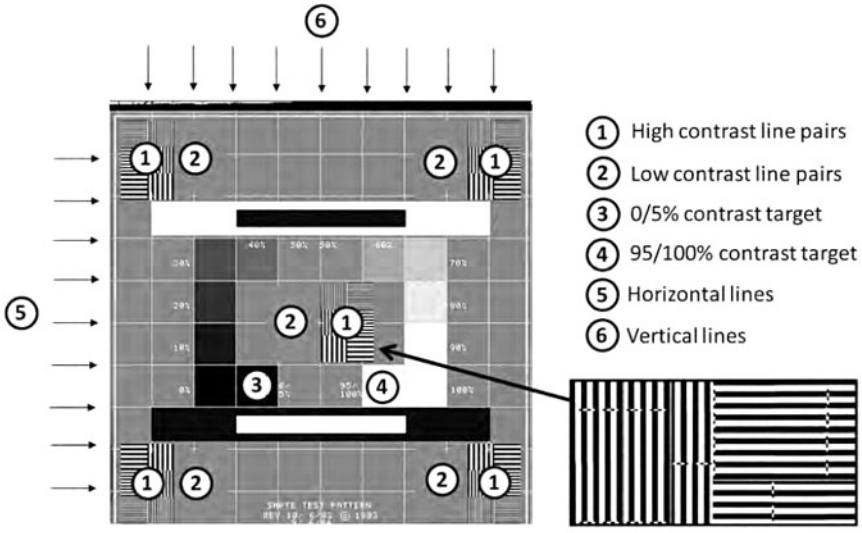


Figure 2–6. Test pattern for display monitor process control.

Visually evaluate the following SMPTE133 test pattern targets as follows:

Display Monitor Process Control Test	
Step	**Description**
1	Verify the low and high contrast. Vertical/horizontal lines are visible at each corner and at the center of the test pattern. (There are five locations of each of the targets 1 and 2 in figure 2–6.)
2	Verify 5% square is visible within 0% square. (Target 3 in figure 2–6.)
3	Verify 95% square is visible within 100% square. (Target 4 in figure 2–6.)
4	Verify no visible distortion of horizontal/vertical crosshatch pattern. (Targets 5 and 6 in figure 2–6.)
5	Acceptance criteria/corrective action is required if any of the test patterns discussed in steps 1–4 are not verified, the display monitor should be repaired or replaced before further use.

System test

There are several tests accomplished using the computed radiography process control standard (CRPCS) or the NAVAIR Phantom.

- *Contrast sensitivity* - evaluate the ability of the CR system to detect variations in image intensity.
- *Spatial resolution* - evaluates the ability of system to detect and distinguish between features.
- *Geometric distortion* - evaluates the image to determine if it is distorted in the X- and/or Y-axis.
- *Laser jitter* - evaluates the image to determine if a lack of smooth movement of the imaging plate and laser-scanning device occurs.
- *Slippage* - evaluates the image to determine if lines of data in the image are uniformly spaced.
- *Scan line dropout* - evaluates the image for lucent or bright white straight lines oriented in the long or slow scan direction.
- *Blooming or Flare* - evaluates the image for evidence of overrun or streaking in areas with high-density contrast.

- *Shading* - evaluates the image for non-uniform intensity across the scanning width, evident as either a gradual change in the shade of gray in the "scan" direction or as "bands" of shading in the "feed" directions.
- *Residual image* - evaluates the erasure performance to ensure a residual image does not remain on the IP, which can affect interpretation of future images.

Contrast sensitivity evaluation

Visually evaluate image for ability to detect low contrast features as follows.

Contrast Sensitivity Evaluation	
Step	**Description**
1	Adjust the magnification so that the CR image of the contrast gauge fills the viewable area of the display monitor (fig. 2–7).
2	Visually optimize the image using brightness/contrast, window/level, or equivalent.
3	Visually evaluate the CR image of the contrast gauge and record the number of steps identified visually.
4	Three steps must be visually identified on the contrast sensitivity gauge, which equates to 2% contrast sensitivity (2% step highlighted by the arrow in fig. 2–7). Inability to achieve the required contrast sensitivity or a reduction in contrast sensitivity from the baseline test data indicates that the CR system shall be evaluated and corrective action taken.

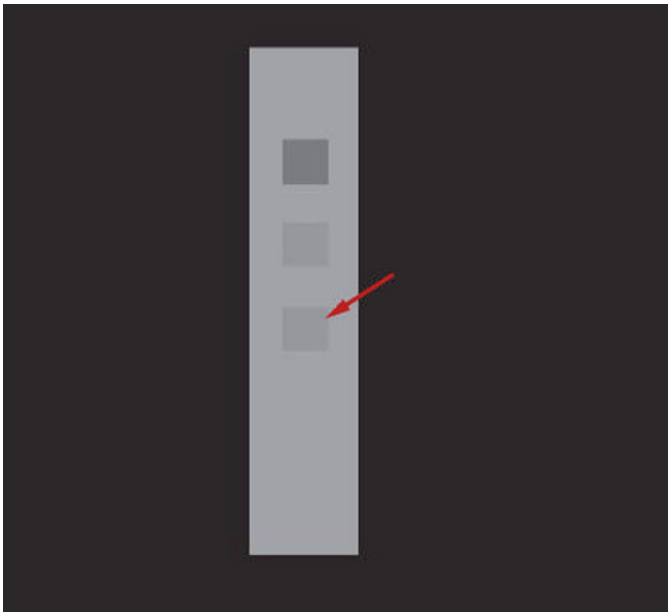


Figure 2–7. Contrast sensitivity evaluation gauge.

Spatial resolution

Visually evaluate the image for ability to resolve small details or features as follows.

Spatial Resolution Evaluation	
Step	**Description**
1	Adjust the magnification so that the CR image of one line pair gauge fills the viewable area of the display monitor (fig. 2–8).
2	Visually optimize the image using brightness and contrast (i.e. window/level). During evaluation of the CR image of the line pair gauges, position operators 12–18 inches from the display monitor.

Spatial Resolution Evaluation	
Step	**Description**
3	Visually evaluate the CR image of the line pair gauge and determine the smallest line pairs per millimeter (LP/mm) that are separated by a continuous visible space along the entire length of the line pair. Record the LP/mm and line pair gauge ID (A or B).
4	While maintaining the same magnification level and image viewing parameters, maneuver the image to view the other line pair gauge and evaluate it in the same manner. Record the LP/mm and line pair gauge ID (A or B).
5	Acceptance criteria: • For general use systems, a minimum of 2.5 LP/mm is required in both orientations. • For crack detection systems, a minimum of 6.0 LP/mm is required in both orientations. • For Welder Certification systems, a minimum of 8.0 LP/mm is required in both orientations. • Inability to achieve the required spatial resolution or a reduction in spatial resolution from the baseline test data indicates degraded performance. Evaluate and take corrective action taken if needed.

Figure 2–8. Line pair gauge.

Geometric distortion

Evaluation of image for overall distortion using special software measurement tools is as follows.

Geometric Distortion Evaluation	
Step	**Description**
1	Adjust the magnification, if necessary, so that the CR image of the entire process control standard (PCS) fits within the viewable area of the display monitor and all geometric distortion markers in the PCS are visible.

Geometric Distortion Evaluation	
Step	**Description**
	NOTE: the markers are small ball bearings within the PCS, highlighted with arrows in figure 2–9.
2	Using the CR image processing software, calibrate the software measurement tool on the known distance (12.5 inches) between two of the geometric distortion markers across the short direction of the IP (markers 1–3 or 2–4).
3	Measure the distance between the geometric distortion markers along one long side and one diagonal on the CR image.

NOTE: See TO 33B–1–2 WP 106–01 for acceptable criteria.

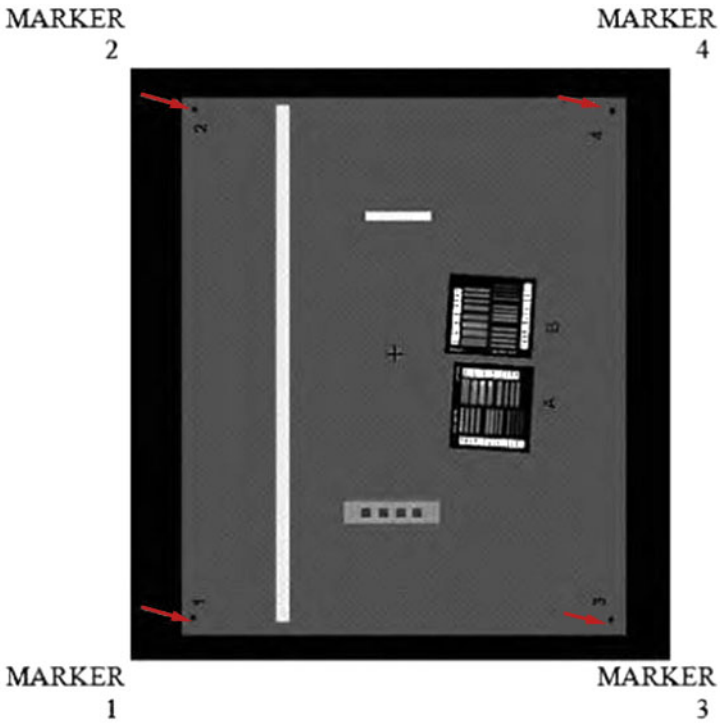


Figure 2–9. Simulated CR image of PCS for geometric distortion.

Laser jitter

Visually evaluate image of jitter target for straight and continuous edges as follows.

Laser Jitter Evaluation	
Step	**Description**
1	Adjust the magnification per the appropriate system specific procedures.
2	Visually evaluate the long edges of the entire length of the jitter target in the CR image. Adjust *only* brightness during this evaluation. Edges should appear straight and continuous (fig. 2–10).
3	Distorted edges along the jitter target (fig. 2–11), which may occur at one or more locations, are indications of laser jitter and shall be evaluated and corrective action taken.

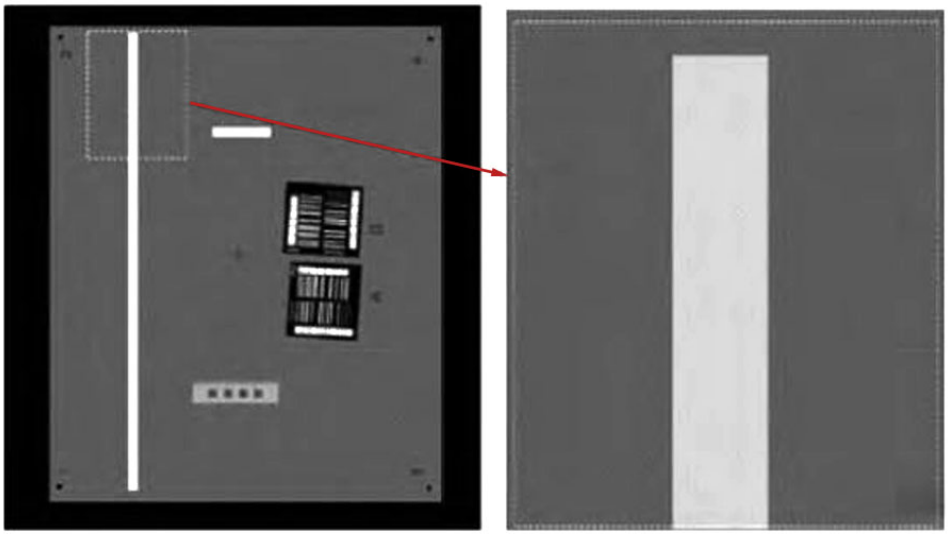


Figure 2–10. Simulated CR image of jitter target.

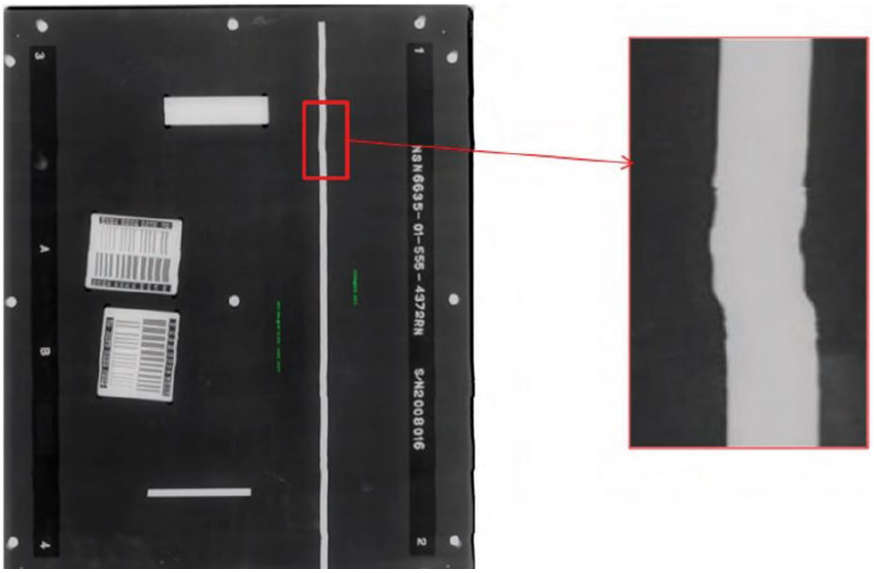


Figure 2–11. Example of jitter.

Slippage, scan line dropout, blooming and shading

A visual evaluation of the CR image for multiple irregularities is as follows.

Slippage, Scan Line Dropout, Blooming and Shading Evaluation	
Step	**Description**
1	Adjust the magnification, if necessary, so that the CR image of the entire PCS fits within the viewable area of the display monitor.
2	Visually evaluate the image for linear slippage, scan line dropout, blooming and shading in the short and/or long directions of the CR image. Adjust brightness *only* during this evaluation to optimize image. See figure 2–12 for examples and descriptions of each irregularity.
3	Slippage indications are evident as a light or dark stripes or bands oriented in the short dimension of the CR image (fig. 2–12, top left). Slippage can occur in more than one location in the image, and may occur as wide or narrow indications depending on the amount of slip. Not all CR readers are susceptible to slip.

Slippage, Scan Line Dropout, Blooming and Shading Evaluation	
Step	**Description**
4	Scan line dropout is evident as a bright white line spanning the entire long dimension of the CR image (fig. 2–12, top right). Scan line dropout can occur in multiple places within the same image and may occur as wide or narrow indications.
5	Shading is evident as light and dark bands oriented in the long direction of the CR image (fig. 2–12, bottom left).
6	Blooming is evident as streaking or overshoot at light to dark transition regions in the short dimension of the IP and is most noticeable at the edges of the target (fig. 2–12, bottom right).
7	If any of the irregularities are visible, the CR system shall be evaluated and corrective action taken.

Figure 2–12. Example of slippage, scan line dropout, blooming and shading evaluation.

Residual image

Evaluate image for proper erasure using special software tools as follows.

Residual Image Evaluation	
Step	**Description**
1	Erase the IP by processing it through the CR eraser.
2	Scan the erased IP and display the CR image on the monitor.
3	Evaluate the CR image of the erased IP by measuring the pixel value and/or intensity over the entire image using the imaging software tools.
4	If the maximum pixel value is greater than the value specified in the system specific acceptance criteria, the CR eraser shall be evaluated and corrective action taken.

IP test

The IP test locates artifacts (e.g., scratches, nicks, etc.) on the CR image for non-relevant indications inherent to the imaging plate as discussed in the following table.

Artifact Evaluation	
Step	**Description**
1	Record the date of the test, model, and serial number(s) of CR reader and CR eraser if applicable.
2	Select a 14 x 17 IP and cassette. Record model and serial number of the IP and the hard/soft cassette.
3	Expose the PCS to X-rays. Recommended test parameters: 25kV, 1.5mA, 20 second exposure, 48 inches distance to source.
4	Multiple IPs can be exposed at one time by placing the IPs side-by-side and centering the shot as shown in (fig. 2–13).
5	Select the CR reader settings typically used for the IP and cassette of interest (e.g., sensitivity, pixel pitch, speed, etc.).
6	Scan the IP and display the CR image on the monitor.
7	Enlarge the CR image of the IP of interest so that it fills the viewable area of the display monitor.
8	See system specific software procedures to confirm the pixel value of the CR image is in an acceptable range.

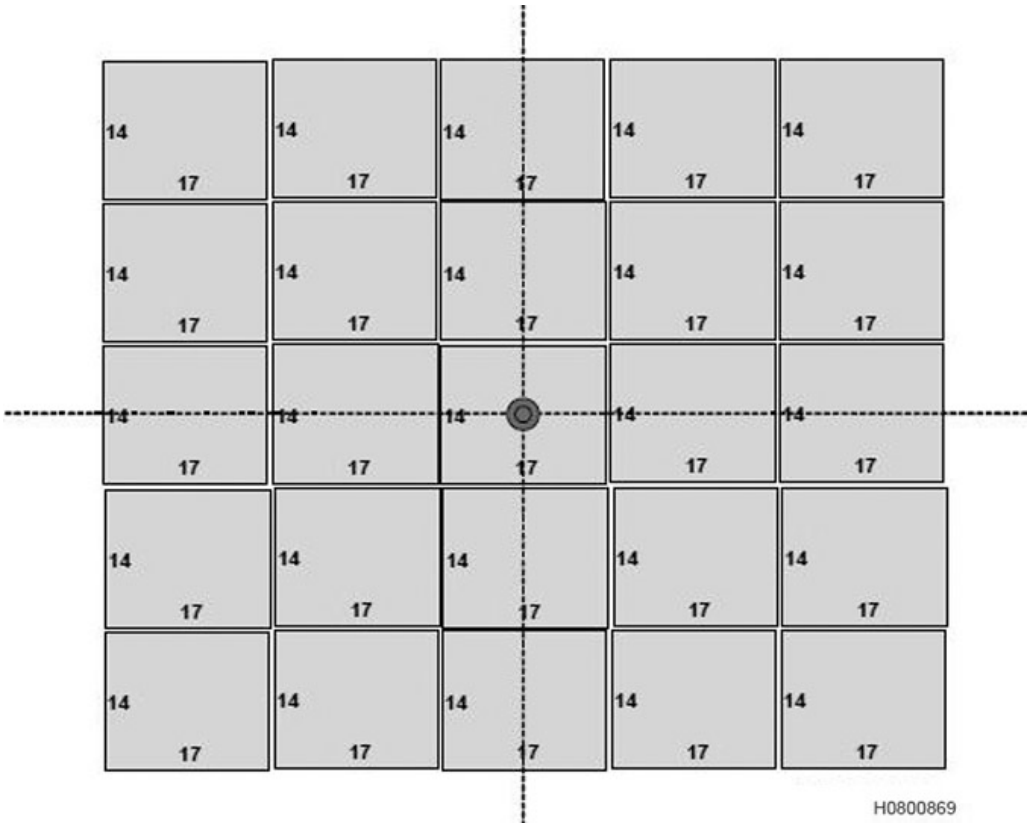


Figure 2–13. Layout Pattern for Performing Artifact Test on Multiple IPs.

Equivalent penetrameter sensitivity

EPS is similar to SNR but is independent of system software. The EPS test provides a measure of image quality that has been correlated to detection performance for critical USAF applications. Percent EPS shows that the value decreases as image quality improves (for example, an EPS of 2.0 percent is equivalent to 2–2T image quality level; an EPS of 1.0 percent is equivalent to 1–2T image quality level).

This test is for crack detection and welder certification systems only and completed by the following table.

EPS Evaluation	
Step	**Description**
1	The EPS standard (fig. 2–14, detail (a)) shall be imaged at a distance of 48 inches from the surface of the standard to the X-ray tube. Place the IP immediately beneath the specimen within the appropriate flexible or hard cassette. A minimum of 1/8 inch thick back screen of lead is required for all exposures.
2	Technique parameters for kV, mA, and time shall be determined, and the kV may be adjusted ±10kV; however, no other technique parameters should be changed.
3	Confirm that the pixel value (intensity) measured near the center of the 8 mil EPS plaque is within the allowable pixel value range.
4	Determine the EPS performance by identifying the hole array where a minimum of 20 holes (out of 30 holes in each hole array) are clearly visible (fig. 2–14, right side).

Figure 2–14. Schematic of EPS specimen.

Operator maintenance

Cause and Corrective Actions		
Process control test	**Most likely cause of test failure**	**Recommended corrective action**
Geometric distortion	Slippage of IP during scanning.	Clean IP.
		Clean scanner surfaces and/or components that contact IP surface.
	Scan rate not calibrated properly or timing error.	Contact manufacturer.
Slippage	Slippage of IP during scanning.	Clean IP.
		Clean scanner surfaces and/or components that contact IP surface.
Scan line drop-out	Dirt in path of scanner optics.	Clean internal optics (contact service).
Shading	Improper flat field calibration	Contact manufacturer.
Blooming	Oversaturated PMT.	Ensure proper scanner settings and adjust technique.
Laser beam jitter	Laser beam function or timing error.	Contact manufacturer.
Spatial resolution	Incorrect IP type selected.	Ensure proper IP type.
	Incorrect scanner settings.	Ensure proper scanner settings.
	Background of PCS image is saturated.	Adjust technique if background is saturated.
	Scan rate not calibrated properly or timing error.	Contact manufacturer.
Contrast sensitivity	Incorrect IP type selected.	Ensure proper IP type.
	Incorrect scanner settings.	Ensure proper scanner settings.
Residual image	Inadequate erasure intensity or erasure time.	Increase erasure power or replace erasure light source.
EPS	Incorrect IP type selected.	Ensure proper IP type.
	Incorrect scanner settings.	Ensure proper scanner settings.
	Noisy power source.	Install line conditioner.
Artifacts	Dirt or particles in scanner optics, on IP, or within cassette.	Clean affected item.
	IP or cassette damage.	Determine if IP or cassette can be used for application. If it cannot be used, then discard IP.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

613. Introduction of lasers

1. What is a red laser light, focused to a small, roughly circular area called?

2. What is a slight smearing of a moving blue emission area called, which is opposite to the direction of motion?

3. How does an adjustable gain setting impact most CR readers?

4. What will not be directed above the horizon near the flight line, as this may be dangerous to flight operations?

614. Process control

1. What are the primary concerns for the operating performance of the CR system?

2. How often is the CR monitor process control test (other than for crack detection) completed?

3. Who has produced a standard that contains an electronic image for evaluating display parameters?

4. Which CR standard consists of a 0.75-inch-thick aluminum absorber?

5. Which system test evaluates the ability of the CR system to detect variations in image intensity?

6. Which system test evaluates an image for evidence of overrun or streaking in areas with high-density contrast?

7. How many steps must be visually identified on the contrast sensitivity gauge?

8. Which process control evaluation uses special software measurement tools?

9. How are slippage indications evident on a CR image?

10. What is evident as a bright white line spanning the entire long dimension of a CR image?

11. What is evident as streaking or overshoot at light to dark transition regions in the short dimension of the IP and is most noticeable at the edges of the target?

12. What are the recommended test parameters for IP tests?

13. The EPS standard shall be imaged at what distance from the surface of the standard to the X-ray tube?

14. What is the recommended corrective action when completing operator maintenance for the scan line drop-out test when you notice dirt in the path of the scanner optics?

15. What is the recommended corrective action when completing operator maintenance for the EPS test when there is a noisy power source?

Answers to Self-Test Questions

610

1. It similar to film-based radiography as it utilizes the same radiation source; however, it differs in how the image is captured and processed.
2. Those that can be performed with low spatial resolution/low SNR, and high spatial resolution/high SNR.
3. Small crystals of a barium fluorobromide.
4. Continuous and discrete.
5. The brightness resolution.
6. Spatial resolution.
7. By a photomultiplier tube.
8. Phosphor filmless imaging.
9. Part noise, dynamic range, and artifacts.
10. Noise.
11. Dynamic range.
12. Artifacts.

611

1. Imaging plates, CR reader, CR eraser, computer workstation.
2. Phosphor imaging plate (IP).
3. Handle only by the edges to prevent skin oils and fingerprints from contacting the active surface.
4. CR reader.
5. Residual or ghost images.
6. Acquisition interface.
7. Low resolution monitor.
8. Either dye sublimation or thermal films.
9. Filtration.
10. A recipe can be stored for the post processing steps (including annotation and analysis); displays may also be recreated for documentation or reporting purposes.
11. Subdued lighting.

612

1. Vector and raster graphics.
2. Raster graphics.

3. Bits.
4. One-bit pixel depth image.

613

1. The focal spot.
2. A tail.
3. It affects the amount of electric current produced by a given amount of light.
4. Lasers and laser pointers.

614

1. The IP reader, eraser, monitor; and degradation of the IPs.
2. Ninety days.
3. SMPTE.
4. EPS test standard.
5. Contrast sensitivity.
6. Blooming or flare.
7. Three steps.
8. Geometric distortion.
9. As light or dark stripes or bands oriented in the short dimension of the CR image.
10. Scan line dropout.
11. Blooming.
12. Twenty five kV, 1.5mA, 20 second exposure, 48 inches distance to source.
13. Forty eight inches.
14. Clean internal optics (contact service).
15. Install line conditioner.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

31. (610) What allows us to retrieve information electronically for easy and accurate manipulation or analysis by a computer?
    a. Digital imaging.
    b. Laser radiography.
    c. Computed radiography.
    d. Conventional radiography.

32. (610) When the dynamic range is greater, the
    a. lower the noise and signal-to noise ratio.
    b. higher the noise and signal-to noise ratio.
    c. lower the contrast and color/grayscale bit depth.
    d. higher the contrast and color/grayscale bit depth.

33. (611) How should you care for image plates (IP)?
    a. Keep stored in a cassette.
    b. Wear cotton gloves to aid in keeping clean.
    c. Do not keep food or drink around when using.
    d. Spray a solvent on them and wipe clean after every use.

34. (611) Which of these is *not* used to store digital radiographs?
    a. Share drive.
    b. Hard drives.
    c. Magnetic tape systems.
    d. Compact discs (CD) or digital versatile discs (DVD).

35. (612) What is defined as a digital image by the pixel it represents?
    a. Brightness resolution.
    b. Spatial resolution.
    c. Capture.
    d. Bits.

36. (612) What type of pixel can display 256 colors or grayscale levels at most?
    a. 1 bit.
    b. 8 bit.
    c. 12 bit.
    d. 24 bit.

37. (613) Who will approve all laser pointers prior to use?
    a. Nondestructive inspection (NDI) office.
    b. Bioenvironmental engineering.
    c. Quality assurance.
    d. Production super

38. (614) Computed radiography (CR) process controls are split into what four tests?
    a. Equivalent penetrameter sensitivity (EPS), display monitor, image film, and resolution tests.
    b. Image plate, computer graphic, pixel, and display screen tests.
    c. Display monitor, system, image plate, and EPS tests.
    d. Quality factor, system, resolution, and screen tests.

39. (614) What acceptable criteria are you looking for during the display monitor process control test?
    a. Evaluates the image to determine if it is distorted.
    b. Evaluates the image for lucent or bright white straight lines.
    c. Verify no visible distortion of horizontal/vertical crosshatch test pattern.
    d. Verify the low and high brightness of vertical/horizontal lines at each corner.

40. (614) During evaluation of the spatial resolution evaluation, how far away from the display monitor shall operators be positioned?
    a. 6–12 inches.
    b. 12–18 inches.
    c. 18–24 inches.
    d. 24–30 inches.

41. (614) Apart from the magnification setting, what is the only item that may be adjusted during the laser jitter evaluation?
    a. Color.
    b. Contrast.
    c. Sharpness.
    d. Brightness.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Oil Analysis Inspection

OIL ANALYSIS IS A MAINTENANCE TOOL designed to provide information related to the internal wear of aircraft engines and other types of machinery with recirculating oil systems. By analyzing oil samples taken from engines, hydraulic systems, transmissions, or other machinery, you can determine the identity and amount of small metal particles suspended in the oil. You can then record and monitor this information to establish trends, such as an abnormally fast increase in a specific metal. By analyzing these trends, you can predict the failure of a component well in advance of its actual breakdown.

In this unit you will learn about spectrometric oil analysis and the equipment used to determine different types of wear metals that may be found in engine oil samples. As an NDI technician, you are responsible for evaluating, certifying, and keeping reports and data from these samples. The most important part of joint oil analysis that you will learn in this unit is trend and evaluation criteria, which may ground aircraft and save lives.

3–1. Oil Analysis Theory and Equipment

Data from spectrometric testing is used as a guideline to assist in identifying emerging mechanical failures or in determining the quality and useful life of the oil. Thus, potential equipment component wear or failure and premature lubricant failure may be detected prior to a major equipment failure or an expensive repair or rebuild. Oil analysis may also be used to identify inadequate or improper maintenance procedures and unsatisfactory equipment parts, components, and assemblies.

615. Spectrometric oil analysis

The purpose of this lesson is to provide you with a more comprehensive knowledge of the *spectrometric oil analysis* as a diagnostic maintenance tool, which is used to determine the type and amount of wear metals in lubricating fluid samples. Engines, transmissions, gearboxes, and hydraulic systems are the types of equipment most frequently monitored. The presence of unusual concentrations of an element in the fluid sample can indicate abnormal wear of the equipment. Once abnormal wear is verified, the equipment may be repaired or removed from service before a major failure of a fluid wetted component occurs. Spectrometric oil analysis enhances personnel safety and material readiness at a minimum cost, and serves as a decisive, preventive maintenance tool.

To fully understand oil analysis and use it as an Air Force maintenance tool, you need a knowledge of lubricants and the systems in which they are used. Your knowledge of oil-wetted systems will help you interpret the results of the samples you test and assist in your isolation of the parts generating wear metal particles.

Wear metals

Wear metals are generated by friction between moving metallic surfaces in mechanical systems. Despite lubrication, wear metal generation occurs in all oil-wetted systems to some degree, and the lubricant serves as a repository for the wear metals. Wear metals may also be generated from corrosive action resulting from moisture and electrolytic action within lubricated systems. Thus, information related directly to the condition of the assembly exists in the circulating lubricating fluid.

Wear metal concentration is measured in parts per million (PPM). A theoretical plot of this wear metal concentration in PPM vs. operating hours is represented in figure 3–1. Any condition, which alters the normal relationship or increases the normal friction between moving parts, will generally accelerate the rate of wear and increase the quantity of wear metal particles produced. An abnormal condition of this type will sharply increase the concentration and rate of buildup of wear metals in stable fluid systems. If the condition is not discovered and corrected, the deterioration will continue to accelerate, usually with major secondary damage to other parts of the assembly, resulting in the eventual failure of the entire assembly. Newly overhauled assemblies may tend to produce wear metals in higher concentrations (in PPM) during the initial break in period.

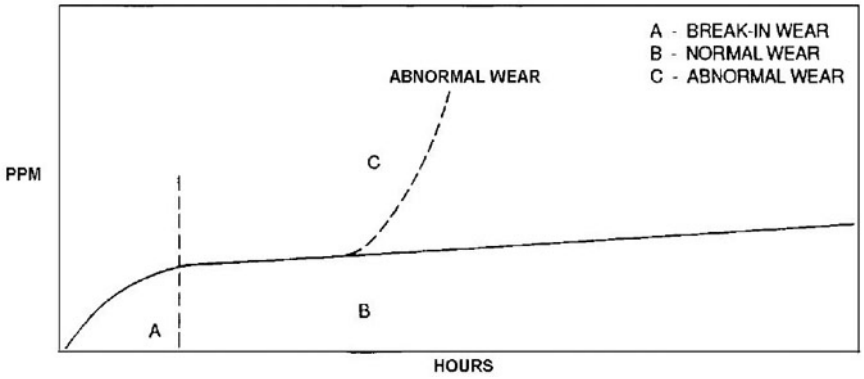


Figure 3–1. Wear metal concentration vs. operating hours.

Measurement of wear metals

Wear metals produced in fluid lubricated mechanical assemblies can be measured in extremely low concentrations by spectrometric analysis of fluid samples taken from the assembly. The analytical instruments currently used for spectrometric oil analysis by the services are atomic emission rotrode instruments. The following table illustrates wear metals found in most fluids.

Wear Metal Elements		
Iron (Fe)	Nickel (Ni)	Magnesium (Mg)
Silver (Ag)	Lead (Pb)	Sodium (Na)
Aluminum (Al)	Silicon (Si)	Boron (B)
Chromium (Cr)	Tin (Sn)	Molybdenum (Mo)
Copper (Cu)	Titanium (Ti)	Zinc (Zn)

The type of instrument used in the Air Force and discussed in this volume is called an *atomic emission spectrometer*.

Physical properties of lubricating fluids

Physical properties of lubricating fluids alter as lubricants degrade or become contaminated through service time and temperature, operational conditions, and faulty maintenance practices. The following are important physical properties of lubricants:

- Viscosity.
- Moisture content.
- Flash point.
- Particulate level (solids).
- Acidity/alkalinity.
- Additive content.

Lubricant degradation

Three basic factors control lubricant degradation, including service time, operating temperature, and contamination.

Time and temperature are directly related. The useful life of a lubricant extends when equipment is operated at moderate operating temperatures. Conversely, it is reduced when equipment is operated at severe operating temperatures, such as sustained engine operation at high loads or continuous operation with high-sulfur fuel.

Lubricant contamination may occur as a consequence of faulty maintenance practices, poor handling techniques with new replacement oil, system-ingested contaminants, or system-generated contaminants.

Atomic emission spectrometer

An emission spectrometer is an optical instrument used to determine the concentration of wear metals in lubricating fluid. The analysis is accomplished by subjecting the sample to a high voltage spark or plasma, which energizes the atomic structure of the metallic elements, causing the emission of light. The following are two commonly used types of emission spectrometers:

- Atomic emission rotrode (AER).
- Inductively coupled plasma (ICP).

Laboratories certified under the joint oil analysis program (JOAP) utilize the AER spectrometer. The emitted light is focused into an optical path and is separated by wavelengths; it is afterwards converted to electrical energy and then measured. The intensity of the emitted light for any element is proportional to the concentration of wear metal suspended in lubricating fluid.

Spectrometric limitations

The spectrometric (spectro) oil analyses detect only small particles and are effective in detecting those failures characterized by an abnormal increase in wear metal content of lubricating fluid. This is particularly true of failures that proceed at a rate slow enough to permit detection by the laboratory. Examples of both detectable and undetectable failures are listed in the following table.

Detectable/Undetectable Failures	
Detectable failure	A slow, progressive wear metal concentration buildup above established abnormal criteria.
	A series of rapid wear metal concentration increases occurring below established abnormal criteria.
Undetectable failure	*Catastrophic failures* - sudden failures not preceded by characteristic wear metal generation, such as fatigue failure, *cannot* be detected by spectrometric oil analysis techniques now in use.
	Failures with no wear metal indications - equipment failure may occur when metal particles too large to be detected by spectrometric methods are generated without the accompanying normal wear metal generation pattern that oil analysis is designed to detect.

616. Principles of atomic emission analysis

Spectrometric analysis involves the measurement of specific wavelengths of light. In the past, AF personnel used instruments to measure the wavelengths of light *absorbed* by the excited electrons. They are known as atomic absorption spectrometers. Today, all Air Force instruments are based on the principles of atomic *emission*. Atomic emission instruments measure the light emitted from excited electrons as we described in the previous lesson.

Atomic excitation

During a spectrometric analysis, wear metals are excited in a fluid sample. The purpose of this is so the microscopic metallic particles will emit or absorb specific wavelengths of light. The emission or absorption of specific wavelengths in this manner characterize the types of metal the sample contains. You can determine the concentration of these metals in a fluid sample by measuring the amount of light absorbed or emitted by the excited sample.

Over the years, much study has gone into the mechanics of spectrum formation as well as into its relationship to the structure of the atom. Although a complete discussion of the science of quantum mechanics is not within the scope of this course, a short simplified explanation of the origin of the spectrum is necessary. For the purpose of this discussion, visualize the atom as simply consisting of a positively charged nucleus and one or more negatively charged electrons—particles revolving around the nucleus in circular or elliptical orbits.

As these electrons revolve around the nucleus of an atom, they maintain one of seven average distances from the nucleus. Each of the seven distances is known as an *orbital shell*. An electron orbiting in one of these shells has a specific energy level associated to the energy the electron needs to maintain a stable orbit.

When an atom is excited, one or more of its electrons absorbs the excitation energy and moves to an orbital shell with a higher energy level. This is not the natural location for the electron, so it instantly (for our purposes) returns to its original orbital shell. This return to a lower energy shell results in the electron releasing the energy it absorbed by radiating light of a wavelength dependent on the original energy level of the electron.

Characteristic light

A specific amount of energy is required to remove the easiest excitable electron from its orbit. If this amount of energy is not supplied, no spectral line is emitted. If enough energy is supplied, one electron is removed from its shell by absorbing the energy and then emitting light of one specific wavelength on return to its shell. When more energy is supplied, more electrons are moved.

Some electrons may be moved through several energy levels, but always remain within the field of the nucleus. In this case, there is more than one possible transition, or path of return. The electron may return directly to its original level, or indirectly through other levels. Each transition that the electron makes releases a spectral line of a definite wavelength. The amount of energy required to excite an electron varies with each atomic element. When an electron absorbs enough energy to move it through more than one energy level, varying possibilities for transition back to normal exist. The most likely transitions for each element are those producing the most intense spectral lines, known as *persistent lines*. Spectroscopy relies on detection of these persistent lines in a spectrum.

Each element of pure metal has its own pattern of various light colors. Not only do the colors vary, but also the intensity of the light varies. After being dispersed by a prism or grating, this light emerges in the form of a unique spectrum characteristic of the metal being excited. The persistent spectral lines of an element are what you will monitor when you test an oil analysis sample. These specific wavelengths of light emitted by an element are called the *characteristic light* of the element. Any characteristic light for an element you detect in a sample automatically tells you there is a certain amount of the element in the sample. The amount of characteristic light you detect will tell you how much of the element is in the sample.

It is important for you to understand the principles of spectroscopy covered thus far so you can understand the basic method of wear metal concentration measurement. Energy is supplied to atoms of an element by an electrical force or by a beam of light. The kinds of elements in a fluid sample are determined by the *wavelengths* of light emitted when the sample is excited. The *concentration* of an element in a fluid sample is determined by the amount of light emitted by the sample having wavelengths characteristic of a specific element.

Analysis of atomic emission instruments

Analysis with atomic emission instruments typically involves the following four distinct groups of components to analyze oil analysis samples:

- Excitation group.
- Optical processing group.
- Integration group.
- Electronics processing group.

Figure 3–2 illustrates the groups in block diagram form. In this lesson, we outline each of these groups in the same order as the oil analysis data is processed through them.

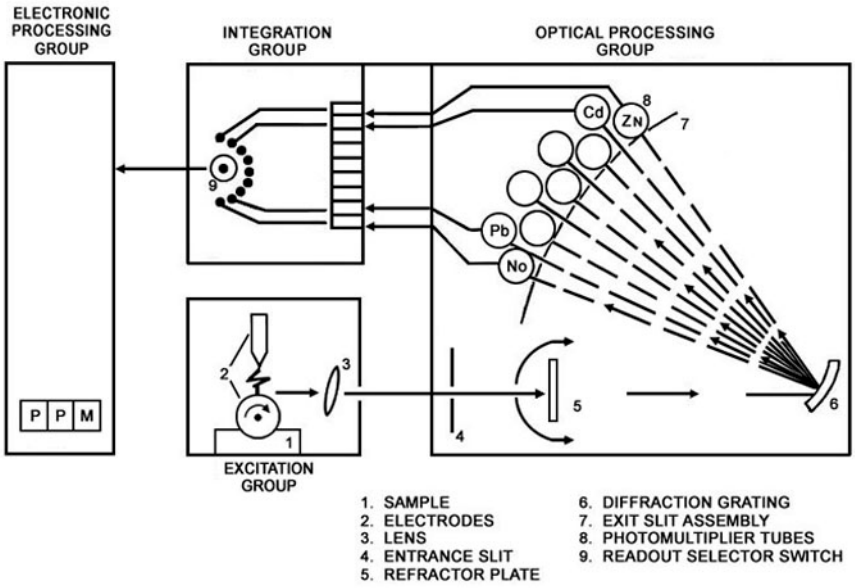


Figure 3–2. Atomic emission functional groups.

Excitation group

The excitation group of components is responsible for exciting the atomic particles in the test sample. This group contains a carbon rod and a carbon disc electrode. During an excitation cycle, the following actions occur:

1. The disc electrode rotates, bringing oil from the sample (fig. 3–2, #1) into the electrical arc formed between the two electrodes (fig. 3–2, #2).
2. The high-voltage arc excites electrons of metal atoms in the sample tested.
3. As the electrons fall back to their stable state, emitted light is projected through a lens (fig. 3–2, #3) into the entrance slit (fig. 3–2, #4) of the next group.

Optical processing group

The optical processing group takes the light emitted during excitation and isolates or breaks it down into its spectral wavelengths for monitoring. This is accomplished as follows:

1. Light passes through the entrance slit and a refractor plate (fig. 3–2, #5) and strikes the diffraction grating (fig. 3–2, #6), which disperses it into a spectrum.
2. Spectral lines of interest are individually isolated for measurement by passing the dispersed light through an exit-slit assembly (fig. 3–2, #7) positioned along the focal curve of the spectrometer. A narrow slit is cut through this assembly in the exact location where the persistent spectral line for each element of interest falls.
3. The persistent spectral lines are directed from the exit-slit assembly to the window of a photomultiplier (PM) tube (fig. 3–2, #8) for the element. The PM tube changes light energy into electrical current and multiplies its intensity several times.
4. The output from each PM tube is sent to the integration group and stored in a capacitor.

Integration group

At this point, background light from the electric arc and from any other source is eliminated, as presented in the following paragraphs.

Integration group capacitors store energy accumulated during the set period of sample excitement. During excitation, an electrical solenoid shifts the spectrum slightly to one side by moving the refractor plate in the optical processing group. This means the persistent spectral lines of the elements no longer align with their respective slits—the light going to the PM tubes is background light only.

At the same time the refractor plate shifts, reverse connections are made to the integration capacitor and it is charged in reverse for a specified amount of time. Forward capacitor charging is done with both background light and persistent spectral lines from the metal of interest. Reverse charging is accomplished with background only. The shifting of the refractor plate occurs several times during the course of an excitation period. This process has the effect of subtracting energy from each capacitor equal to the background light energy and leaving only the energy corresponding to the intensity of the spectral line of interest.

During calibration of the spectrometer, energy levels for each element at various concentration levels are stored in integration capacitors for reference. These reference levels enable the instrument to convert the energy stored during the excitation cycle into a quantitative value by comparing the obtained level to the reference levels.

At this point, automated instruments will automatically send all energy level data to the electronics-processing group for display or printout. In older instruments, energy levels for all capacitors are sent to the electronics-processing group, one element at a time, by placing a readout selector switch to the position for each element of interest.

Electronics processing group

The electronics processing group performs the final analysis processing step. It contains a device to transform the energy potential of the integration capacitor into a digital or electronic readout in PPM. Once the required data is recorded manually or into a computer database, all stored energy is automatically lost by discharging the integration capacitors when excitation of the next sample is started.

617. Scanning electron microscope/energy dispersive X-ray

Wear metals are metallic particles of microscopic size resulting from friction of moving parts. Due to the microscopic size of wear metals, they are suspended throughout the oil. When we are trying to detect a condition, we are dealing with advanced or abrasive wear of internal components. In this type of fatigue failure, large particles, or even small chunks of metal, are torn away from components. These larger particles are beyond the scope of detection and analysis by the spectrometric oil analysis as they are too large to be analyzed using atomic emission spectrometry (AES) techniques. This lesson discuses principles and the process of scanning electron microscope/energy dispersive X-ray (SEM/EDX). As with any other NDI equipment, operation and maintenance of SEM/EDX equipment should be accomplished in accordance with the current TO for the type and model of instrument used.

This lesson serves only as a general reference of typical Air Force equipment and will familiarize you with operating and maintenance procedures. *Do not* use this CDC for exact, step-by-step instructions for operating or maintaining your equipment.

Principles of SEM/EDX

Modern jet engines operate at the very limits of mechanical technology. The speeds and temperatures of the internal components are pushed to maximum performance at minimum weight, while being able to deliver performance and reliability that will maintain safety and mission capability. The main engine bearings that support the high speed rotating shafts of the engine operate in a particularly challenging environment, while needing to support the loads of the internal engine speeds and pressures generated by the aircraft. These engine loads are as much as 15,000 pounds on each bearing. These loads are supported on minute contact areas between the balls or rollers and the bearing races they run on, all while riding an oil film just microns thick.

The unavoidable result of loads on ball bearings or rollers is metal fatigue that is caused by the repeated stress of the bearing's surface metal. Over time this repeated stress and metal fatigue can lead to the surface of the bearing or bearing races breaking off in flakes of material in a condition normally referred to as *spalling*. When spalling occurs, metal fragments are displaced, causing the bearing surfaces which are normally very smooth to become rough and abrasive. As the bearing continues to run on this rough surface, it will become damaged and ultimately result in breakup of the bearing and seizure of the engine. In single-engine aircraft, such as an F–16, this becomes critical as undetected spalling can result in engine failure and can lead to loss of the aircraft.

Most jet engine bearings operate at speeds that will result in fatigue failure of some of the bearings. The detection of the metallic particles or debris in the oil system is essential to prevent full engine failure. The use of AES, as part of the Air Force Oil Analysis Program (OAP), focuses on the detection of these tiny wear metal particles present in the engine oil and has been successful in detecting bearing and other component problems or impending failures.

There are other various reasons these larger particles are not normally detected, but the most common reasons are that they are carried away in the flow of the oil and can settle in the oil system sump, become trapped in a filter or they can be captured by the master magnetic chip detector plug. These larger particles are critical indicators of the internal condition of an engine. Filters, screens, and chip detectors are designed into the engine oil system as methods to isolate these particles.

In the past, detection and identification of large particles were exclusively dependent on the visual inspection of these components. Filters and screens were examined at specific intervals; however, in day to day operations, the primary method of detection was examination of the engine master chip detector. In this process, the master chip detector was removed from the engine, after which it was examined using a magnifying glass; if no significant material was noted, it was replaced and the engine was considered to safe to fly. However, advancements in engineering and analysis of aircraft engines demonstrated that this process might have not always been the most successful process for detection and identification of particles that are indicators of an impending bearing failure.

The detection and identification of these particles is very important and has shown to be successful in detection of spalling failures. These larger particles are carried in the engine oil as the oil follows its path throughout the engine. While there may be multiple particles of various compositions, the ferromagnetic particles are caught by the magnetic chip detector that we are concerned with. The biggest downfall of this technique is that some of the bearings are located deep within the engine. As a result, particles generated from these surfaces have a long and sometimes obstructed path that may prevent all of the generated metal particles from the bearing surfaces making it to the master chip detector. Consequently, in some cases, very little metal debris may be available on the chip detector to indicate the impending failure; therefore, all debris captured is considered critical to the detection of possible bearing or engine failure. Because of this factor, there are very tight limits on the allowable size and amount of particles/chips that can be on the master chip detector during inspection.

One of the biggest problems with the visual method is that particles as small as 20 thousandths of an inch can indicate a potential failure.

Today, inspection of filters and screens still take place. However, when it comes to the inspection of the magnetic chip detector plug, the United States Air Force (USAF) implemented technology to enhance this inspection and to improve the process of detecting spalling long before any kind of failure occurs in main engine bearings.

The SEM/EDX

The SEM/EDX system utilizes a scanning electron microscope with an energy dispersive X-ray. The first part of the system, the SEM, is a type of microscope capable of detecting and producing high resolution images of materials in macro and submicron ranges or down to about ten angstroms (0.001 microns). The second part, the EDX, is used to identify the type of material.

The scanning electron microscope

A SEM generates high-energy electrons, focuses them on a specimen, and then scans the surface of the specimen. As the beam of electrons interact with the specimen, electrons are disrupted or displaced; in turn, energy is produced. The released electrons are captured by one of the two detectors within the microscope analysis chamber. This sends a signal to an amplifier which builds the final image from the number of electrons emitted from each spot on the sample. This information is then electronically processed and converted to a signal that is sent to a viewing screen; in a process very similar to a television signal, it produces an image that is displayed on a television type screen.

The energy dispersive x-ray

Viewing images of microscopic particles only solves half of the analysis problem. Now it is necessary to identify the different elements associated with the specimen. This is accomplished by using the built-in spectrometer called an EDX. This is an analytical technique that uses the interaction of the beam electrons and the sample electrons and radiation that are generated from this interaction in the form of X-rays. When specimens are exposed to the electron beam, the emitted X-rays are used to identify the elemental composition of the specimen. Just like in conventional oil analysis using the AES units, the energy of the emitted radiation - in this case X-ray radiation - is characteristic of the element from which the X-ray was emitted. Using these emissions, a spectrum of the energy and the counts or number of the X-rays emitted is obtained and evaluated for qualitative and quantitative determinations of the elements present.

Utilizing the combined abilities of SEM/EDX, these units are able to detect and identify material type, but this is only the first step. The units then apply an automated wear metal debris detection and classification computer program that is able to identify the type and amount of material in the sample. The program then applies a number of factors to determine if the material is an indication of an engine with problems; it also provides determination in the form of a risk factor.

On conclusion of the analysis, which typically takes around two minutes per sample, a report will be generated for each engine. If metal debris is detected that exceeds limits, a risk factor warning is generated. Some of the information that is provided in the SEM/EDX report includes the following:

- Number of particles of each material type.
- Size of each particle.
- Composition of each particle.
- Calculated risk level.

Using these results, propulsion maintenance personnel are able to complete further inspection of the engine and then make informed decisions concerning the equipment’s condition. Finally, they initiate appropriate maintenance actions based on technical order guidance.

Another useful feature of the SEM/EDX systems includes the ability of the SEM to generate a characteristic three-dimensional image of metal particles, because of the manner in which the images are created. These images are useful for judging the structure of the particles in the sample allowing determination of the type of debris detected. The ability to dimensionally classify the type of metal debris detected is critical in the overall process; the reason is due to the physical form of the debris also being used as an indicator of the engines internal condition. The following table is an overview of particle types routinely detected and their conditions they may indicate.

Particle Types	
Particle Type	**Description**
Fuzz	Light debris or fuzz-like particles observed during normal day-to-day operations.
Slivers	Appear as a hair-like substance of magnetic material. Normally this indicates wear interference on new or rebuilt engines.
Curls	Spiral coils of machining debris that may be found in new engines.
Flakes	Paper thin chips, normally shiny, which may indicate that a bearing is spalling.
Chunks	Three-dimensional particles, these may indicate that a gear is failing.

The USAF currently has two different systems in the field. The trade names of these are JetSCAN® and ASPEX Jet Engine Mobile Monitor (JEMM). Each system employs an SEM with an EDX. These systems are essentially highly accurate SEMs with EDXs that are used to detect the material composition of the particle they are examining. While these are complex pieces of equipment, they both have been “ruggedized” to tolerate the normal conditions where they might be installed and to be movable to deployed locations. Just as importantly, both have been developed for ease of use with minimal training requirements. It must be noted that even with the ease of use of the SEM/EDX systems, strict TO guidance and proper use of either of these machines are required to reduce engine-related mishaps.

The SEM/EDX process on flight line

The SEM/EDX analysis process begins with the flight line personnel (crew chief) removing the master chip detector from the engine and in its place, a clean chip detector is installed. The crew chief then inspects the chip detector removed from the engine with a 10X magnifier. If the crew chief notices any visual debris material on the detector, it is annotated within the aircraft forms. Once the visual inspection is completed, the crew chief then covers the chip detector with a protective cap to prevent disturbing any particles that may have been collected; afterwards, he or she submits the detector to the NDI/JOAP laboratory for SEM/EDX analysis. It is critical in this process that flight line personnel still perform a visual inspection of the detector prior to sending it the NDI/JOAP lab as the lab analysis may not always be complete prior to the next flight.

Although SEM/EDX technology is available for use on any turbine engine, it is currently only used in NDI laboratories that support F–16 and U2 aircraft that have GE F–110–GE–100/118/129/132 engines. Because of this, not all NDI laboratories have SEM/EDX units. It is important to note that even though SEM/EDX is only used for the F–16 and U2 aircraft, other potential applications are under consideration.

Frequency of SEM/EDX sampling is not currently aligned with JOAP criteria and for the aircraft that SEM/EDX is currently supporting, the magnetic chip detectors are analyzed after each flight. While this may seem extreme, it must be noted that through use of SEM/EDX, impending failures have been detected and maintenance actions have been initiated, preventing loss of aircraft and life, enhancing both flight safety and operational readiness.

The SEM/EDX process in the NDI lab

As stated earlier in this section, SEM/EDX is used to identify and monitor material characteristics that can give an indication of accelerated wear or impending failure of typical oil wetted parts and

components. The process of performing SEM/EDX analysis can be broken down into three steps. The first step takes place off the machine as the debris samples are prepared to be analyzed. The second and third steps of the operation take place within the SEM/EDX unit.

Step 1, sample preparation

The first part of the process, and one of the most critical aspects of the SEM/EDX process, is to remove all debris particles from the chip detector and place them on a carbon adhesive tab. This is where SEM/EDX differs from the conventional spectrometric oil analysis technique. In conventional oil analysis, the oil is used to keep the wear metals in suspension; however, in SEM/EDX analysis, the metal debris particles must be free of oil. To accomplish this, the magnetic chip detector is washed or dipped in an alcohol bath to dissolve and remove the oil, and then allowed to dry. Then the technician must carefully transfer all of the particles onto the carbon tab that is mounted on a sample holder that will be placed within the unit for analysis.

Step 2, sample analysis

The second step begins once the sample-mounting block with the carbon tabs holding the debris sample(s) are loaded onto the analysis chamber for the actual analysis. The operator then inputs basic data relating to the origin of the debris to be analyzed. This is the same basic data that is used in AES analysis, such as engine serial number, total operating hours, and time since last sample taken. The chamber is then evacuated or pumped down to the required vacuum level. Once the required vacuum level is reached, the user will initiate the analysis process. The system automatically runs through a series of set up and calibration modes; when all details and calibration requirements are satisfied, the system will prompt the operator to initiate the sample analysis run.

Once the operator initiates the analysis run, the unit will automatically align each sample stub under the electron beam. The system then performs an analysis of the sample stub with no further input or oversight from the operator. The system uses the SEM to scan each sample stub, examining each sample for any particles. When particles are detected, the system then uses the EDX detector to perform a full analysis to determine each particle's elemental composition. Following an analysis run, the unit will store its results in a Microsoft Access database.

The criteria regarding risk analysis and debris assessment is completed immediately after the sample run. Using data obtained during the sample analysis, a software program completes a risk factor calculation using a mathematic algorithm. The algorithm takes into consideration the size, shape, and quantity as well as material characteristics of each particle individually, and then completes the same calculation using the sum of all the particles. Finally, it compares the results to known alloys used in the engine bearings, gears, and other oil system components, and then compares the analysis results against programmed limits for each material. When the risk factor process is complete, the unit provides a detailed report of each sample analyzed, identifying all material types detected and then assigning a level risk factor warning. The level warning assigned is based on the type of material detected, the amount of each material, and the size and shape of each particle.

The following are the four risk factor level warnings:

No risk factor level

No material was detected.

Level 1

Material Detected, but Within Limits: This is a "Level 1 warning," indicating that a significant amount of material has been detected, but that it is not at a critical level. No maintenance action required.

Level 2

MATERIAL LIMIT EXCEEDED: This is a “Level 2 warning,” indicating that there is a significant amount of material detected, and troubleshooting must be initiated. Troubleshoot the engine in accordance with applicable engine TO.

Level 3

HIGH LIMIT EXCEEDED: This is a “Level 3 warning,” indicating that there is an unusually large amount of material present and that troubleshooting of the engine is required.

Step 3, reporting results

The 3rd and final step in the SEM/EDX process is the reporting of results. NDI personnel play a critical role in the SEM/EDX program as operators of the equipment and the individuals who process the sample for analysis. Proper sample preparation is critical to the SEM/EDX units being able to fully and properly analyze metal debris from the master chip detector; however, the most important task NDI personnel have in the SEM/EDX process is that of reporting results. When an engine sample analysis results in a risk factor level warning, it is critical that these results be reported immediately to allow engine maintenance personnel to investigate the situation and determine if the engine is safe to fly.

The overall goal of this program is to improve both the safety of flight and maintenance actions by the early and correct diagnosis of bearing failure.

618. Oil analysis equipment and maintenance

Air Force OAPs will meet specific laboratory equipment and configuration requirements. Each lab will have a Spectroil M or M/N with sufficient ventilation and sufficient bench space to manage the sample workload.

Basic responsibility for maintenance of the spectrometer rests with the organization using the equipment. To assure consistent analysis results, it is necessary for the operator to perform some maintenance. Any needed maintenance beyond the scope presented in the spectrometer TO will require authorization from the Air Force OAP office for manufacturer assistance. The manufacturer’s service representative will normally guide you through additional troubleshooting via the phone and email. If the repair cannot be accomplished by personnel in your shop/unit, the AF OAP office will authorize a manufacturer service call.

This section contains basic information and instructions regarding equipment and supplies used, spectrometer maintenance, and diagnostic checks for operation of a JOAP laboratory performing spectrometric analysis.

Laboratory instruments

The Spectro, Science Model M and Spectro, Science Model M/N atomic emission rotrode instruments are approved for use in the JOAP and are eligible for JOAP certification when enrolled and operated by DOD laboratory personnel.

Spectro, Inc. Model M

The “M” is a bench top spectrometer designed for both laboratory and mobility use. It has many built-in safety features for power applications and routine operation. The spectrometer is configured for the fifteen JOAP elements and is shown in figure 3–3.

Spectro, Inc. Model M/N

The “M/N” is essentially the same as the “M.” The “M/N has electro-magnetic interference (EMI) protection that meets the requirements of the US Navy. Additionally, the “M/N” has a convenient port for measuring the source frequency. Adjustment of the source frequency is made with a control that has been placed in the burn chamber. This model is shown in figure 3–4.

Figure 3–3. Spectro model M.

Figure 3–4. Spectro model M/N.

Three instrument requirements include environmental controls, power, and exhaust vent.

Environmental controls

Temperature and humidity will be controlled at 75 ± 10 °F and relative humidity should be controlled between approximately 20 percent and 60 percent. In general this means that environmental conditions should not be allowed to change by more than 10 °F or 10 percent relative humidity during a 60 minute working period. If a computer is used or is an integral part of the instrument, problems may occur if excessive heat is encountered.

For spectrometers in deployed locations, every effort must be made to meet these requirements, as a minimum the spectrometer shall be utilized indoors. In the event that a deployed location cannot meet the temperature and humidity requirements due to mission necessity, then the lab shall contact the appropriate program manager for guidance and assistance. If temperature and humidity requirements listed are not utilized at deployed locations, standardization and operation issues may likely be encountered. For efficient computer operation and to prevent frequent standardizations, environmental control is necessary.

Power requirements

Refer to the spectrometer manufacturer's information concerning the application of power to the instrument as the requirements vary from instrument to instrument and country to country. Ensure that all measures are taken to set up the instrument for the correct voltage and frequency (Hz) before applying power. If a multimeter is available, ensure the voltage is constant and within specifications.

Exhaust vent

Fumes from the spectrometer must be vented to the outdoors to protect the operator. If you are operating the spectrometer outdoors with mobility equipment, vent the exhaust away from the operator to a sufficient distance to avoid inhalation of fumes. For exhaust systems longer than 25 feet in length, a booster fan is needed to insure adequate ventilation.

Laboratory supplies

JOAP supplies consist of oil standards, electrodes, oil sample vessels (bottle caps), and other supplies.

Oil standards

The D12 and D3 standards are soluble complex metallo-organic compounds that are blended in hydrocarbon base oil. The D12 standards contain approximately the same weight of each of 12 elements. The D3 standards contain approximately the same weight of each of 3 elements (boron,

molybdenum, and zinc). The D19–0 standard is base oil with no elements added. All standards have a minimum flash point of 340 °F and a viscosity of approximately 245 centistokes at 100 °F.

Electrodes

A suggested six month supply of electrodes is required to be kept on hand. Only electrodes available through the DOD supply system are approved for use. Rods are six inches long and normally provide for 25−30 analyses. Discs are 0.200 inch thick and are used for one time only.

Oil sample vessels

Bottle caps will be used for performing a sample analysis when a JOAP approved cap is not provided with the oil analysis bottle. Reusable sample vessels (aluminum boats) are also authorized for use but must be cleaned after each use.

Miscellaneous supplies

Miscellaneous supplies also needed for JOAP include cleaning compounds, paper tissue, disk filters, and ultrasonic cleaners; additionally, each machine requires an electrode sharpener.

Spectrometer maintenance

The basic responsibility for maintenance of the spectrometer rests with the organization using the equipment. To assure consistent analyses results, it is necessary for the operator to perform some maintenance. Any needed maintenance beyond the scope presented in the spectrometer TO will require authorization from the Air Force OAP office for manufacturer assistance. The manufacturer's service representative will normally guide you through additional troubleshooting via the phone and email. If the repair cannot be accomplished by personnel in your shop/unit, the AF OAP office will authorize a manufacturer service call.

Maintenance Intervals		
Interval	**Description**	
Daily	1.	Wipe clean the shaft, the sample table, and the sample plate area between the disc electrode shaft and the rod electrode clamp after *each* burn cycle.
	2.	Remove oil and carbon buildup from sample stand components every five burns if wiping after each burn cycle does not prevent buildup.
	3.	Clean quartz window with an alcohol or ammonia based window cleaner after the warm up, daily standardization, and every five routine analysis burns.
	4.	Clean the entire sample chamber, including the inside of the door, after each operational shift. Normally, this ends up being twice per day after each eight hour shift of JOAP lab operation.
	5.	Clean sample stand sensors with alcohol or ammonia based window cleaner daily.
	6.	Clean readout and control panel daily if oil splashes and carbon deposits are present.
	7.	Clean exterior panels and frame daily if oil splashes and carbon deposits are present.
	8.	Clean printer of dirt and dust buildup daily. Replace worn ribbon and tighten loose connections as required on a daily basis.
	9.	Maintain electrode sharpener daily by empting carbon shavings and rotating cutting blade to a sharp edge as needed.
	10.	Inspect and clean sample stand exhaust finger guard and filter daily or as required.
Weekly	1.	Clean heat exchanger filter of dust and dirt buildup weekly or as required.
Monthly	1.	Inspect exterior panels and frame monthly, clean and/or repaint as required.
	2.	Inspect, clean, and lubricate sample stand door hinges monthly.
	3.	Inspect exterior monthly for loose, missing, or corroded fasteners.
	4.	Inspect spectrometer external cables for damaged and loose connections monthly.
	5.	Clean varnish residue from splined end of disc electrode shaft monthly.

Maintenance Intervals	
Interval	**Description**
Every six months or 2000 burns	There are several inspection/maintenance actions that are to be performed at the six month or 2000 burn interval. Refer to the inspection and maintenance chapter of the spectrometer manual for specific requirements for internal housing, excitation source, power distribution, and microprocessor maintenance inspections.

Diagnostic checks

Diagnostic checks are performed to help troubleshoot an instrument's inability to standardize properly and to produce accurate analyses results. The following are four basic diagnostic checks that may be performed by the operator to check the instrument:

- Calibration curve verification.
- Repeatability.
- Accuracy.
- Dark current test.

Calibration curve verification

The purpose of performing calibration curve verification is to determine if the instrument repeats the curve generated at the factory or by an authorized service representative. To perform a calibration curve verification, the instrument must first be standardized. When the instrument has been standardized using the calibration standards, the calibration curve verification can be performed. The calibration curve verification consists of performing an analysis of each standard as if it were an unknown sample. It is recommended that the operator conduct ten analyses of each standard and then obtain the average and standard deviation for each element. Instrument performance for a wear metal analysis should be within the limits listed in the manual.

Repeatability

Perhaps one of the most important technical characteristics of a spectrometer is its ability to perform the same measurement over and over again with the same result. This characteristic is referred to as repeatability.

- Repeatability is determined by the standard deviation of a series of measurements made on the same sample.
- The level of repeatability is obtained by burning the same standard ten times in succession. In order to achieve this level of repeatability or better, the repeatability test must be done under ideal conditions.

The following table presents some of the numerous factors that affect repeatability.

Factors Affecting Repeatability	
Factor	**Description**
1.	The sample must be homogenous. The repeatability test done at the spectrometer manufacturer is *always* done with standards. Routine samples are *never* used for repeatability testing because of unknown amounts of elements and contamination will affect repeatability.
2.	The spectrometer must be on profile. If analytical lines are off profile, the repeatability will be adversely affected. If the repeatability specifications cannot be met, one of the first diagnostic tests is to check the profile.
3.	The quality and handling of the disc and rod electrodes will affect repeatability. Only electrodes that that have been approved for use by the Air Force OAP program office shall be used. Care must be taken to properly sharpen the rod electrode. Proper care must also be exercised when handling and installing all electrodes to prevent contamination.
4.	The sample must be homogenized by shaking before filling the sample holders.
5.	The sample holders must be filled to the same level.

Factors Affecting Repeatability	
Factor	**Description**
6.	Line voltage to the spectrometer must be within specifications.
7.	Electronic stability of the spectrometer will affect repeatability. An easy diagnostic test to perform is the dark current test.
8.	Sample stand geometry will affect repeatability. The rod electrode to disc electrode gap distance, the quartz lens assembly to arc distance, the position of the fiber optic within the lens assembly mounting block, and the angle of the quartz lens assembly with respect to the arc will affect not only the intensity of the light entering the entrance slit of the optical assembly, but will also affect the repeatability. The calibration of the spectrometer at the factory optimizes these adjustments.
9.	Any mechanical or electronic faults could degrade repeatability. Among these are faulty photomultiplier tubes, mechanical damage to any of the polychromator components such as the entrance slit, any of the exit slits or the holographic grating, or damage to the fiber optic cable.

The operator has control over the first five factors of the repeatability factors listed in the preceding table. If care is taken to properly operate the spectrometer, and repeatability is still not within specifications, and if the spectrometer passes the dark current test and is on profile, then it is recommended that the manufacturer's service engineer be consulted. It is strongly recommended that adjustments to the sample stand as described in #8 of the repeatability factors listed in the preceding table be made only by, or at the direction of a qualified service representative.

NOTE: Under *NO* circumstances, should the polychromator cabinet be opened unless by specific direction of the manufacturer's personnel.

Accuracy

The spectrometer is expected to perform within accuracy specifications in the same way that it performs within repeatability specifications. Accuracy is the ability of a spectrometer to give the correct concentration value of a standard. The spectrometer operation and maintenance manual gives acceptable accuracy readings for wear metal elements as a function of the concentration of the standard. The manufacturer's service representative should be consulted if the spectrometer is unable to meet the accuracy criteria.

Dark current test

The dark current electronic stability test is used to assure that the spectrometer has reached electronic stability. It is performed as a diagnostic test to assure that the unit is functioning properly. The dark current test is performed without burning a sample. It assures that the outputs of the PMTs are stable when in complete darkness and that the electronics from the PMTs to the readout are stable.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

615. Spectrometric oil analysis

1. What is a diagnostic maintenance tool used to determine the type and amount of wear metals in lubricating fluid samples?

2. What are generated by friction between moving metallic surfaces in mechanical systems?

3. What are the analytical instruments currently used for spectrometric oil analysis?

4. What is the element abbreviation for the wear metal tin?

5. How does an atomic emission spectrometer work?

6. What type of spectrometric limitation has a slow, progressive wear metal concentration buildup above established abnormal criteria?

616. Principles of atomic emission analysis

1. What happens during spectrometric analysis?

2. What happens when an atom is excited?

3. How are characteristic lights of an element created?

4. How is the concentration of an element in a fluid sample determined?

5. What four distinct groups are typically involved during an analysis with atomic emission instruments in order to analyze oil analysis samples?

6. What group of components within atomic emission is responsible for exciting the atomic particles in a test sample and contains a carbon rod and a disc electrode?

7. What is the third step of the optical processing group?

8. What process has the effect of subtracting energy from each capacitor equal to the background light energy and leaving only the energy corresponding to the intensity of the spectral line of interest?

617. Scanning electron microscope/energy dispersive X-ray

1. What focuses on the detection of tiny wear metal particles present in an engine?

2. What methods are designed into an engine oil system to isolate particles?

3. What system utilizes a scanning electron microscope with an energy dispersive X-ray?

4. What generates high-energy electrons, focuses them on a specimen, and then scans the surface of the specimen?

5. What identifies different elements associated with a sample specimen?

6. What happens after the first step of the SEM/EDX detecting and identifying a material type?

7. Using sample results, who is able to complete further inspection of the engine and then make informed decisions concerning the equipment's condition?

8. What particle type appears as a hair-like substance of magnetic material that normally indicates wear interference on new or rebuilt engines?

9. What are the two different USAF systems used in the field?

10. Who removes the master chip detector from the engine and replaces it with a clean chip detector?

11. What is the first part of the SEM/EDX process?

12. What is based on the type of material detected, the amount of each material, and the size and shape of each particle?

13. What is the most important task NDI personnel have in the SEM/EDX process?

618. Oil analysis equipment and maintenance

1. What two atomic emission rotrode instruments are approved for use in the JOAP certification program when enrolled and operated by DOD laboratory personnel?

2. What is the maximum allowable change to relative humidity that environmental conditions for oil analysis equipment should be allowed to experience during a 60 minute working period?

3. Which standards are soluble complex metallo-organic compounds that are blended in hydrocarbon base oil?

4. What is a suggested amount of electrode supply required to be kept on hand?

5. How often do you clean varnish residue from the splined end of disc electrode shafts?

6. What needs to be accomplished before you can perform a calibration curve verification test?

7. What is the name of one of the most important technical characteristics of a spectrometer when it performs the same measurement over and over again with the same result?

8. Which diagnostic check is performed without burning a sample?

3–2. Oil Analysis Correlation Program and Procedures

The JOAP correlation program ensures uniform and continuous high quality oil analyses results. The correlation program quickly identifies laboratories experiencing instrument or operator problems and provides managers and laboratory personnel a means to compare their performance with other laboratories having the same type of spectrometer.

619. Requirements and responsibilities of oil analysis

The following items make up the stated purpose of the OAP:

- Detect changes in the condition of used oil and other fluids.
- Detect unusual wear.
- Predict impending equipment failures.

Oil analysis laboratory recommendations are the result of careful trending and in-depth analyses of equipment history and should normally be followed; however, it is ultimately the customer's responsibility to decide what action to take in regard to any recommendation from the JOAP laboratory. A customer representative must work closely with the supporting oil analysis laboratory to ensure adequate maintenance procedures are implemented, which will result in reduced maintenance costs and increased operational and personnel safety.

Oil analysis responsibilities

Oil analysis responsibilities can be translated into improving equipment operational safety and reliability. This increases maintenance effectiveness through performance of the right maintenance, at the right time, at the lowest level, consistent with good maintenance practices. An effective OAP can also enhance maintenance workload planning by early identification of unscheduled maintenance requirements, and improve the quality of maintenance and equipment operating practices. The results of oil analyses ultimately results in improved maintenance procedures and equipment design.

The following list of responsibilities are for each JOAP lab:

- Each lab should conduct internal accounting and record keeping to ensure that all samples for equipment entered in the OAP are taken correctly and on time.
- Ensure that all personnel involved with the OAP are properly trained in their duties and thoroughly aware of the importance of, and the benefits to be obtained by an effective OAP.
- Ensure that timely response is made to laboratory requests for samples or laboratory recommendations for maintenance actions and that prompt and complete feedback is provided to the laboratory concerning any condition or maintenance action that may affect the condition of the equipment's oil system.
- Designate a unit point of contact to monitor activity compliance with oil analysis requirements.
- Although the laboratory operator/evaluators are responsible for evaluating analysis results and providing recommendations to the customers, the customer has the ultimate responsibility to determine what action, if any, is required in response to a laboratory recommendation. In order to fulfill this responsibility, certain equipment oil analysis and maintenance information must be available to the maintenance manager.

Oil analysis requirements

The purpose of JOAP is to standardize laboratory requirements and operating procedures. As discussed, the primary test performed by all JOAP laboratories is the spectrometric wear metal analysis of in-service oil samples.

Each NDI lab has specific requirements that must be accomplished, including the following:

- Use the most current software.

- Backup software on a weekly basis to an external device.
- Backup all spectrometers assigned monthly.
- Perform daily supervisor reviews.

Sampling procedures

The success and effectiveness of the OAP is dependent upon reliable samples. A reliable sample is one which is truly representative of the circulating fluid in the equipment being evaluated. Two important things you need to know about sampling include when samples are taken, and how they are taken.

When samples are taken

Samples should be taken as soon as possible but within 30 minutes of engine/equipment shutdown and before any fluid is added to the system. If more than 30 minutes have passed, the engine should be run at engine idle/motored for a minimum of five minutes and resampled. All aircraft oil samples will be taken and delivered as soon as possible after engine shutdown, not to exceed 75 minutes. The following table provides a brief overview of two samples.

Types of Samples		
Routine samples	Routine sampling intervals shall be as specified in appropriate service documentation governing operation and maintenance of each type/model/series of equipment. Cognizant weapon system/model engineering activities establish and maintain sample interval documentation to provide effective oil analysis coverage.	
Special samples	Special samples from equipment monitored by the service OAPs will be taken in accordance with the following guidelines:	
	1.	Whenever requested by the laboratory.
	2.	Whenever directed by the unit maintenance activity to investigate suspected deficiencies.
	3.	Immediately following an operation in which any abnormal condition or incident occurred resulting from either malfunction of the oil lubricated system, or damage to the oil lubricated system from excessive loss of engine oil, or low/fluctuating or zero oil pressure.
	4.	Immediately prior to and after maintenance is performed affecting the oil lubricated system, including the removal and replacement of an oil lubricated system component. Systems, which are sampled after each flight, do not require samples taken prior to maintenance, provided an analysis was accomplished after the last flight.
	5.	After flight test following installation of new, overhauled, or repaired aircraft engines.
	6.	At completion of a test cell run. If unit is operated on oil previously used in the test cell system, a sample is required both prior to and at the completion of the test cell run.
	7.	Whenever excessive vibration or a chip light indication is experienced on an aircraft engine or component during flight, ground, or test run.
	8.	Immediately following all aircraft incidents involving failure of internal enclosed lubricated parts or unplanned/unexpected shutdown affecting operation of internal enclosed lubricated parts.
	9.	Immediately following all aircraft accidents regardless of cause and resulting damage. These samples will be taken by any means possible to obtain a representative sample.
	10.	Prior to overseas deployment or redeployment of any equipment already being monitored by oil analysis. Samples should be taken far enough in advance to assure receipt of analysis prior to unit deployment or redeployment. **NOTE:** A sample prior to departure is not required if the aircraft is on routine sample.
	11.	Oil analysis records will accompany the aircraft. **NOTE:** The normal sampling interval can be maintained due to the availability of an oil analysis facility at the destination.

How samples are taken

The three basic techniques used to take samples include dip tube, drain/valve, and pump.

Detailed sampling procedures for specific equipment are established in applicable service documentation governing the use and operation of such equipment.

620. Joint oil analysis program certification program

All DOD oil analysis laboratories (organic or under contract to a DOD agency or US military service for the purpose of analyzing samples from US government equipment or supplies) will participate in the JOAP Correlation Program. This section looks at certifying a new lab, recertifying a lab, and the procedures needed to manage the program.

Certification program

The Air Force OAP Correlation Team certifies laboratories upon their initial establishment and relocation based on the service program manager's attestation that the laboratory/spectrometer meets specified criteria and the laboratory/spectrometer's satisfactory participation in the JOAP correlation program. The certification checklist enables the Air Force OAP Correlation Team to ensure that laboratories meet minimum criteria required for an operating laboratory. An electronic USAF/United State of America (USA) Certification-Verification Checklist is available from the Air Force Program Management Office at af.oil.analysis@us.af.mil. Air Force laboratory personnel must maintain on hand the current certification-verification checklist with signatures including attestation by the program manager. Laboratories must be either certified or uncertified during the use of this program.

Certified labs

Certified labs must have a monthly correlation score of 80 percent or above and all certification checklist requirements are required to maintain a certified lab. Completed annual certification checklists are required and must be sent to oapcorr@us.af.mil and the appropriate service program manager's office. The completed annual certification checklist must be submitted as part of the correlation program requirements by 1 March each year to the respective service program manager.

When a laboratory or spectrometer certification is withdrawn because of a one-month score below 80 percent, the applicable service program manager may approve a one-time repeat of correlation samples analysis and submission of results. The new results must be submitted and scored within five days of service program manager approval. If a score of 80 percent or above is received on the re-submittal, certification is reinstated.

Uncertified labs

If a score is not received on a re-submittal, the laboratory certification is withdrawn, and the unit must use troubleshooting procedures immediately.

Reasons for reduction to uncertified labs include the following:

- Score falls below 80 percent.
- Failure to submit monthly correlation results prior to the next month's due date. Unless late submittal is authorized.
- Failure to submit an annual approved verification checklist.
- Failure to meet full operating requirements.
- Laboratory/spectrometer is physically relocated.
- Laboratory is deactivated.
- Upon direction of the service program manager.

Initial certification/recertification procedures

A laboratory must complete the following steps to become certified:

1. Complete one special certification sample set (two pair) with an average of 80 percent or above. The new JOAP, commercial, contract or previously stored instrument schedule is completed on same duty day.
2. Sign and forward the applicable certification verification checklist to their service program manager; who will forward to the Air Force OAP Correlation Team.

Reported maintenance status

Laboratories reporting reported maintenance (RM) status for a spectrometer will receive no calculated correlation score for that spectrometer if the RM period extends past the correlation sample analysis due date. During RM periods, spectrometers will be placed in an RM status and will not be authorized to perform any operational oil analysis support functions.

When the spectrometer has been repaired, up to two months of correlation samples that were on hold may be analyzed. If only one set of samples are overdue, analyze the correlation samples on hand immediately after repair. If two sets of samples are overdue, analyze one set on the first workday after repair, and the second set on the second workday after repair. In other words, analyze up to one overdue set of samples for each workday after repair. This procedure is to ensure that a different standardization is accomplished for each set.

Spectrometers will be decertified when the third correlation due date is missed. When the laboratory reports the spectrometer repaired, it will also complete the certification procedures.

Deployed spectrometers

Deployable laboratory spectrometers must have a full standardization completed prior to use at deployed location to verify serviceability. If a successful full standardization cannot be achieved, the operator will perform the appropriate troubleshooting procedures.

After the spectrometer has been returned to the laboratory from deployment, laboratory personnel must perform a complete standardization to ensure that the spectrometer is again fully operational prior to re-deployment. This will reduce the risk of deploying with or storing an unserviceable spectrometer.

Correlation procedures

The correlation program for spectrometers is conducted monthly by the Air Force OAP Correlation Team. Two sample pairs are mailed from the correlation team to each participating JOAP laboratory, and scheduled to arrive no later than the fifth working day of the month. Correlations are to be analyzed within five duty days of receipt. The spectrometer is standardized, and the same qualified operator analyzes the sample pairs. Results are submitted to the Air Force OAP Correlation Team to arrive no later than the 21st of each month.

NOTE: Correlation printouts, including all standardization data, and all left over correlation oil samples shall be retained for three months. The service program managers may also request printouts as a quality assurance check at any time.

621. Daily start-up and standardization procedures

Standardization is among the more important steps you can take when using an oil analysis instrument. Standardization is necessary to adjust an instrument to recognize the correct wear metal quantities in your test samples based on known quantities in reference standards. Reference standards with upper and lower concentration levels in PPM are used. Once properly standardized, atomic emission instruments will produce highly accurate readouts.

After you have all of the necessary supplies and equipment, such as oil standards, bottle caps, and paper towels, proceed with the initial set-up of the instrument as discussed in this section.

Cleaning sample stand area

Open the sample excitation housing door, and lower the oil vessel platform. If an oil vessel is present, remove it. If disc or rod electrodes are present, remove them. Using the tissue paper, remove all visible oil splashes from the analytical gap area, sample stand, quartz window, and disc electrode shaft. Use an approved solvent to aid in cleaning any heavy carbon or oil buildup. If solvent is used, ensure it has completely dried before performing any burns in the chamber. Clean the quartz window using a clean, soft, disposable laboratory tissue, and wet one corner of the towel with an ammonia-based window cleaner. With your forefinger, rub the wet portion of the paper towel along the surface of the window while applying moderate clockwise pressure on the window. This will disperse the oil film. Now take the dry portion of the paper towel, and repeat this procedure until no oil can be seen on the tissue paper. A cotton swab can also be used for this purpose.

NOTE: Ensure the sample excitation area is kept completely dry before, during, and after operation. This precaution will prevent possible damage due to high-voltage arcing.

Installing electrodes

Electrodes must be treated with some degree of care. *Do not* touch the outer rim of the disc, sharpened tip of the rod, or allow the electrodes to touch any foreign matter. If they become contaminated, erroneous results will occur.

The disc electrode is always installed first. Always handle electrodes with a clean tissue. Using the tissue, install a new disc electrode on the pin shaft. Push it straight in, making sure it is firmly seated against the back shoulder on the shaft. Press and hold inward on the rod electrode clamp knob and position a sharpened rod electrode in the holder jaws and release. Press and release the knob once more to allow the sharpened end of the rod electrode to slide down and make contact with the disc electrode.

The correct analytical gap between the spectrometer electrodes is obtained by slowly raising the analytical gap setting lever upward until it stops and gently releasing it back to the resting position. Rapidly pressing, releasing, or jarring the electrode holder or gap setting lever can result in erroneous instrument readings due to inconsistent gap spacing. It should look like the example in figure 3–5.

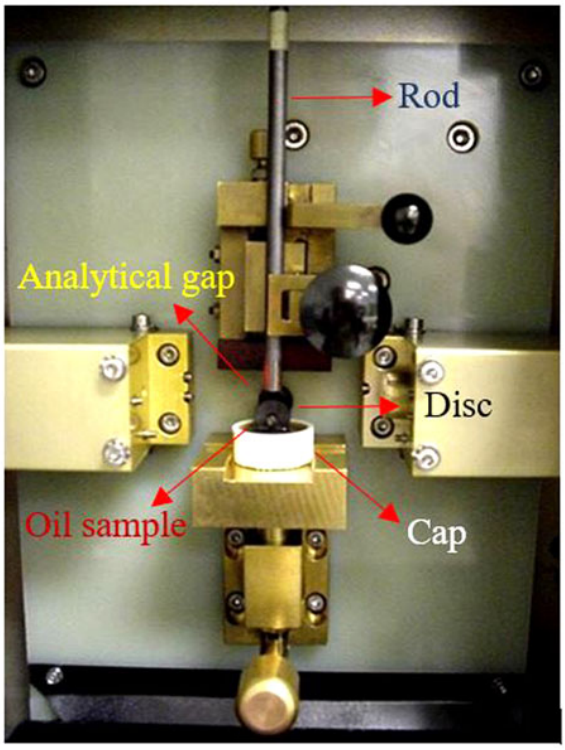


Figure 3–5. Sample stand with rod, disc, cap, and oil sample.

Warm-up

Complete the warm-up by conducting three or four analysis burns with “slop oil.” You *do not* need to change the electrodes between burns, but you must correctly re-gap the electrodes before each burn. Do not burn the same sample more than twice to prevent sample ignition. After completing the five warm-up burns, remove the electrodes and thoroughly clean the burn chamber.

CAUTION: Electrodes are extremely hot following a burn cycle and multiple burn cycles increase this hazard. Care must be taken when removing the electrodes to avoid operator injury.

Daily standardization check

You can use the daily standardization check as a fast, time saving procedure to verify that the instrument has maintained calibration. The three standards you select for this check should include the expected concentration range of the used oil samples to be analyzed. Standards normally used for the daily standardization check are 0, 5, and 10 PPM standards. The results in PPM are then checked against the limits listed in the table to the right.

If the results of the analysis fall within the limits just given, you are ready to burn the used oil samples for concentration measurement. If the results of the analysis *do not* fall within these limits, you must proceed with full instrument standardization and then perform the daily standardization check again.

The following table shows the applicable PPM range for each standard needed for daily and complete standardizations.

Acceptable Standardization Range		
Concentration	**Minimum**	**Maximum**
0	0.0	1.0*
5	3.8	6.2
10	8.5	11.5
30	27.0	33.0
50	45.0	55.0
100	90.0	110.0
* This range does not apply to the elements Al, Ag, Mg, or Sn. The acceptable range for these elements is 0–0.5 for the average of three burns.		

Complete standardization

Complete standardization is a procedure performed to place the calibration of the instrument as close to the standard values as the instrument originally produced during factory calibration. This procedure involves burning oil standards at predetermined points along the calibration curve. After these standards are analyzed, the computer software will determine mathematical factors to correct for any change in the calibration. Complete standardization is performed if any of the following conditions exist:

- When the instrument has been relocated to another site for operation. This is generally performed after the optical profile procedure has been completed.
- When results from the daily standardization check fall outside of acceptable limits for operation.
- Prior to the analysis of JOAP monthly correlation samples.
- After the optical profiling procedure has been performed.

Complete standardization is performed by burning two or more calibration standards which have been pre-selected during the factory calibration of the instrument. The concentration levels for complete standardization are selected based on the application and typical operating range for the elements of interest. In general, all elements are standardized at 0 PPM to determine the background level, all wear metal and contaminant elements are standardized at 100 PPM.

It is strongly recommended that accurate records of the complete standardization data be kept for future reference. Printing a copy of the standardization values table and the standardization factors table found at the end of the standardization process will help the manufacturer troubleshoot the instrument if a major malfunction does occur.

If you completed the full standardization because your daily check failed, you should now perform another daily standardization check.

If your second daily check fails, you will be instructed by your spectrometer TO in order to perform an *optical profile check* and an *electrode offset procedure* before you complete a second full standardization.

Optical profiling

It is necessary to perform the optical profile procedure at least monthly just prior to analyzing your monthly correlation program samples. Even though the spectrometer is designed to withstand a certain amount of physical movement and temperature change, occasionally, the optics will need to be profiled. It is recommended to profile the optics whenever the instrument is moved to a new facility or has been subjected to a temperature change of 15 °F or more.

The optics of the Spectroil M are shock-mounted and designed for thermal stability. Consequently, the optics do not need to be profiled frequently; however, detection limit and repeatability suffer when the optics are off profile.

Electrode offset procedure

The portable spectrometer, Spectroil M, is designed to incorporate a background measurement and correction system. The purpose of this system is to offset or null the output of all element PMTs when measuring a zero PPM standard. This is also known as measuring background light because zero PPM has no concentration of elements present in the sample; therefore, the light produced when analyzing a zero PPM standard must only be background emission. This is only true in theory. In practice, elemental contamination is present in everything used for the analysis process. The sample holders may pick up contamination from the environment, the zero PPM standard may have sub-PPM trace levels of certain elements, and the graphite electrodes are known to have trace contamination. Manufacturers of graphite electrodes commonly list and quantify the known trace or spot impurities on each box of electrodes.

The purpose of the electrode offset procedure is to *offset* these trace contaminates in the consumables and must be performed. This procedure is performed every time a new batch and/or lot number of electrodes is used. For maximum efficiency in a laboratory operation, all graphite electrodes should be grouped and stored by batch and lot number. Only one batch or lot should be used at a time until they are totally consumed. Once a new lot is opened, and the instrument is standardized to the new lot, the low end of the calibration curve (five PPM and/or ten PPM) should always be checked. If accuracy at these levels fails to meet the specified criteria, it may be due to variance in trace contaminant levels, and the electrode offset procedure should be performed to correct for the presence of this contamination.

Once these procedures have been completed, and you have accomplished the second full standardization, you will be directed to perform another daily standardization check. Follow your spectrometer TO guidance for any additional diagnostic checks that may be required.

Excitation source frequency

This is extremely important because it ensures adequate power across the analytical gap. The two units used to check the source frequency include the source frequency test meter (SFTM) and the oscilloscope. Checking the excitation source frequency is required during the following:

- Prior to performing monthly correlation samples.
- Each time the instrument is deployed where line frequency is other than 60 Hz.
- If the elevation or environment is different from the last time the frequency was set.
- Upon completion of every 2000 burns.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

619. Requirements and responsibilities of oil analysis

1. What is the stated purpose of the OAP?

2. What is the purpose of the JOAP?

3. How often do you backup software to an external oil analysis device?

4. Samples should be taken within how long of engine/equipment shutdown?

5. What type of sample is needed after a flight test following installation of new, overhauled, or repaired aircraft engines?

6. What are the three basic techniques used to take oil samples?

620. Joint oil analysis program certification program

1. Who will participate in the JOAP Correlation Program?

2. What must be sent to the appropriate service program manager’s office in order to become a certified lab?

3. How many sets of samples with an average of 80 percent or above must be completed in order to certify a lab?

4. When a spectrometer has been repaired after being in RM status, up to how many months of correlation samples may be analyzed?

5. How often is the correlation program for spectrometers conducted by the Air Force OAP Correlation Team?

6. Results are submitted to the Air Force OAP Correlation Team and should arrive when?

621. Daily start-up and standardization procedures

1. How should you clean the quartz window of a spectrometer unit?

2. Why is it important to keep the sample excitation area completely dry before, during, and after operation?

3. How must electrodes be treated when installing them?

4. How is the correct analytical gap between the spectrometer electrodes obtained?

5. What can be done to ensure a fast, time saving procedure to verify that the instrument has maintained calibration?

6. What should you do if results of the daily standardization check *do not* fall within limits?

7. What is the acceptable standardization range of the 100 concentration oil?

8. What should you do if your second daily check fails?

9. When is an optical profile completed?

10. What is completed after every 2,000 burns?

3–3. Analysis Forms and Trends

It is 1430 on a Tuesday afternoon. You and your supervisor are sitting in the oil analysis laboratory reviewing the calibration procedures for the spectrometer. Suddenly, your training is interrupted as the production super and the chief of maintenance operations center enters the room with great urgency. “We need you to secure all of the oil analysis and maintenance records for aircraft 0923!” Your supervisor simply responds “They will be ready in 15 minutes.” All supervisors know that, traditionally, only one event brings such an urgent matter—the base has lost an aircraft.

Your supervisor knows that oil analysis records are one of the most important investigative tools to determine whether an engine failure was the cause of an accident. The records can also be used to eliminate oil-wetted component failure as a likely cause for an engine loss. In either case, your oil analysis laboratory is about to be scrutinized by many individuals who have little or no idea of how you do your job on a daily basis. Their sole impression of your OAP will be based on how well or how poorly your trend analysis of the aircraft engine was accomplished. Your complete understanding of all the programs, policies, and procedures associated with the OAP will help to ensure your oil analysis laboratory is never placed at fault for an aircraft or engine loss.

In this section, we introduce you to documentation, which includes record keeping, equipment trend analysis, and quality control measures involved with oil analysis. We describe how each oil OAP works and how you use existing documentation to analyze oil samples on a daily basis.

The Air Force OAP is one of the most fascinating and challenging techniques used as a preventative maintenance tool. Your ability to apply basic principles of spectroscopy to aerospace equipment oil samples is critical to the AF mission.

622. Oil analysis forms and reports

The importance of identifying every oil sample properly cannot be overemphasized. If you are unable to positively identify a sample to a specific piece of equipment, analysis data derived from the sample is useless. Whenever forms are incomplete or incorrectly filled out, all of your other efforts to provide a valid evaluation are seriously degraded. In this lesson, we cover the primary documentation procedures for Department of Defense (DD) Form 2026, Oil Analysis Request and other forms used to document oil analysis historical data.

DD Form 2026 - Oil Analysis Request

This form is used for the following purposes:

- Submission of routine or special oil samples.
- Reporting chip detector inspection results.
- Documenting/reporting analysis results when automated reporting systems are not available.

The personnel submitting the DD Form 2026 (fig. 3–6) need to properly and completely fill out the form; this is a vital step in the evaluation process upon which maintenance actions are based. When forms are incomplete or have erroneous information, all other efforts to produce a valid evaluation are degraded or impossible. When you receive the form on initial samples, such as the first one after an engine has been replaced, the REMARKS block should be used to inform you of any changes in the status of the equipment (such as engine removed for maintenance and reasons for the suspected discrepancy).

THIS FORM MUST ACCOMPANY THE SAMPLE. DO NOT APPLY ADHESIVES OR TAPE TO THIS FORM.

OIL ANALYSIS REQUEST

TO: OIL ANALYSIS LABORATORY: Nellis AFB

FROM:
- MAJOR COMMAND: ACC
- OPERATING ACTIVITY NAME AND ADDRESS (Include Zip/APO): 575 AMXS/NELLIS AFB, NV 89191
- UIC: | DMS ADDRESS (Navy):
- POC:NAME/RANK/EMP #: Kramer Cosmo/SSgt/01012
- POC:PHONE/FAX/EMAIL: 716-836-8110/cosmo.kramer@us.af.mil
- MMCO:NAME/EMAIL:

SOURCE OF SAMPLE: ☒ AERONAUTICAL ☐ GROUND ☐ SHIP EQUIPMENT ☐ OTHER

EQUIPMENT MODEL/APPLICATION: F110-GE0129

EQUIPMENT/COMPONENT SERIAL NUMBER: 538443

END ITEM MODEL/SHIP NAME & HULL NUMBER (with Dash): F-16

END ITEM SERIAL NUMBER: 81-1069-1

MACHINERY/VALVE ID:

DATE SAMPLE TAKEN (DAY/MO/YR): 04/12/2017 | LOCAL TIME SAMPLE TAKEN: 0700

HOURS/MILES SINCE OVERHAUL: 1233.5

HOURS/MILES SINCE OIL CHANGE: 15.5

CURRENT ODOMETER/HOURS READING:

REASON FOR SAMPLE: ☒ ROUTINE ☐ LAB REQUEST ☐ TEST CELL ☐ OTHER (Specify)

OIL ADDED SINCE LAST SAMPLE (OZ, PTS, QTS, GALS):

HOW TAKEN: ☐ DRAIN ☒ TUBE | SAMPLE TEMPERATURE: ☒ HOT ☐ COLD | TYPE OIL: MIL-PRF-7808

REMARKS | A/C ENGINE POSITION: 1

MCD VISUAL INSP OF DEBRIS: ☐ WITHIN LIMITS ☐ EXCEEDS LIMITS ☐ UNKNOWN/NA

POC SIGNATURE:

SUBMITTING ACTIVITY SAMPLE NUMBER: 23

FOR LABORATORY USE ONLY

SAMPLE RESPONSE TIME:

WEAR METAL ANALYSIS

Fe	Ag	Al	Cr	Cu	Mg	Na	Ni	Pb	Si
0	0	1	2	1	0	5	1	2	2

Sn	Ti	B	Mo	Zn	Ba	V	Mn	Cd	
2	1	1	0	0					

WATER CONTENT	CRACKLE	ACID NUMBER	VISCOSITY @ 40C	VISCOSITY @100c	FUEL DILUTION

PARTICLE COUNT

5 - 15 um	15 - 25 um	25 - 50 um	50 - 100 um	> 100 um	OVERALL NAS CLASS

SEM/EDX LEVEL

MCD LEVEL: | WEAR METAL TYPE:

LABORATORY SAMPLE NUMBER(S)	OAP CODE	OPERATOR INITIALS
010	A	HMC

DD FORM 2026, AUG 2014 PREVIOUS EDITIONS OBSOLETE

Figure 3–6. DD Form 2026.

Each sample will have their own form and filled out by flightline personnel. The back of the form (fig. 3–7) is used for transit aircraft oil analysis data. The completed DD Form 2026 is the source

document for input to the oil analysis program data collection. Oil analysis lab personnel are responsible for ensuring this data is forwarded to JOAP-TSC (Technical Support Center).

THIS FORM MUST ACCOMPANY THE SAMPLE. DO NOT APPLY ADHESIVES OR TAPE TO THIS FORM.

TRANSIENT AIRCRAFT OIL ANALYSIS RECORD

ASSIGNED OIL ANALYSIS LABORATORY	LABORATORY TELEPHONE NO.	END ITEM MODEL AND SERIAL NO.
JOAP Lboratory Nellis AFB, NV	*(DSN):* 456-8239 *(Commercial):* (702) 459-8239	B-1B/78-0320 EQUIPMENT MODEL AND SERIAL NO. F101-GE-102/PT-6A-34B

LAB CODE	DATE	TOTAL TIME SINCE OIL CHG	TOTAL TIME SINCE OVERHAUL	FE	AG	AL	CR	CU	MG	NA	PB	SI	SN	TI	NI	B	MO	ZN	BA	V	MN	CD	LAB REC
WPA	4/12/17	103	740	1	1	0	0	1	1		1	2		2			0	0					A
WPA	4/13/17	114	751	1	2	0	1	1	2		0	2		0			0	0					A
WPA	4/17/17	124	761	2	2	1	1	1	2		1	2		2			0	0					A

DATE DEPARTED *(Return this form with aircraft)*
Apr 18, 2017

REMARKS (Place MCD Tabs here)

DD FORM 2026, AUG 2014 PREVIOUS EDITIONS OBSOLETE

Figure 3–7. Back of DD Form 2026.

NOTE: Filling out the bottom of the DD Form 2026 by lab personnel is not required unless specified by individual service policy.

NDI laboratories will accomplish the following:

- Keep DD Form 2026 forms on file for 90 days.
- When equipment is temporarily deployed, print out at least the last three burns.
- Forward copies to the gaining unit.
- Update records upon return.
- Notify deployed laboratory of receipt of records.

Historical data

A historical data form is an oil trend history which usually accompanies an aircraft to a deployment, TDY, or new home station. Historical data of monitored equipment is not normally used by automated labs unless required for back-up in the event of computer system failure. Records from previous home station should be kept on file for one year as historical data.

Retention of records

Use the following table as the required retention time for hard copy documents within the oil analysis program:

Retention of Records				
Historical data	**DD Form 2026**	**Correlation Records**	**Daily Calibration Records**	**Supervisory Review Records**
12 months	3 months	3 months	1 month	1 month

623. Oil analysis trend and evaluation criteria

Knowing how to determine normal and accelerated wear and the difference between the two is the basis of the evaluation process. Wear metal trends are the basis for oil analysis; when compared to other equipment characteristics, they are the only criteria for predicting failure. The prediction of any mechanical system failure is reliable only when it is based on accurate information gathered from a number of areas.

Understanding operating hours

Hours since overhaul and hours since oil change are the two categories oil analysis evaluation includes within the accumulated operating hours.

Hours since overhaul

Wear metals may appear in a higher PPM range on low-time engines during break-in. This is especially true in elements indicating cylinder barrel, ring, or piston wear. Expect similar high initial readings in most types of gearboxes and transmissions during break-in. However, in modern jet engines, wear metal content normally builds up slowly. A 1,000 hour engine will often contain almost the same level of wear metals as a 10 hour engine, unless a discrepancy is developing.

Hours since oil change

The *hours since oil change* time is normally critical *only* during the first 10–15 hours of flight. After this, the wear metal concentration tends to level off, and except for minor fluctuations, does not change very much until the oil is changed again; therefore, evaluate any subsequent increases solely on wear metal content without regard for the last oil change.

Wear metal buildup rate

The results of any one analysis can be evaluated only after it has been entered into the appropriate oil analysis record. One analysis does not make up an oil analyses trend. Only a number of analyses readouts over a given period of time establish the data necessary to make trend analysis possible. Once you have a sufficient number of samples, you can make logical recommendations to the customer by considering the following:

- Wear metal trends.
- Information from intermediate maintenance reports.
- Your knowledge of the metals used in different parts of the equipment.

Proper wear metal trend analyses reveals engine problems before they become too serious. An indication of abnormal friction is the development of an abnormal rate of wear metal increase. A rapid buildup could indicate a likely imminent failure. Abnormal trend values are established for each element critical for a particular piece of equipment. These abnormal trend limits are necessary because the increase of rapid wear metal (even at low concentrations) is a good indication of impending failure. Even if the buildup is slow and steady, at some point the friction will result in an abnormal level wear metal concentration.

Wear metal concentration levels

Statistical data of wear metal concentrations from samples taken at normal sampling intervals, and operating conditions are used to establish wear metal concentration ranges in the following four levels:

- Normal.
- Marginal.
- High.
- Abnormal.

These levels are established to reduce the possibility of wear metal concentrations jumping from normal to abnormal ranges without a sample being taken. It is impossible for accurate concentration values at each level to be predicted or calculated in advance by studying engine configuration or metallurgy. When wear metal concentration levels from routine samples are compared to equipment tear-down findings, the information gained can be used to revise the concentration values used for each level. Historical data from detected failures or oil analysis hits are also used to establish a critical point of concentration level. The critical level for each wear metal is known as the *abnormal wear metal concentration*.

An abnormal concentration level in a sample is not an absolute go/no-go situation when making an oil analysis recommendation to a customer. Wear metal concentrations exceeding the abnormal level, but having normal trends, may be acceptable. Typically, your laboratory will ensure samples from the affected equipment are taken at more frequent intervals than normal to minimize the possibility of missing an impending failure.

Decision making guidance

The decision making guidance provides guidelines for the evaluator concerning appropriate recommendations that should be issued after the samples are analyzed. When making a decision of a trend, which may increase, a decision making table is recommended for use. This table is listed in TO 33–1–37–3, *Joint Oil Analysis Program Manual Volume III*.

Decision Making Guidance				
Sample Range (Current sample)	**Sample Range (Previous sample)**	**Trend**	**Category I**	**Category II**
Normal		Normal	Routine	N/A
	Normal	Abnormal	Resample or surveillance required	Surveillance required
	Marginal	N/A	Routine or resample required	Surveillance X2 required
	High	N/A	Routine or resample required	Surveillance X2 required
	Abnormal	N/A	Routine or resample required	Surveillance X2 required
Marginal		Normal	Routine or resample required	Surveillance required
	Normal	Abnormal	Resample required	Surveillance required
		Normal	Routine	N/A
	Marginal	Abnormal	Resample required	Surveillance required
	High	N/A	Routine or resample required	Surveillance X2 required
High		Normal	Resample required	Surveillance required
	Normal	Abnormal	Resample required	Resample or inspection
		Normal	Surveillance required	Surveillance required
	Marginal	Abnormal	Resample required	Resample or inspection
		Normal	Surveillance required	Surveillance required
	High	Abnormal	Resample required	Resample or inspection
	Abnormal	N/A	Resample or surveillance required	Surveillance X2 required
Abnormal		Normal	Resample required	Surveillance required
	Normal	Abnormal	Resample required	Resample or inspection
		Normal	Surveillance required	Surveillance required

Decision Making Guidance				
Sample Range (Current sample)	**Sample Range (Previous sample)**	**Trend**	**Category I**	**Category II**
	Marginal	Abnormal	Resample required	Resample or inspection
		Normal	Surveillance required	Surveillance required
	High	Abnormal	Resample required	Resample or inspection
		Normal	Resample required	Resample or inspection
	Abnormal	Abnormal	Inspection required	Inspection required
NOTE: See laboratory recommendation codes.				

Evaluator experience and judgment are extremely important factors in determining an effective recommendation. The evaluator may use additional information not contained in the computer statistical program in order to arrive at a more accurate decision for a particular set of circumstances.

Trend categories

Determine the wear metal trend between the last sample and the current sample, and compare it with the trend limit listed in the evaluation criteria table. Trend categories are described in the following table.

Trend Categories	
Category	**Descriptions**
Level (little or no change)	• Considered normal. • Slightly to moderately increasing or decreasing.
Sharply increasing or decreasing:	• A sudden increase that may indicate the start of an equipment problem. • A sudden decrease may indicate defective sampling procedures, oil addition, or change without documentation or sample identification problems. • Recommend verification samples for sharp increases. • Investigate sampling procedure or undocumented oil addition for sharp decreases.
Erratic increases and decreases:	• Usually indicates a problem in sampling procedure. • Should trigger a request to review activity sampling procedures and submit a monitored verification sample.
Increases exceeding trend limits:	• Generally indicative of equipment problems. • Consult decision making guide and review equipment history. • Request resample or maintenance action recommendation.

Recommendation codes

Spectrometric values which exceed guidelines listed on applicable criteria tables should be evaluated to determine whether a critical situation exists and the appropriate laboratory recommendation should be assigned. For example, a verification sample that confirms excessive wear metal concentrations is considered a critical situation and warrants a recommendation for maintenance action; however, an increasing wear trend on a routine sample is not considered a critical situation; it warrants a recommendation for resampling. Review the following table of laboratory recommendation codes.

Laboratory Recommendation Codes	
Code	**General Lab Recommendations**
A	Sample results normal; continue routine sampling.

Laboratory Recommendation Codes	
Code	**General Lab Recommendations**
X	Analysis results supplied to customer; no recommendation required.
Z	Previous recommendation still applies.
Code	**Inspection Recommendations (Requires Feedback)**
D	Documentation error to include incorrect/missing engine serial number, incorrect/missing aircraft tail number, incorrect/missing engine time, incorrect/missing oil time, incorrect/missing oil added. Do not fly or operate until discrepancy is corrected on DD Form 2026 or other approved automated forms.
H	Inspect unit and advise lab of finding. Abnormal wear indicated by *** PPM (element).
R	Do not fly or operate; inspect filters, screens, chip detector, and sumps; advise laboratory of results.
T	Do not fly or operate. Examine for discrepancy and advise laboratory of results and disposition. If discrepancy is found and corrected, continue operation and submit resample after *** hours of operation. If discrepancy is not found, recommend remove component from service and send to maintenance.
Code	**Oil Change Recommendation (Requires Resample)**
J	Contamination **** confirmed. Change oil, sample after *** minute run-up and after *** operating hours.
W	Contamination**** suspected. Change oil; run for *** additional hours, take samples hourly.
Code	**Lab Requested Resamples (Requires Resample)**
B	Resample as soon as possible; do not change oil.
C	Resample after *** hours; do not change oil.
E	Do not change oil. Restrict operations to local flights or reduced load operation, maintain close surveillance and submit check samples after each flight or *** operating hours until further notice.
F	Do not change oil. Submit resample after ground or test run. Do not operate until after receipt of laboratory result or advice.
G	Contamination **** suspected. Do not change oil, resample unit and submit sample from new oil servicing this unit.
P	Do not fly or operate; do not change oil; resubmit resample as soon as possible.
Q	Normal PPM reading was obtained from test cell run after complete phased engine inspection (P.E.) where oil lubricated parts were changed/removed/replaced. Monitor engine closely after installation to ensure a normal trend before release to routine sampling.
NOTES: * Resample (red cap) required. ** Maintenance feedback required; advise laboratory of findings. *** Laboratory will specify time limit. **** Contamination is defined as water, coolant, silicon, etc. and not wear metals. Use the appropriate recommendation codes for increasing trends or elevated wear metal conditions.	

Every oil sample you analyze requires you to assign a recommendation code to the results. It is common practice in Air Force laboratories to request and analyze a check sample from the equipment to confirm the wear metal readings before you assign a recommendation code other than A, B, or P.

As you can see from the explanation of each code, you have the authority to place the equipment under surveillance by requesting that a new resample be taken from the equipment at designated intervals. Until the equipment is placed back on a routine sample interval, each resample is known in the maintenance community as a **RED CAP** sample. The name evolved from the accepted practice of maintainers

marking the cap of non-routine samples with a red marking, usually a **red X** across the top. You can also see that you have the authority to direct maintenance actions, and even ground an aircraft until the reason for marginal, high, or abnormal readings in one or more elements has been determined. You will learn that having this amount of authority comes with an equally great amount of responsibility. Only through experience will you learn when to use each code for particular situations.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

622. Oil analysis forms and reports

1. What purposes would the DD Form 2026 be used for?

2. What information should be placed in the REMARKS block of the front side of DD Form 2026?

3. What should you do if a piece of equipment is going to be temporarily deployed?

4. How long should correlation records be kept on file?

623. Oil analysis trend and evaluation criteria

1. Oil analysis evaluation includes what two categories of accumulated operating hours?

2. What does a number of analyses readouts over a given period of time establish?

3. What does proper wear metal trend analyses reveal?

4. What is used from detected failures to establish a critical point of concentration level?

5. What provides guidelines for the evaluator concerning appropriate recommendations that should be issued after the samples are analyzed?

6. What will generally show an indication of equipment problems?

7. Which inspection recommendation code is used to indicate “Do not fly or operate Examine for discrepancy and advise laboratory of results and disposition. If discrepancy is found and corrected, continue operation and submit resample after *** hours of operation”?

8. What is another term used in the maintenance community for a resample?

Answers to Self-Test Questions

615

1. Spectrometric oil analysis.
2. Wear metals.
3. Atomic emission rotrode instruments.
4. Sn.
5. The analysis is accomplished by subjecting the sample to a high voltage spark or plasma, which energizes the atomic structure of the metallic elements, causing the emission of light.
6. Detectable failure.

616

1. Wear metals are excited in a fluid sample.
2. One or more of its electrons absorbs the excitation energy and moves to an orbital shell with a higher energy level.
3. Specific wavelengths of light are emitted by the element in question.
4. By the amount of light emitted by the sample having wavelengths characteristic of a specific element.
5. Excitation group, optical processing group, integration group, electronics processing group.
6. The excitation group.
7. The persistent spectral lines are directed from the exit slit assembly to the window of a PM tube for the element. The PM tube changes light energy into electrical current and multiplies its intensity several times.
8. Integration group.

617

1. The use of AES as part of the Air Force OAP.
2. Use of filters, screens, and chip detectors.
3. SEM/EDX.
4. A SEM.
5. EDX.
6. The units then applies an automated wear metal debris detection and classification computer program that is able to identify the type and amount of material in the sample.
7. Propulsion maintenance personnel.
8. Slivers.
9. JetSCAN® and ASPEX JEMM.
10. Flight line personnel (crew chief).
11. Remove all debris particles from the chip detector and place them on a carbon adhesive tab.
12. The level warning assigned.
13. Reporting results.

618

1. Spectro, Inc. Model M and Spectro, Inc. Model M/N.
2. 10 °F or 10 percent.
3. The D12 and D3.
4. 6 months.
5. Monthly.
6. The instrument must first be standardized.
7. Repeatability.
8. The dark current test.

619

1. Detect changes in the condition of used oil and other fluids, detect unusual wear, and predict impending equipment failures.
2. Standardize laboratory requirements and operating procedures.
3. Weekly.
4. Thirty minutes.
5. Special sample.
6. Dip tube, drain/valve, and pump.

620

1. All DOD oil analysis laboratories.
2. Completed annual certification checklist.
3. One special certification sample set (two pair).
4. Two.
5. Monthly.
6. No later than the 21st of each month.

621

1. Use a clean, soft, disposable laboratory tissue and wet one corner of the towel with an ammonia-based window cleaner. With your forefinger, rub the wetted portion of the paper towel along the surface of the window while applying moderate clockwise pressure on the window. This will disperse the oil film. Now take the dry portion of the paper towel and repeat this procedure until no oil can be seen on the tissue paper. A cotton swab can also be used for this purpose.
2. To prevent possible damage due to high-voltage arcing.
3. Do not touch the outer rim of the disc, sharpened tip of the rod, or allow the electrodes to touch any foreign matter.
4. By slowly raising the analytical gap setting lever upward until it stops and gently releasing it back to the resting position.
5. A daily standardization check.
6. Proceed with full instrument standardization and then perform the daily standardization check again.
7. 90.0–110.0.
8. Perform an optical profile check and an electrode offset procedure before you complete a second full standardization.
9. Monthly, just prior to analyzing your monthly correlation program samples; additionally, whenever the instrument is moved to a new facility or has been subjected to a temperature change of 15 °F or more.
10. Excitation source frequency.

622

1. Submission of routine or special oil samples, reporting chip detector inspection results, and documenting/reporting analysis results when automated reporting systems are not available.

2. Engine removed for maintenance and reasons for the suspected discrepancy.
3. Print out a DD Form 2026 with at least the last three burns.
4. Three months.

623

1. Hours since overhaul and hours since oil change.
2. The data necessary to make trend analyses possible.
3. Engine problems before they become too serious.
4. Historical data.
5. The decision making guidance.
6. An increase exceeding trend limits.
7. Code T.
8. Red cap.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

42. (615) How is wear metal concentration measured?
    a. Hours.
    b. Pounds.
    c. Angstroms.
    d. Parts per million.

43. (615) Sudden failures not preceded by characteristic wear metal generation, such as fatigue failure, is
    a. undetectable, and known as a catastrophic failure.
    b. detectable and made up of a series of rapid increases.
    c. undetectable with no obvious wear metal indications.
    d. detectable and made up of a slow progressive buildup.

44. (616) The concentration of metals in fluid samples is measured by the
    a. amount of light absorbed or emitted by the excited sample.
    b. intense spectral lines detected in a spectrum.
    c. amount of energy emitted from electrons.
    d. wavelength intensity.

45. (616) Spectroscopy relies on the
    a. energy levels for each element at various concentration levels.
    b. detection of persistent lines in a spectrum.
    c. structure of the particles in each sample.
    d. detection and identification of particles.

46. (616) Which atomic emission group takes the light emitted during excitation and isolates or breaks it down into its spectral wavelengths for monitoring?
    a. Excitation.
    b. Integration.
    c. Optical processing.
    d. Electronic processing.

47. (617) What information is *not* provided in a scanning electron microscope/energy dispersive X-ray (SEM/EDX) report?
    a. Risk level.
    b. Particle size.
    c. A three-dimensional image.
    d. Number of particles for each material type.

48. (617) What process includes the ability to generate three-dimensional images of metal particles?
    a. Spectro, Science. Model M.
    b. Spectro, Science. Model M/N.
    c. Joint oil analysis program (JOAP).
    d. Scanning electron microscope/energy dispersive X-ray (SEM/EDX).

49. (617) Scanning electron microscope/energy dispersive X-ray (SEM/EDX) technology is currently only used in nondestructive inspection (NDI) laboratories that support which aircraft?
    a. F–16 and U2.
    b. F–15 and F–16.
    c. F–22 and F–35.
    d. F–15 and F–22.

50. (617) Which level warning indicates that there is a significant amount of material detected and troubleshooting must be initiated?
    a. Level 1.
    b. Level 2.
    c. Level 3.
    d. No risk factor level.

51. (618) How should temperature and humidity be controlled in joint oil analysis program (JOAP) labs?
    a. 65 ± 5 °F with 10 percent and 60 percent humidity.
    b. 70 ± 5 °F with 20 percent and 50 percent humidity.
    c. 60 ± 10 °F with 20 percent and 50 percent humidity.
    d. 75 ± 10 °F with 20 percent and 60 percent humidity.

52. (618) The D3 standard contains approximately the same weight of which three elements?
    a. Iron, silver, and aluminum.
    b. Silver, titanium, and copper.
    c. Boron, molybdenum, and zinc.
    d. Magnesium, sodium, and boron.

53. (618) Which diagnostic check is used to assure that the spectrometer has reached electronic stability?
    a. The dark current electronic stability test.
    b. Calibration curve verification test.
    c. Repeatability test.
    d. Accuracy test.

54. (619) Ultimately, the responsibility to decide what action to take in regard to any recommendation from the joint oil analysis program (JOAP) laboratory rests with the
    a. nondestructive inspection (NDI) technician.
    b. lab supervisor.
    c. crew chief.
    d. customer.

55. (619) How often do you backup all assigned spectrometers?
    a. Daily.
    b. Weekly.
    c. Monthly.
    d. Quarterly.

56. (620) What monthly correlation score must labs maintain to keep labs certified?
    a. 65 percent or above.
    b. 70 percent or above.
    c. 75 percent or above.
    d. 80 percent or above.

57. (620) Which is not a reason for a lab to become uncertified?
    a. Failure to meet full operating requirements.
    b. Laboratory/spectrometer is physically relocated.
    c. Failure to submit an annual approved verification checklist.
    d. Upon direction of the joint oil analysis program (JOAP) lab supervisor.

58. (620) Once a spectrometer in reported maintenance (RM) status has been repaired, you may analyze up to
    a. two months of overdue correlation samples, with up to one overdue sample set for each workday.
    b. two months of overdue correlation samples, with up to two overdue sample sets for each workday.
    c. only one month of overdue correlation samples, with up to one overdue sample set for each workday.
    d. only one month of overdue correlation samples, with up to two overdue sample sets for each workday.

59. (621) How many analysis burns are completed for the warm-up?
    a. One to three.
    b. Two to four.
    c. Two or three.
    d. Three or four.

60. (621) If your daily check fails, you should complete
    a. a full standardization only.
    b. an optical daily profile check.
    c. a full standardization and then another daily standardization check.
    d. an optical profile and an electrode offset check before performing another daily check.

61. (621) What will you need to do every time a new batch and/or lot number of electrodes is used?
    a. Electrode offset procedure and optical profiling check.
    b. Electrode offset procedure.
    c. Complete standardization.
    d. Optical profiling check.

62. (622) How long will nondestructive inspection (NDI) laboratories keep a Department of Defense (DD) Form 2026 on file?
    a. 30 days.
    b. 60 days.
    c. 90 days.
    d. 120 days.

63. (622) Which oil analysis program record is kept on file for 12 months?
    a. Supervisory reviews.
    b. Historical data form.
    c. Correlation records.
    d. DD Form 2026.

64. (623) The hours of flight since oil change time is normally critical only during the
    a. first 10–15 hours.
    b. last 10–15 hours.
    c. first 5–10 hours.
    d. last 5–10 hours.

65. (623) Which lab code recommends a “resample after *** hours; do not change oil”?
    a. Code A.
    b. Code B.
    c. Code C.
    d. Code D.

Please read the unit menu for unit 4 and continue ➔

Unit 4. Specialized Inspection Methods

DENNIS GABOR, WHO WAS AWARDED the Nobel Prize in 1971 for his work in holography, described the principles of holography in the late 1940s; however, it was only with the development of the laser in the 1960s that a light source with sufficient power and coherence became available for practical applications of holography. During the 1960s and 1970s, holographic interferometry, based on work by Karl Stetson, was developed for NDI purposes.

The electronic image shearing interferometer was pioneered in the early 1980s by three researchers: Dr. John Butters at Loughborough University in the United Kingdom, Dr. S. Nakadate in Japan, and Dr. Mike Hung at Oakland University in the USA. The commercial development of the shearography camera as a tool for nondestructive testing led to the delivery of the world's first production of the shearography NDI system in 1987 for select aircraft production programs. The introduction of the first portable shearography systems occurred in 1989 to fill a need for fast, large-area field inspection of aircraft honeycomb structures.

In this unit, you will study the basic principles of laser shearography, thermography, and mobile automated scanner system (MAUSS). We will discuss applications and the equipment used for each method.

624. Laser shearography inspection

Shearography interferometry NDI is a laser-based imaging system that uses interferometers to detect, measure, and analyze surface and subsurface variances in materials or structures. This is accomplished by imaging submicroscopic changes to a test part surface when an appropriate stress is applied.

Shearography NDI methods are mature and effective solutions for a wide range of aerospace NDI applications, including composite aircraft panels, aircraft tires, control surfaces, metal honeycomb, or foam core panels with metal or composite face sheets, elastomer or cork bonds, composite over-wrap pressure vessels (COPV), spray on foam insulation (SOFI), and solid composite laminates.

Principles of shearography inspection

A shearography NDI system consists of a laser light source, a shearing image interferometer, an image-processing computer, a display monitor, and a means to provide a controlled and repeatable stress to the test object. The shearography optical system is what is referred to as a common path imaging interferometer. Shearography cameras create images showing the first derivative of the out-of-plane deformation of the test part surface in response to a change in load. Shearography is relatively insensitive to test object bending or deformation due to the applied stress but is still highly sensitive to local defect deformation.

Shearography cameras are sensitive to changes in the distance from the object surface to the camera. In practice, z-axis surface deformations may be as small as 2–20 nanometers depending on the environmental noise. Large test parts can be inspected with a small number of images using a large field of view (FOV) or a large number of images with a smaller FOV that may be automatically stitched together. The FOV for a shearography camera depends on the maximum allowable defect size, camera resolution, laser illumination power, the ability to uniformly apply a stress change, and the amount of background noise.

Shearography inspection equipment

When selecting laser shearography equipment, the inspector must consider the location of the part under inspection and the optimum stressing method to reveal any flaws. A variety of equipment is

available which can be used for systems that attach to or stand independent to the part under inspection.

In the simplest form, a shearography system consists of the components in the following table:

Shearography Inspection Equipment	
Equipment type	**Description**
Stress mechanism	Some method of stressing is necessary to cause the necessary displacement of the test articles surface. There are four types of equipment types for stress mechanism. • Thermal. • Vacuum. • Vibration. • Pressure.
Laser	Some manufactures have the lasers enclosed within the same housing as the camera, while others have the lasers attached around the camera. Regardless to the physical location of the laser, ensure the safety requirements in are followed to protect all maintainers.
Shear camera	The shear camera is an image shearing interferometer, usually including features for adjustment of focus, iris, zoom, shear vector and projection, and adjustment of coherent light onto the test object area to be inspected.
Processing system	A computer interface used to operate the shear camera, process the image acquired from the shear camera, operate the shear camera, and allow for evaluation of the image.

Application of laser shearography inspection

The operation of a shearography NDI system involves a series of important system setup steps to be performed in order to achieve acceptable test results. The following are six steps for set up and processing.

1. Fixture the test object.
2. Determination of the FOV.
3. Development of a test scan plan.
4. Focusing the camera.
5. Optimizing of the shearography camera settings.
6. Selection of an appropriate stress test method.

Fixture the test object

Test part mechanical stability is important during shearography. A part that moves during stressing or data acquisition may cause the image to de-correlate, requiring re-test. Parts should be securely positioned against a mechanically stable backstop or support fixture. Any debris should be removed from the surface of the fixture. Thin or light-weight test parts may vibrate due to vacuum chamber noise or ambient machinery in the area of the test. Shims, clamps, tape, or foam pads may be used to secure the part and dampen vibration.

A secured part will appear black when the reference images are captured. Care must be taken to place honeycomb parts on the outer skin and not rest on the honeycomb material. During partial vacuum stress, the honeycomb may expand and cause the part to become mechanically unstable resulting in decorrelation of the shearography image.

Determination of the FOV

Shearography applied to aircraft and spacecraft structures can use a FOV varying from 4 x 4 inches to more than 36 × 36 inches; however, the sensitivity to defects will change considerably as the FOV is

increased. The technician should use the zoom control to adjust the FOV per the specific inspection procedures. In order to obtain the maximum throughput for in-process shearography inspection, the maximum FOV is desired.

Key factors affecting the FOV for a shearography camera are camera pixel count in the *x* and the *y* direction, the maximum allowable defect size for a specific structure and application, defect indication definition (area), and image noise.

Development of a test scan plan

Test targets larger than a single FOV image require multiple images to cover the surface to be inspected. Multiple images must have overlap to ensure that no region is missed. Typically, a 10 percent overlap in both directions is recommended when developing a testing scan plan. Manual handheld shearography systems can use a visual marking method as guidance for camera placement on large panels. It may be necessary to grid out the scan plan to verify the coverage. Large gantry systems usually have a graphical interface to allow rapid scan programming on large parts.

Focusing the camera

It is necessary for the camera to be in focus to allow for the best result from the inspection process. In order to obtain the sharpest focus from the shearography camera, it is critical to focus with the camera set to its minimum practical depth of field. This is obtained by opening the iris of the camera lens until the "live" image of the test article is as bright as possible while still being able to resolve some surface details (required for focusing). Adjust the focus control of the camera to achieve the sharpest image of the selected surface details or use a "focusing target" attached to the surface of the test article.

Optimizing of the shearography camera settings

In order to provide the best images on screen, it is necessary to optimize the iris, shear vector, and complete the calibration of the video caliper.

The iris used in the camera settings will allow the maximum amount of light into the shearography camera while maintaining good imaging of the test article itself. Shear vector indications generally possess a "double lobed" shape, and the orientation of the shape provides information as to the shear axis of the shearography camera. The *shear axis* is defined by the separation of the "sheared" image of the test article as seen through the camera. The direction of the shear defines the direction of maximum sensitivity for the test results. The shear vector in a shearography test procedure is expressed as the amount of image separation and angle used in a shear angle convention.

Selection of an appropriate stress test method

The selection of the shearography stress method for a particular structure is highly dependent on the defect type, geometry of the structure, and material properties. One stress method may reveal anomalies where another method will not reveal the anomalies in the test article.

Image interpretation

Shearography images provide a straightforward measurement of defect dimensions, SNRs, Z-axis deformation, and for shearography specifically, deformation rate as a function of load change. The computer software does the calculations for the technicians.

The cosine of the shear vector angle, multiplied by the magnitude of the shear vector, is subtracted from the measurement to obtain the actual size. Precision measurements can be made only when an indication is in the center of the camera FOV. Away from the center, the test part surface may be at an angle to the camera in one or two axes. As with all full field optical systems, the cosine errors for all axes must be summed to correct the final indication measurements. In practice, the operator may move the defect to the center of the FOV and retest, thereby allowing the precise measurement of the indication as seen in figure 4–1.

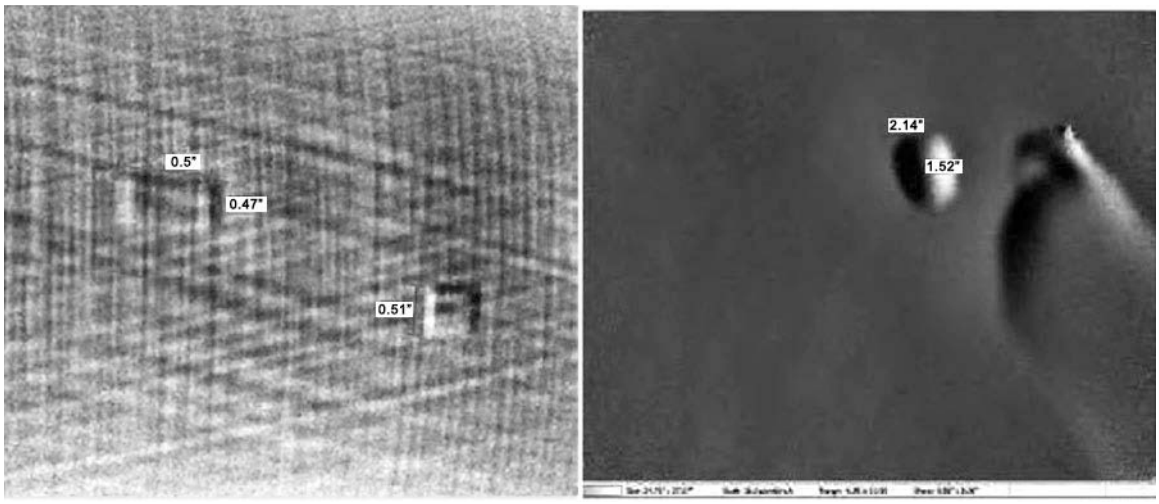


Figure 4–1. Measurement of shearography indications.

Shearography test standards

In shearography, as with all NDI methods, proper test standards are important for the development of the NDI procedure and should be used to determine the correct operation of a system before and after a production test or run, as determined by written practice. It is important to understand the various defect types and characteristics in a given structure and to design NDI standards appropriately.

An NDI standard built with Teflon inserts, ideal for simulating foreign material in a composite laminate panel for ultrasound, may bond during the panel cure. While ultrasound detects the signal change in through-transmission or a reflection from the Teflon inserts, due to the impedance change, may not represent a disbond for vacuum stress shearography. This is due to the fact that, Teflon inserts will only detect actual disbond conditions. The mismatch in thermal expansion between the materials is often enough to allow detection of a Teflon insert. Figure 4–2 is an example of a honeycomb test standard using shearography.

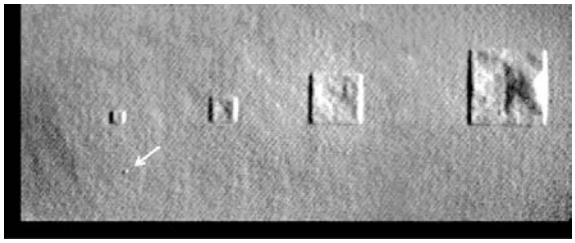


Figure 4–2. Honeycomb standard panel for shearography.

625. Thermography

New and emerging technologies are ever changing in NDI. This lesson introduces thermography and gives a basic overview of how it works. While this type of inspection is generally completed at depot level, it is still important that you understand it.

Principles of thermograph

Infrared imaging uses thermographic cameras that detect radiation along the infrared range of an electromagnetic spectrum which produce images called *thermograms*. Since objects with a temperature above zero emit infrared radiation, it makes it possible to see objects with or without visible illumination. The amount of radiation emitted by an object increases with heat allowing you to see variations in temperature. When viewed through a thermal imaging camera, warm objects stand out against cooler backgrounds making them more visible.

Thermographic inspection

Thermographic inspection refers to testing parts, materials, or systems through images of the thermal patterns surface. This inspection is a nondestructive, nonintrusive, noncontact mapping or thermal patterns on the surface of parts using a type of infrared detector.

Usually, the following are the two approaches used in thermographic inspection:

- Passive.
- Active.

Passive thermographic inspection

This inspection uses a higher or lower temperature than the background so that images are easily seen. It detects moisture and delaminations associated with aircraft parts.

Active thermographic inspection

Active thermographic inspection uses an energy source to produce a thermal contrast between the area of interest and the background. It measures the part's thermal response after its external excitation, which can bring some energy to the material. Halogen lamps, flash lamps, ultrasound generators, or other sources can act as an excitation source.

Thermal shearography

Thermal shearography can be applied successfully to a wide range of structures and material types including solid laminates, metal or composite sandwich panels (limited to near side inspections only), and crack detection in metal and ceramics. Unlike thermography, which images surface temperature changes over time, thermal shearography uses a temperature change to reveal local changes in the coefficient of thermal expansion due to the presence of an anomaly. This does not affect the test part and is able to inspect bare aluminum or painted surfaces without any preparation except to remove greases or dew. For materials such as carbon laminate, aluminum, steel, and fiberglass, the test part surface is heated. For materials such as kevlar, the component part must be tested by cooling the surface. Figure 4–3 illustrates an aircraft radome using thermal shearography.

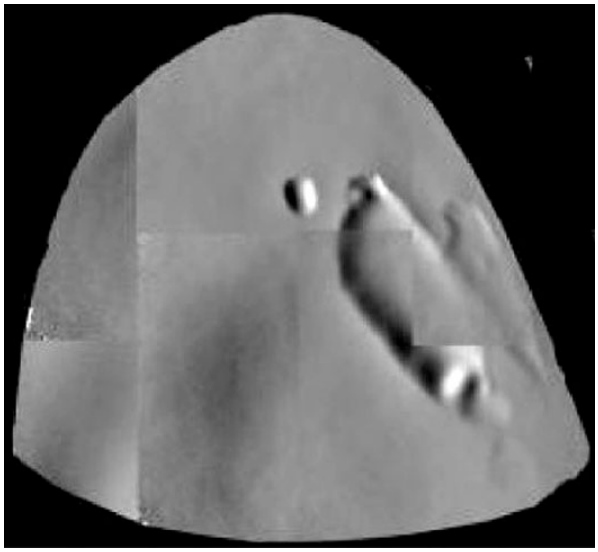


Figure 4–3. Thermal shearogram of an aircraft radome.

626. Mobile automated scanner system

The requirement for rapidly detecting corrosion and disbonds in lap joints of transport aircraft has prompted the development of various new NDI methods and large-area imaging systems; however, there is still great potential for speeding up conventional methods such as eddy-currents and ultrasonics using automated or semi-automated scanners. Currently there are several systems available that scan either a single transducer in a raster scan or several single element transducers simultaneously.

MAUSS

MAUSS is a portable c-scan inspection system that integrates several traditional inspection techniques into a single package. This system is effective in a variety of production manufacturing and aircraft maintenance environments for process quality inspections, damage assessment, aging structure evaluation, and for validating that a repair is complete.

MAUSS equipment

The equipment features portability, ease of setup, inspection versatility, and very fast inspection rates. These features contribute to an efficient approach for the on-site inspection of large structures. Inspection applications include metals, composites, hybrids, composite-metals, and bonded structures. Other features are:

- Scan speeds up to 100 sq ft per hour are possible.
- Pulse-echo, thru-transmission, or shear wave sensors provide ultrasonic time-of-flight and attenuation information for thickness gauging, detection of laminar defects and porosity, or crack detection applications.
- Resonance, pitch/catch, or mechanical impedance sensors provide indications of voids or porosity in an adhesive bondline.
- Single and dual frequency eddy current methods support crack and/or corrosion detection in aging metallic structure.
- Several raster scanner options are available, ranging from small hand scanners to large track scanners.
- Rotational scanning option supports detailed interrogation around installed fasteners.
- Advanced imaging and data analysis features enhance inspection data interpretation.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

624. Laser shearography inspection

1. What is shearography interferometry NDI?

2. What type of aerospace applications are used with shearography NDI methods?

3. What does a shearography NDI system consist of?

4. What must be considered when selecting laser shearography equipment?

5. What application step uses shims, clamps, tape, or foam pads used to secure the part and dampen vibration?

6. Which application step uses multiple images that overlap to ensure that no region is missed?

7. What is the selection of the shearography stress method highly dependent upon?

8. What may not represent a disbond for vacuum stress shearography?

625. Thermography

1. What type of images are produced by infrared imaging, using thermographic cameras that detect radiation along the infrared range of an electromagnetic spectrum?

2. What are the two approaches used in thermographic inspection?

3. What inspection can be applied successfully to a wide range of structures and material types including solid laminates, metal or composite sandwich panels (limited to near side inspections only), and crack detection in metal and ceramics?

626. Mobile automated scanner system

1. What is a portable c-scan inspection system that integrates several traditional inspection techniques into a single package?

2. What type of structures are used with MAUSS inspection systems?

Answers to Self-Test Questions

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1. A laser-based imaging system that uses interferometers to detect, measure, and analyze surface and subsurface variances in materials or structures.
2. Composite aircraft panels, aircraft tires, control surfaces, metal honeycomb, or foam core panels with metal or composite face sheets, elastomer or cork bonds, COPYs, SOFI, and solid composite laminates.
3. A laser light source, a shearing image interferometer, an image-processing computer, display monitor, and a means to provide a controlled and repeatable stress to the test object.
4. Location of the part under inspection and the optimum stressing method to reveal any flaws.
5. Fixture the test object.
6. Developing a testing scan plan.
7. The defect type, geometry of the structure, and material properties.
8. Teflon inserts.

625

1. Thermograms.

2. Passive and active.
3. Thermal shearography.

626

1. MAUSS.
2. Metals, composites, hybrid, composite-metals, and bonded structures.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

66. (624) What is relatively insensitive to test object bending or deformation due to the applied stress, but is still highly sensitive to local defect deformation?
    a. Shearography.
    b. Thermography.
    c. Mobile automated scanner system (MAUSS).
    d. Thermal shearoraphy nondestructive inspection (NDI) system.

67. (624) When interpreting an image in shearography, what are you doing if you move a defect to the center of the field of view (FOV) and retest the test part?
    a. Verifying your procedure.
    b. Precisely measuring an indication.
    c. Finding the exact location of the defect.
    d. Focusing the shear camera on the test object.

68. (625) Which of these does not act as an active thermographic excitation source?
    a. Flash lamps.
    b. Halogen lamps.
    c. Ultrasound generators.
    d. Eddy current initiators.

69. (625) Which material is tested by cooling instead of heating the surface in thermal shearography?
    a. Carbon laminate.
    b. Aluminum.
    c. Kevlar.
    d. Steel.

70. (626) What is the maximum possible scan speed in square feet per hour when using a mobile automated scanner system (MAUSS)?
    a. 100.
    b. 115.
    c. 130.
    d. 145.

Student Notes

Glossary of Abbreviations and Acronyms

AER	atomic emission rotrode
AES	atomic emission spectrometry
AFTO	Air Force technical order
Ag	Silver
Al	Aluminum
ALARA	as low as reasonably achievable
B	Boron
cc	cubic centimeter
CCD	charged coupled device
CD	compact disc
CDC	career development course
COPV	composite over wrap pressure vessels
CR	computed radiography
Cr	Chromium
CRPCS	CR Process Control Standard
Cu	Copper
D	Distance
DAD	digital alarm dosimeter
DD	Department of Defense (when used with forms)
DOD	Department of Defense
DVD	digital versatile disc
E	energy
EPD	electronic personnel dosimeter
EMI	electro-magnetic interference
EPS	equivalent penetrameter sensitivity
F	focal spot
Fe	Iron
FOV	field of view
GE	General Electric
GIF	graphic interchange format
GM	Geiger-Mueller
Hz	frequency
ICP	inductively coupled plasma
IQI	image quality indicator
IP	image plates
JEMM	jet engine mobile monitor
JOAP	joint oil analysis program
keV	kiloelectron-volt

kV	kilovoltage
LP	line pairs
MAS	milliampere seconds
MAUSS	mobile automated scanner system
mA	milliamperage
mc^2	mass times the square of the velocity of light
MeV	miloelectron-volt
Mg	Magnesium
mil	.001 of an inch (or one thousandth of an inch)
ml	milliliters
mm	millimeter
Mo	Molybdenum
mr	milliroentgen
mR	one-thousandth of a roentgen
mrad	millirad
mrem	millirem
MTF	modular transfer function
Na	Sodium
NDI	nondestructive inspection
Ni	Nickel
OAP	oil analysis program
Pb	Lead
PCS	process control standard
P.E.	phased engine inspection
PM	photomultiplier
PMEL	precision measurement equipment laboratory
PMT	photomultiplier tube
PPM	parts per million
psig	pounds per square inch, gauge
PSL	photostimulable luminescence
PSP	photostimulable phosphor
QF	quality factor
R	roentegen
rad	radiation absorbed dose
rem	roentgen equivalent man
RM	reported maintenance
RP	recommended practice
RSO	radiation safety officer
SEM/EDX	scanning electron microscope/energy dispersive X-ray
SFD	Source-to-film distance

SFTM	source frequency test meter
Si	Silicon
SMPTE	Society of Motion Pictures and Television Engineers
Sn	Tin
SNR	signal-to-noise ratio
SOFI	spray on foam insulation
TEDE	total effective dose equivalent
Th	Thorium
Ti	Titanium
TLD	thermoluminescent dosimeter
TO	technical order
TSC	Technical Support Center
USA	United States of America
USAF	United States Air Force
VMI	vendor managed inventory
WebREMS	web-based real-time environmental monitoring system
WP	work package
Zn	Zinc

Student Notes

Student Notes

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