highest energy available with an x-ray unit should not be used because contrast is reduced. In too many cases, the higher energy is chosen and the resultant radiograph does not have that high-contrast image that makes interpretation much more meaningful. Radiographic film is another area where high quality is sacrificed for speed. Fast film, which results in images with noticeable graininess, is used in preference to the slow film in order to achieve the shortest exposure time. The slow, fine-grain film, which requires longer exposure times, produces a much sharper image with better definition. When all these factors are combined (a fast film with a short source to film distance, and the highest energy used), the resultant image will fall far short of the sensitivity goal that can be achieved. The goal should be to always use a technique that will provide the highest possible quality image.

Lead screens have a major effect on the quality level, primarily affecting definition. Lead screens serve two very important functions in radiography: they intensify the primary radiation and they absorb "soft" or secondary scatter radiation. Lead screens are typically 0.005 inches or 0.010 inches in thickness. Based on the energy of the radiation, either will be used. One lead screen will be placed on top and the other beneath the film, inside a light-tight cassette. The purpose of the top lead screen is to intensify the primary radiation that passes through the object. This intensification occurs as a result of the emission of secondary electrons from the interaction of the photons with the atoms in the lead. This intensification actually creates a sharper, denser image on the film because of this secondary emission. The lead screens also serve to absorb scatter radiation. These lead screens easily absorb scatter, which consists of long-wavelength, lower-energy radiation, whereas the primary radiation passes through with relative ease. The primary source of scatter radiation is from the object itself, and results when the radiation passes and interacts with the material atoms. Again, radiation will penetrate the object, be scattered, and be absorbed. With lead screens, the scattered radiation is absorbed to a great extent and the primary beam is intensified.

The lead screens under the film also improve the image quality by absorbing backscattered radiation, which comes from objects such as floors and tables, etc. underneath the film cassette. Lead screens are effective for both x-rays and gamma rays with energies above approximately 125 kV. When lower energies are used, the lead screens tend to absorb a portion of this lower-energy radiation rather than intensifying it. For gamma radiography using iridium 192, it is quite common to use 0.010 inch lead screens on the top and underneath the film.

Any type of contaminant or blemish on the lead screen surfaces, such as the lower screen in Figure 6-21, will cause corresponding images of that condition on the radiographic film, so it is extremely important that these lead screens be kept in excellent condition. They should be virtually mirror smooth and should be inspected periodically to assure that there are no conditions that would cause artifacts. It is recommended that a small, unique identification number be scratched into the lead at one of the corners. In the event that there is an artifact, it will be easy to see that number as an image on the film, facilitating the identification and removal of the faulty lead screen.

Other types of screens used in radiography are the fluorescent types. Fluorescent and fluorometallic screens result in a significant reduction in exposure time since the radiation causes visible light to be emitted that greatly increases the exposure effect on the film. The major problem with fluorescent screens is that light diffusion occurs, which reduces the definition of the image. It is however, an excellent way to radiograph test specimens that are either extremely thick or dense, where conventional radiography with lead screens would be impossible. Quality levels that would meet most code requirements are difficult to achieve with the use of fluorescent screens. This again is due to the light diffusion of the fluorescent material in the screens.

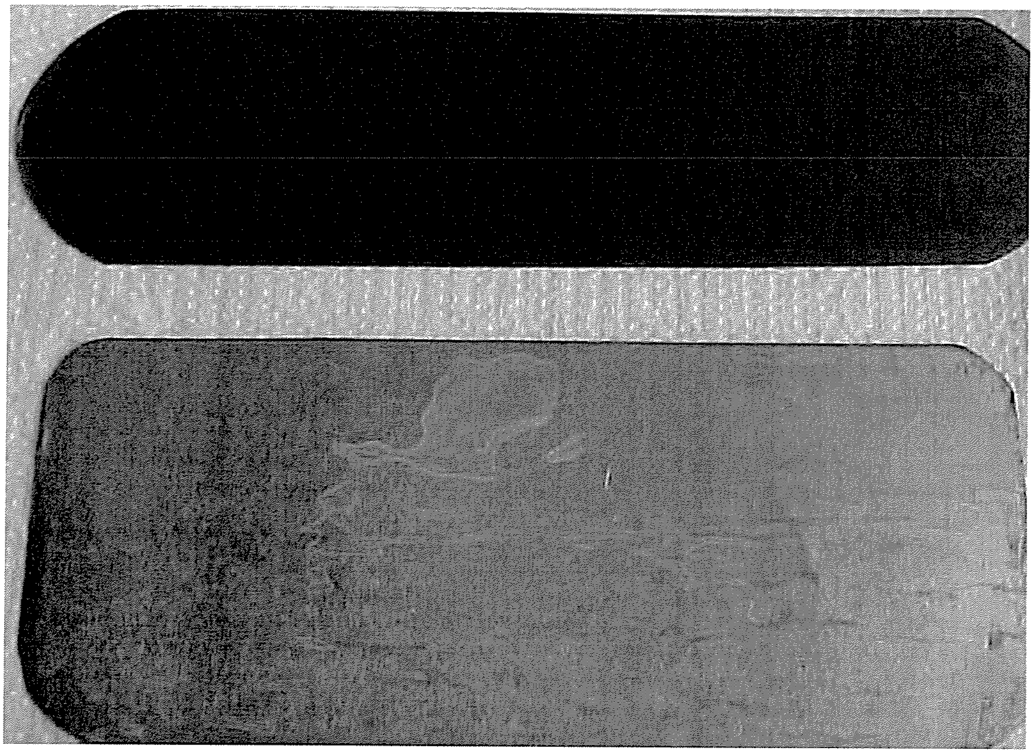


FIGURE 6-21 Lead screens (screen on bottom is unacceptable). (Courtesy Charles J. Hellier.)

V. TECHNIQUES AND PROCEDURES

The most effective technique used in radiography is one in which the radiation passes through a single thickness and the film is in contact with the surface opposite the source side. This technique is referred to as the "single wall exposure, single view technique" (Figure 6-22). The radiation passes through one wall of the object (a single thickness), and that thickness is evaluated or "viewed."

The second most common technique is referred as the "double wall exposure, single view technique." In this case, the radiation passes through two walls but only that area closest to the film is evaluated. This technique is depicted in Figure 6-23.

The third radiographic technique requires the radiation to pass through both walls of the object and both walls are evaluated. This technique is referred to as the "double wall exposure, double view technique" and is usually restricted to parts with small diameters, typically equal to or less than 3.5″. This technique is illustrated in Figure 6-24. In this technique, the source of radiation may be positioned directly over the area of interest, thus superimposing the top portion with the region directly under it. As an alternative, the source may be offset by an angle of approximately 15° in order to observe both the top and bottom walls. When the source is offset, the technique is often referred to as the "ellipse" or "elliptical" technique.

In the single wall exposure, single view technique, the penetrameter is placed on the source side of the object (the surface opposite the film). In the double wall exposure, single view technique, the penetrameter may be on the source side of the object or the film

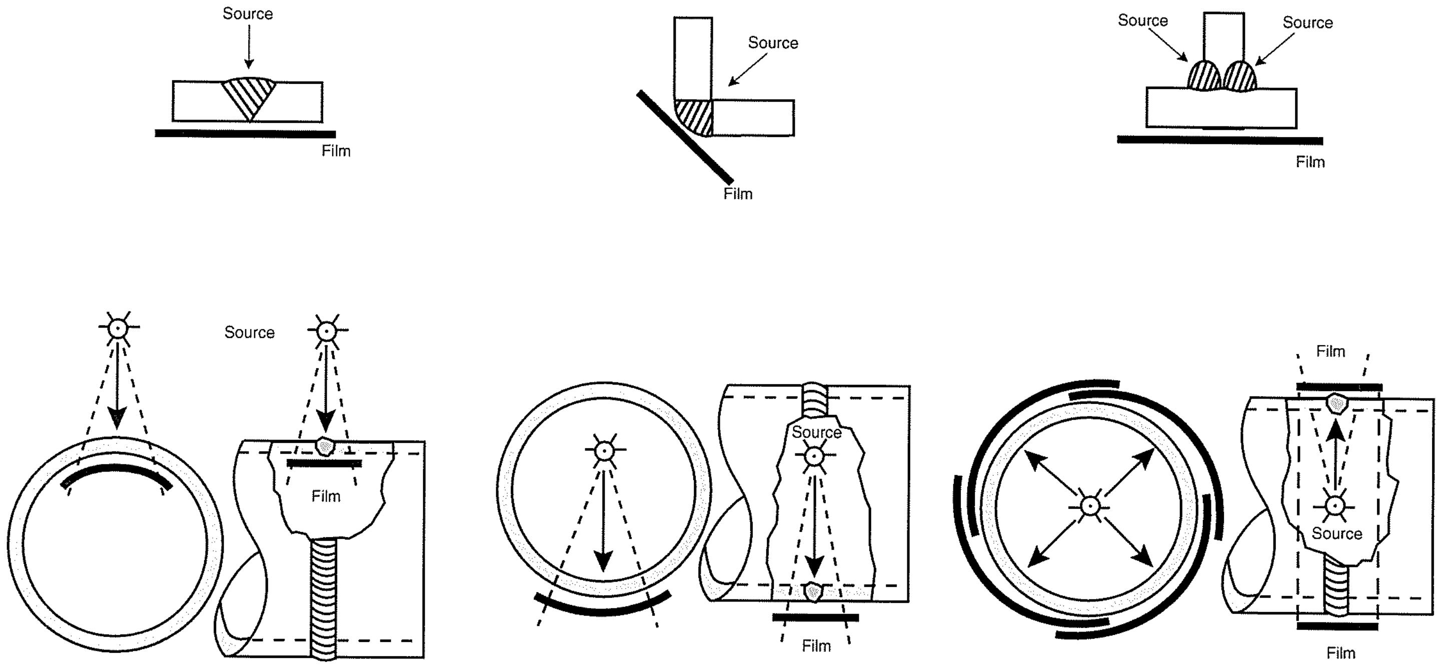


FIGURE 6-22 Single wall exposure, single view technique.

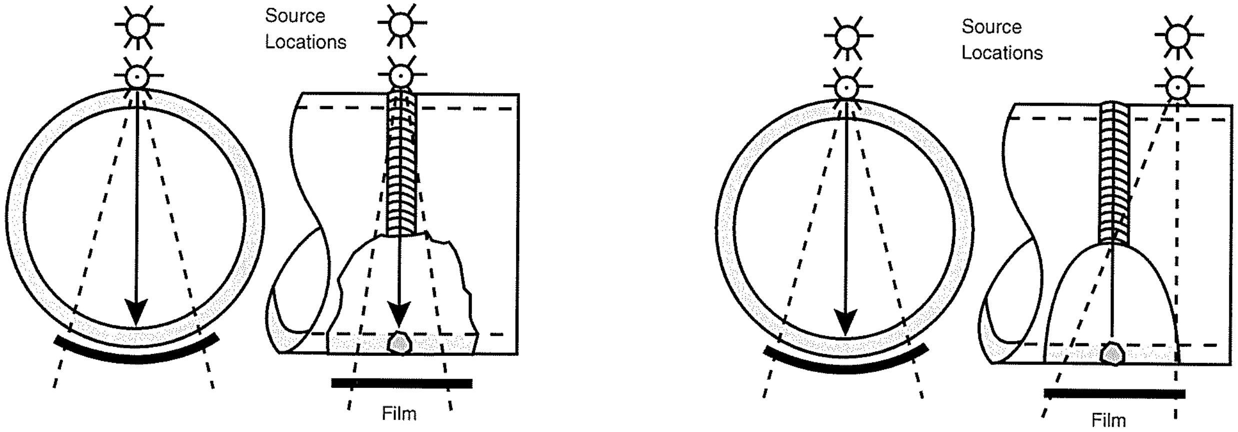


FIGURE 6-23 Double wall exposure, single view technique.

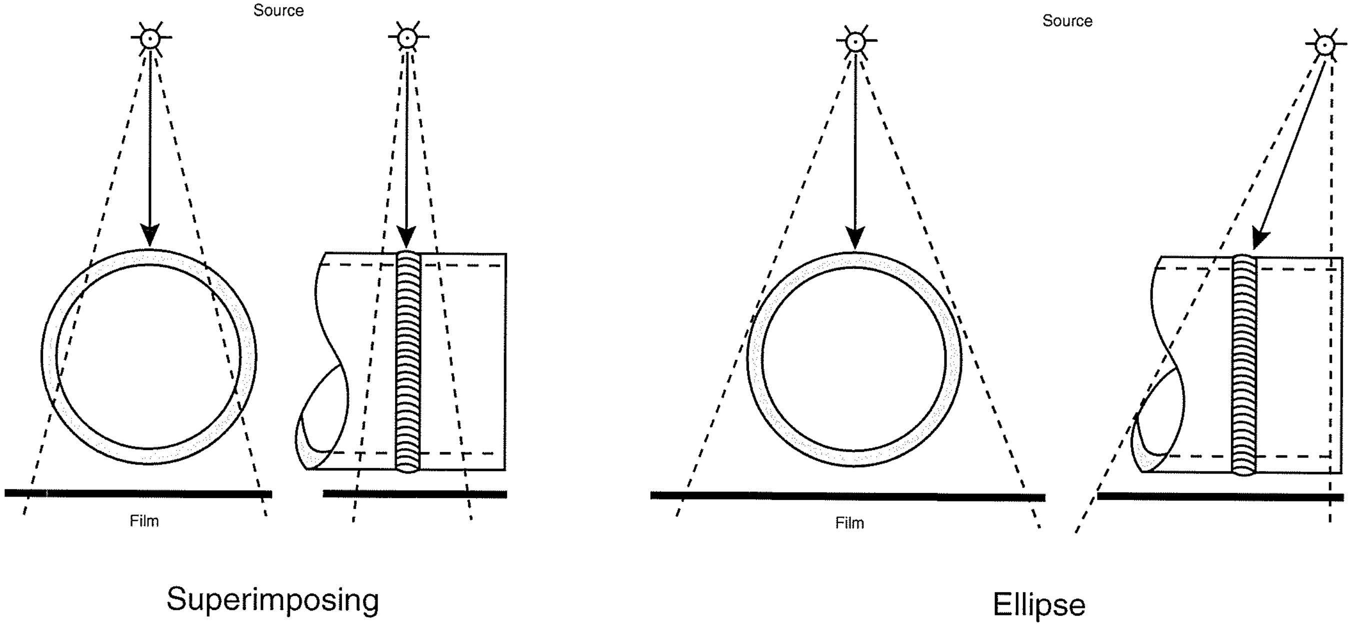


FIGURE 6-24 Double wall exposure, double view technique.

side, depending upon accessibility. The double wall exposure, double view technique usually permits the penetrameter to be placed on the source side.

In all of these techniques, the goal is to achieve the highest possible quality level. The penetrameter placement should be as close to the area of interest as possible. If the object being radiographed is a weld, the penetrameter should be as close as possible to the weld, without interfering with the weld image. In the case of castings, it may be necessary to place the penetrameter in the area of interest, depending upon the size and shape of the casting. In other cases, the technique may permit an object of similar radiographic density and thickness to be placed adjacent to the test object. This will serve as a location for the penetrameter to be placed. If the weld has reinforcement, it may be necessary to use a shim of radiographically similar material upon which the penetrameter is placed, as illustrated in Figure 6-20a. The purpose of the shim is to provide the penetrameter with a through thickness that will closely approximate the weld thickness, including the reinforcement. This is especially important when the codes and specifications require that the density range in the area of interest have a density within a certain percentage of the density through the penetrameter image. More details on this will be found in the section on density (page 6.47).

With all of these techniques, it is necessary that there be some form of "shooting sketch" that indicates the key aspects of the technique, such as the source location, film location, penetrameter placement and test part position. This serves as a great aid to the radiographic film interpreter who may not be totally familiar with the radiographic technique used.

One other important aspect of radiography has to do with the source placement. In far too many cases, the radiographic technique is designed to show the best possible image of the penetrameter. It seems that the goal in many cases, is to produce a good "picture" of the penetrameter and the essential hole, whereas the goal should be to display the best images of discontinuities, especially those that may not be oriented in a direction favorable to the radiation source. Radiography is extremely sensitive to the orientation of tight planar discontinuities. If a tight planar discontinuity is expected to be at an angle to the source of radiation, it will be difficult if not impossible to detect. These aspects of discontinuity orientation should be taken into consideration when developing the technique. Since the purpose of radiography is to detect discontinuities, the nature, location, and orientation of the expected discontinuities should always be a major factor in establishing the technique.

Procedure

A typical procedure is outlined below to provide guidance, especially when radiography of a specific object is being attempted for the first time. The recommended steps in a radiographic procedure are:

1. Understand the codes, specifications, and customer requirements thoroughly
2. Develop a technique based on the thickness and type of material
3. Prepare a shooting sketch
4. In the darkroom, carefully place the radiographic film in the cassette with the proper lead screens
5. Place the film under the area of interest
6. Ensure that the correct source to film distance is being employed
7. Place the appropriate station markers and identification numbers in the area of interest to assure easy correlation with a discontinuity if one is detected

8. Set up the exposure parameters
9. Make the exposure
10. In the darkroom, unload and process the film
11. Evaluate the film for artifacts
12. Evaluate the film for compliance
13. Complete a report and store the film

Radiographic Film

Radiographic film is, by far, the most important permanent record in nondestructive testing. Standard industrial radiographic film contains two emulsions, one on each side of the film base. There are seven layers that make up the cross section of the film. The base, which occupies the vast majority of the thickness, is made from cellulose, triacetate, or polyester. Both sides of this base have a very thin layer that contains an adhesive, and adhering to the adhesive are the layers of emulsion. The emulsion contains many small silver halide crystals, which are suspended in gelatin. This is where the chemical changes take place when the emulsion is exposed to radiation or light. On the two outer surfaces, there is a very thin layer of hardened gelatin, which is designed to protect the emulsion. The emulsion is very sensitive to handling, chemicals, abrasion, and various levels of light exposure, so it essential that the film be treated with extreme care.

There are four general classifications of industrial radiographic film. *Class I* is described as extra-fine grain, low speed, with very high contrast capabilities. This film is generally used for lower-density materials and can be used with or without lead screens. *Class II* is a fine-grain, medium-speed, high-contrast film that is also used for the lower-density materials with low- and medium-energy radiation. This film classification tends to be more widely used than the Class I since it provides very good definition, has fine grain, and is slightly higher in film speed than Class I. It can also be used with or without lead screens. *Class III* is a high-speed film, and therefore requires shorter exposure times. It is typically used for x-rays or gamma rays with higher energies, and can be used with or without lead screens. It is considered a medium-contrast film with high graininess. The *Special Class* includes films with very high definition and very fine grain. There are other classes of wide lattitude films that are not used as frequently as the four groups above.

Film Processing

After the radiograph has been taken, the film is ready for processing. A typical manual film processing system is illustrated in Figure 6-25. The first step in manual processing is to carefully place the film onto a stainless steel hanger, which is designed for manual processing, or carefully place it into the feed-in end of the automatic processor (Figure 6-26). The first step that the film will undergo is development. Developers are alkaline solutions that change the latent or chemically stored image in the radiographic emulsion into a visible image, resulting in various shades of gray or black, depending upon the amount of exposure. Agents in the developer reduce the exposed silver halide to metallic silver. There is also an accelerator, which speeds up the development; a preservative, which prevents the oxidation of the developer; and a restrainer, which helps to control and reduce the chemical fog that can occur during the processing of the film. It is fairly common to use a development time of 5 to 8 minutes at a temperature of 68 °F (20 °C). Some film manufacturers recommend 4 to 7 minutes at 68 °F. If the temperature is higher than 68 °F, a shorter development time will be appropriate. On the other hand, if the temperature of the developer is lower than 68 °F, a longer development time will be necessary. Just as it is

FIGURE 6-25 Manual film processing tanks. (Courtesy Charles J. Hellier.)

important to follow a procedure for taking the radiograph, it is also important to follow a consistent procedure for the processing of the film. A standard time and temperature for the development should be adopted and remain consistent throughout the radiographic operation.

When the radiographic film is being processed manually, it is necessary to agitate the film while it is in the developer solution. This provides a more uniform development and prevents the formation of air bubbles on the film surface. If the film is not properly agitated, the chemical activity in the development will be inconsistent and a condition called "streaking" may result, characterized by variations in film density.

The next step is to arrest or stop the development. This can be done in one of two ways. The film can be taken out of the developer and placed into a water bath for several minutes, or it can be placed in an acidic solution called stop bath. The stop bath is an excellent way to immediately and consistently arrest the development activity. The acid

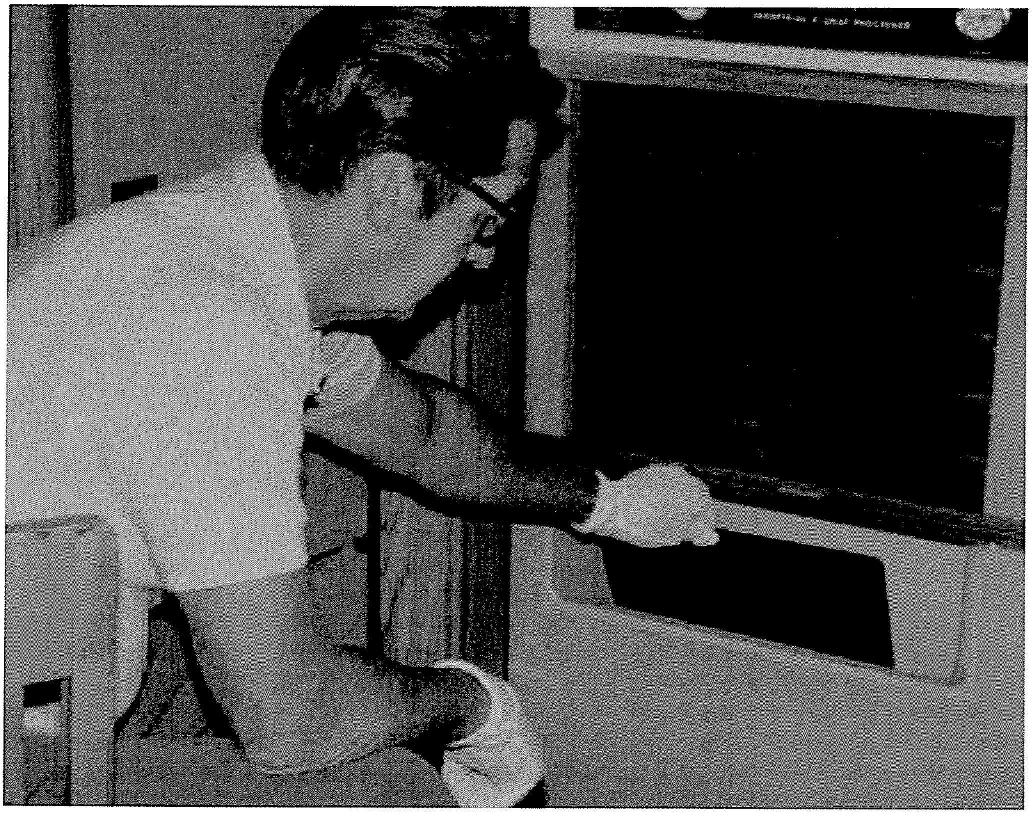


FIGURE 6-26 Automatic processor. (Courtesy Charles J. Hellier.)

neutralizes the alkaline developer and protects the acidity of the fixer, which is the next step.

The fixer serves two major functions. First, it clears out the unexposed silver halide crystals remaining in the film and, second, it fixes or hardens the image. The fixer also influences the archival properties of the film. Many times, shortcuts are taken in the fixing process and the film is taken out before it is totally fixed or hardened. In this case, the film may still contain some unexposed silver halide crystals and they will continue to develop on their own. This could ultimately result in the image of the film having a yellowish or brownish appearance. It is good practice to keep the film in the fixer for about 15 minutes, although some film manufacturers recommend at least double the clearing time. Clearing time is the time that it takes for the remaining silver halide crystals to be removed from the emulsion, clearing up the image.

After fixing, the film goes into a water rinse for a period of time, typically 30 minutes. The water should be continually changed in order to remove any remaining traces of the developer or the fixer. If the film is removed from the water rinse prematurely, shortened archival properties can result and the film can eventually turn yellow or brown. At the end of the water rinse time, it is recommended that the film be placed in water containing a wetting agent. This uniformly wets or coats the film so that droplets of water will not form, causing artifacts when the film is dried. It also facilitates consistent drying of the film.

The final step in processing is to dry the film, which is normally done in a warm air recirculating drier designed for this purpose.

The entire film processing procedure (apart from the drying operation) is accomplished under safelight conditions in a darkroom. The darkroom safelights should be tested periodically for film safety. An unexposed film with a coin or some other opaque object on the emulsion should be placed on the worktable. After a period of time that exceeds the longest time that films would be exposed to the safelight, the object should be removed and the film processed. There should be no change in the density of the film in the area of the opaque object. If an image of the object appears on the film, it indicates that the safelight is not "safe" and should be changed.

With automatic processors, the dry-to-dry time is about ten minutes, compared to over an hour for manual processing. This is because the developer solution is more concentrated and the development temperature is higher, which speeds up the entire process. The automatic processor is the optimal way to process film, since it results in consistent images with fewer film artifacts compared to manual processing. Automatic processors are very expensive and there should be a sufficient quantity of radiographs to be processed in order to make it cost effective. The key to successful film processing with automatic processors is maintenance. The automatic processor must be cleaned often. The roller system must be removed and carefully maintained, otherwise there will be many problems. Even the most exceptional technique capable of producing the highest quality radiographic images can be rendered meaningless because of problems in processing.

Summary

The first and most important consideration in radiography is the handling of the film. In far too many cases, film artifacts are the cause for the rejection of the final radiograph. Handling the film properly in the darkroom will help to minimize this. The darkroom should have a "wet" side and a "dry" side. The dry side is the area where the film is stored and handled, i.e., loaded into and removed from cassettes. The wet side is where the processor is located, whether it is manual or automatic. The darkroom should be hospital-clean at all times. A darkroom that is dirty and untidy is usually a darkroom where film will be scrapped as a result of artifacts.

The five steps in the processing of the film are:

1. Developing
2. Stop bath
3. Fixing
4. Washing
5. Drying

The precautions that should be taken include:

1. Proper control of the development temperature and time
2. Periodic maintenance of the developer and fixer solutions
3. Agitation in the manual system during the development step
4. Maintaining a safelight condition in the darkroom
5. Most important, cleanliness

Density

In radiography, film density is defined as the quantitative measure of film blackening as a result of exposure and processing. It can be expressed mathematically as follows:

$$D = \log \frac{I_0}{I_t}$$

where:
D = density
I_0 = light incident on the film
I_t = light intensity transmitted through the film

If a film is processed and it has not been exposed to light or radiation, it will be virtually clear. A film that has zero density is totally clear and has a film density reading of zero. If a film is exposed and the resultant film density is one, the amount of light that passes through the film is 10% of the incident light. For a film density of 2.0, only 1% of the incident light passes through. A film density of 3.0 permits 0.1% of the incident light to pass through, a film density of 4.0, 0.01%, and so on. Most specifications require that the film density in the area of interest be between 2.0 and 4.0. There are other specifications that differ slightly, but generally, the density range of 2.0 to 4.0 is quite common. Film density is measured with a densitometer (see Figure 6-27).

It is essential that densitometers be calibrated prior to each use to assure that the readings are accurate. In the past, film density strips were used to compare known densities to densities in the area of interest. This required a great deal of conjecture and, even though still employed today, the readings are not nearly as accurate as the readings obtained with the densitometer.

As mentioned earlier, the base density of a radiograph is established by taking a density reading through the penetrameter. The density range in the area of interest must not

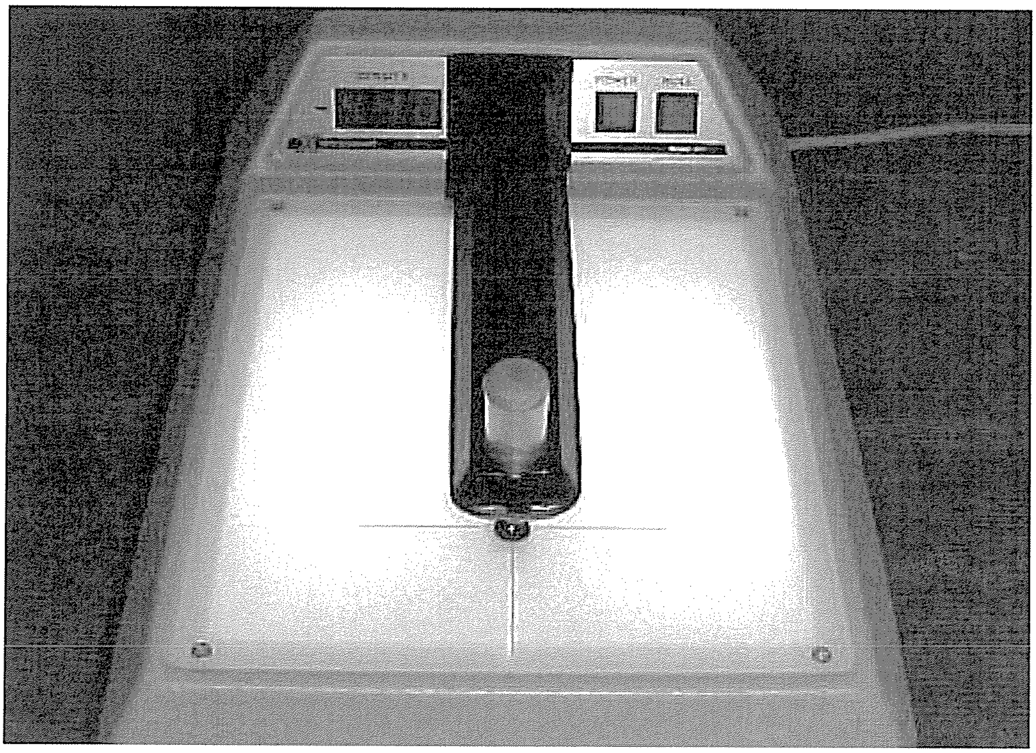


FIGURE 6-27 Densitometer. (Courtesy Charles J. Hellier.)

vary greater or less than a percentage of that base density. It is not unusual to have a density range requirement for the area of interest of +30% to −15% of the base density established through the penetrameter. This, in fact, is good radiographic practice. The quality level of the radiographic technique is established by the penetrameter image and it has been determined that that quality level will also apply to a defined density range. Table 6-8 shows density readings and the +30/−15% range. Notice that for a base density reading of 3.0 (i.e., the density through the penetrameter), the maximum density that is considered acceptable in the area of interest would be 3.9 and the minimum density would be 2.55. Most codes and specifications require that even with the application of this range, densities greater than a specified maximum (usually 4.0) and a minimum (usually 2.0) not be exceeded. The density readings in the area of interest should be taken at random in that area. Density readings should not be taken through an area containing discontinuity. It should be remembered that the density is a measure of establishing that the correct exposure has been employed. The density readings for both the penetrameter and the area of interest should be entered on the radiographic report.

TABLE 6-8 Film Densities

Density reading through penetrameter	+30%	−15%
1.5	1.95	1.28
1.6	2.08	1.36
1.7	2.21	1.45
1.8	2.34	1.53
1.9	2.47	1.62
2.0	2.60	1.70
2.1	2.73	1.79
2.2	2.86	1.87
2.3	2.99	1.96
2.4	3.12	2.04
2.5	3.25	2.13
2.6	3.38	2.21
2.7	3.51	2.30
2.8	3.64	2.38
2.9	3.77	2.47
3.0	3.90	2.55
3.1	4.03	2.64
3.2	4.16	2.72
3.3	4.29	2.81
3.4	4.42	2.89
3.5	4.55	2.98
3.6	4.68	3.06
3.7	4.81	3.15
3.8	4.94	3.23
3.9	5.07	3.32
4.0	5.20	3.40

Note: Typical acceptable density range for the penetrameter and area of interest is 2.0–4.0. Some specifications may require different ranges.

VI. RADIOGRAPHIC EVALUATION

The final step in the radiographic process, and by far the most important, is the evaluation of the radiograph. At times, radiographic interpretation has been referred to as a mix of art and science. Science involves all of the physics and principles involved with producing the radiographic image. Interpretation of the image involves art, to an extent. Interpretation of radiographs cannot be taught in a classroom, although that can provide a good foundation. It requires hours of reviewing and understanding the different types of images and the various conditions that are prevalent in industrial radiography. There are individuals who have been evaluating radiographs for decades who will admit that they are still learning how to interpret with each additional radiograph.

After the film density readings are completed, the next step in evaluating radiographs is to take an overall look at the appearance of the radiographic image, as well as the condition of the film itself. This initial look will generally indicate the overall quality that has been achieved. After that, the quality level should be confirmed by observing the image of the IQI and assuring that the essential hole in the shim-type penetrameter, or wire in the wire-type penetrameter, is clearly and discernibly displayed.

The radiographic interpreter should always wear cloth gloves (preferably cotton) when evaluating radiographs. This prevents fingerprints, smears, and smudges from being placed on the surface of the radiograph. After the quality level has been established, it is then appropriate to review the radiographic image for artifacts. There are a large number of artifacts that can appear in a radiograph. Artifacts, or false indications, are classified based on when they were formed, i.e., prior to processing, during processing, or after processing.

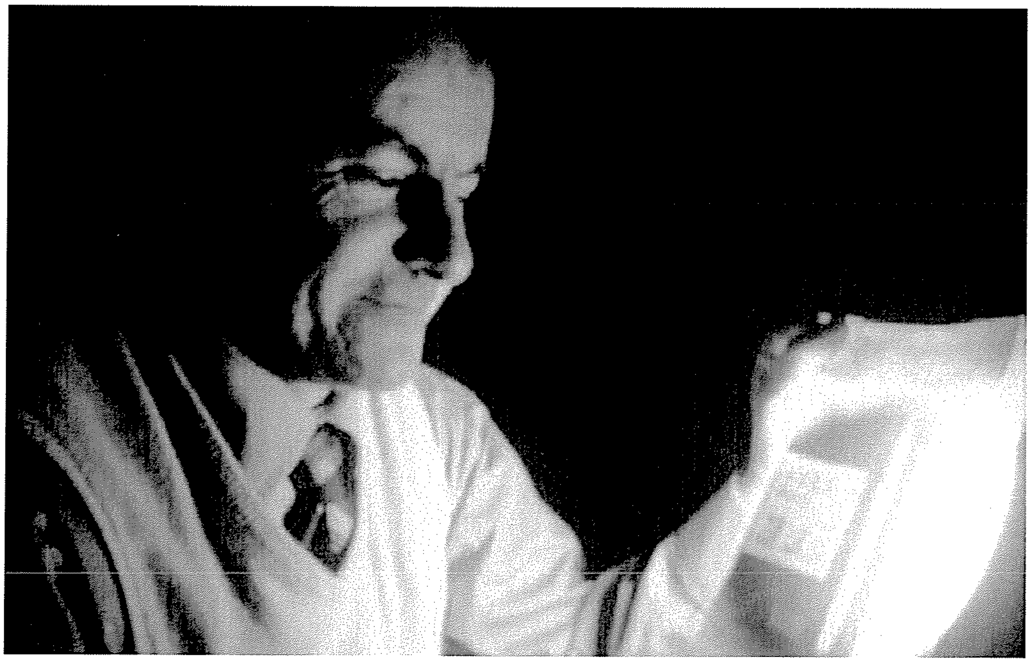


FIGURE 6-28 Interpretation of a radiograph with a high-intensity illuminator. (Courtesy Charles J. Hellier.)

The high-intensity illuminator (Figure 6-28) designed for viewing the radiographs should be in good working condition. Even before the radiograph is initially reviewed, the illuminator should be checked to make sure that the high-intensity light bulbs are working property and that the viewing area is clean and free from any scratches or artifacts that could be superimposed on the image of the radiograph. The illuminator should be properly designed to dissipate the heat that is created when the high-intensity lights are in operation. There should also be an intensity control to allow the interpreter to increase or decrease the brightness of the light source. Is essential that any light not coming through the radiograph be masked. The light intensity given off from these high-intensity illuminators is very intense and can cause severe discomfort to the eye, so masks are very strongly recommended to assure that the light coming through the film is the only light reaching the eye. Most high-intensity illuminators are operated with a foot switch, which permits the interpreter to turn the light on and off while keeping both hands free to handle the film. This is another area where caution is warranted. The light switch should not be activated until the film is in place on the viewing area of the viewer and the light should be switched off prior to its removal.

There seems to be a lack of agreement as to whether magnification should be employed during the evaluation of radiographs. Magnifiers are, in fact, encouraged when they can assist in the proper detection and identification of the different discontinuities. When magnification exceeds a certain power, it can become quite useless, since the grains in the film are also magnified and the images of the discontinuity tend to be diffused.

Radiographs should be viewed in a darkened area. It is advisable to allow the eyes to become used to the dimly lit conditions prior to radiographic viewing. Recommendations vary regarding the length of dark adaptation time. Experience has shown that periods from one to as high as 15 minutes may be necessary to properly distinguish the density changes within the image. The issues to consider are those such as:

a) The minimum density changes sought. Small or tight discontinuities may appear as very slight changes in the density of the radiographic image.

b) If the interpreter has recently been in bright sunlight, longer times may be required for dark adaptation.

For critical interpretation, it may be necessary to mask the lighter parts of the image where the low-density (lighter) areas allow the brighter transmitted light to reduce the interpreter's perception of changes in density.

Evaluation for Artifacts

Film Artifacts or False Indications that are Caused Prior to Processing

These include:

- Lead screen marks
- Static marks
- Film scratches
- Exposure to light
- Fog due to exposure to low levels of light or aging
- Finger marks
- Pressure marks
- Crimp marks

Artifacts that are Caused during the Processing of the Film

These include:

- Pressure marks (from rollers in an automatic processor)
- Chemical and delay streaks
- Pi lines (in automatic processors)
- Chemical spots
- Dirt

Artifacts Caused after Processing

These are primarily in the form of scratches and fingerprints. Fingerprints will be minimized with the use of cotton gloves.

Evaluation for Discontinuities

After the radiograph is evaluated for artifacts, it is finally time to evaluate for discontinuities. Discontinuity conditions that are normally found in welds include those in the following subsections, listed in order of severity.

Cracks

There are many different types of cracks that are classified by their orientation and location. They will always appear as dark, irregular, linear indications in a radiograph and are the most serious of all discontinuities. They are generally tight and not always detectable by radiography unless their orientation is somewhat in the same plane as the direction of the radiation. The most common types of cracks are those that are oriented longitudinally (along the length of a weld). Others may occur as star-shaped patterns, usually at the end of a weld pass. Some will occasionally be transverse to the length of a weld. Cracks can also appear at the toe of the weld or at the edge of the root pass. Underbead cracks will typically be angular, extending from the fusion zone.

Lack of Fusion

This serious discontinuity results from an absence of metallurgical fusion, either between a weld pass and the base material (weld edge prep) or between two successive weld passes. Lack of fusion is usually very narrow, linear, and tends to be straighter than the crack. At its extremities, the condition "feathers" down to an unusually sharp edge. In many cases, the image of lack of sidewall or lack of fusion appears somewhat straight along one edge and slightly wavy on the other.

Incomplete Penetration

This discontinuity is an absence of weld metal or an area of "nonfusion" in the root pass of the weld. Its appearance is very straight, dark, linear, and usually "crisp" in sharpness. It can be short but usually has significant length.

Inclusions (Dense and Less Dense)

Inclusions are basically materials that have been entrapped in the weld that do not belong there. They will have a variety of shapes and dimensions ranging from short and isolated to linear and numerous. The lighter-density inclusions will result in a darker image on the radiograph and the more dense inclusions, such as tungsten, as a lighter image.

Porosity

When gas is trapped in a weld metal, the void-type condition created is referred to as gas or porosity. Porosity comes in different shapes (globular, tailed, elongated) and distributions (linearly aligned, clustered, isolated, scattered). Porosity will always appear darker, since they are gas filled, and are the easiest of all weld discontinuities to detect.

Geometric Conditions

There are also geometric conditions that can occur in welds that are observable in a radiograph and should be further addressed by visual examination and dimensional checks. When possible, these conditions should be measured with mechanical gauges. These geometric conditions include the following.

Concavity—a concave condition at the root of a weld resulting in a thinner region through the weld cross section. The image of concavity in a radiograph is usually easy to identify since it is a broad indication with a gradual change of density as compared to the abrupt change associated with incomplete penetration.

Convexity—usually considered the opposite of concavity since this condition is a thicker protrusion at the root pass. It is caused by excessive deposit of the root pass and is sometimes referred to as excessive penetration. In extreme cases, the weld metal will "burn through" and may form droplets that are referred to as "icicles." The concern is the abrupt change in contour and the possibility of flow constriction in a pipe due to the protrusion of additional weld metal.

Undercut—a depression that occurs at the edge of the weld where it has fused into the base metal at the outer or inner surface. It is like a slight "valley" that continues along the length of the weld and varies in depth. The depth is the measurable dimension that determines its seriousness.

Underfill—sometimes interpreted as undercut since it can appear in the same region of the weld. In fact, it is a different condition that occurs when the weld groove is not completely filled with weld metal. Also, unlike the undercut, the contour of the bottom of this condition is more V-shaped or notch-like as compared to the generally broad gradual configuration of the undercut.

Overreinforcement—this condition results from an excessive depositing of weld metal on the outer surface of the weld. The concern is the geometric change that may create a stress riser condition at the outside surface where stresses normally tend to be higher by design.

Casting Discontinuities

Discontinuities that occur in castings that can be detected radiographically include the following, listed in order of their severity.

Hot tears and cracks—both serious ruptures or fissures that typically occur in an isolated zone due to the high stresses that build up during the cooling of the casting. Hot tears usually form during initial cooling and cracks later, usually at or near room temperature. On a radiograph, both conditions appear linear and branch-like and are most likely to be in or near an area of thickness change, where the different rates of cooling cause stresses to build up.

Shrinkage—usually in the form of a zone of minute fissures as a result of stresses during cooling. Shrinkage comes in various shapes. Sponge shrinkage has a "spongy" appearance and can be isolated, scattered, or significant in size and density variations. Microshrinkage is feathery in appearance and the change in density is often quite minor.

Slag and sand inclusions—the entrapment of inclusion materials and sand cause these conditions, which will have irregular shapes and variations in density due to the nature of the included matter.

Gas voids and porosity—unlike the inclusions, gas voids and porosity are more uniform, typically globular and dark in appearance. In fact, these discontinuities just look like voids, are normally easy to detect (they are not subject to alignment limitations like cracks), and readily recognizable.

Cold shuts—very tight discontinuities that occur when a surface that has begun to solidify comes in contact with other molten metal as the casting is in the process of being poured. There is usually a thin film of oxide present that prevents total metallurgical fusion. It is a very difficult discontinuity to detect with radiography due to its tight condition and angular orientation.

Geometric Conditions

As with welds, there are also geometric conditions in castings that can be observed radiographically. These geometric conditions include the following.

Misrun—this condition is actually an absence of metal due to the inadequate filling of the casting mold. It is easily detected by a simple visual test.

Unfused chaplets—metal supports that are strategically placed in the casting mold for support of the mold walls. They are designed to be consumed when the molten metal comes into contact with them, and when this does not happen, the circular shape of the chaplet will be apparent in the radiograph.

Note. A compendium at the end of this chapter contains radiographs showing examples of false indications, and weld and casting discontinuities.

Responsibility of the Interpreter

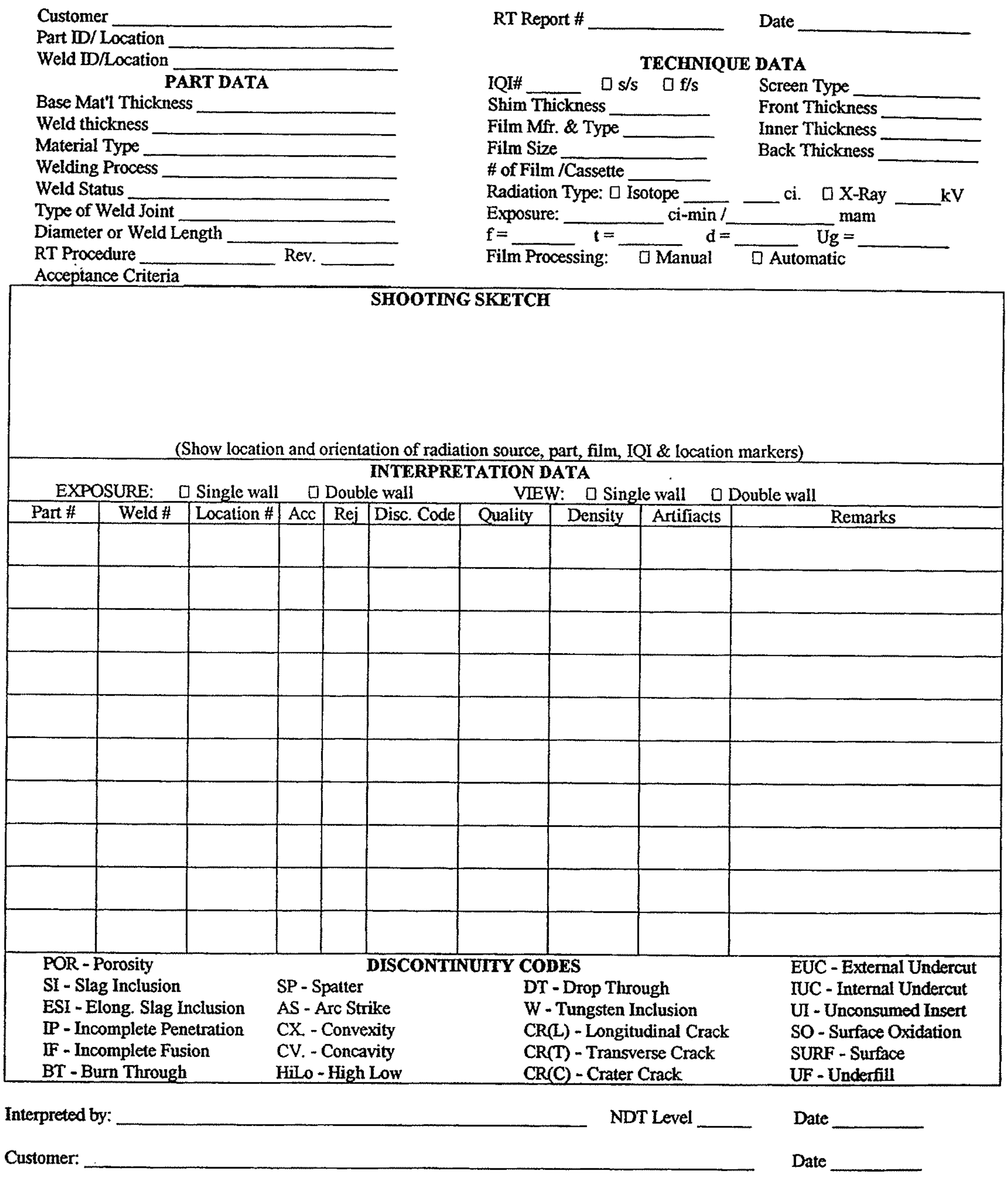
In order to effectively evaluate radiographs, it is essential that the interpreter be thoroughly familiar with the parts, dimensions, and material, in order to properly judge whether it is acceptable or not. The interpreter should be thoroughly familiar with the technique that was used to produce the radiograph, how the film was processed, the codes and standards that apply, and acceptance criteria.

If there is a rejectable discontinuity, it is extremely important that the condition be suitably identified as to its exact location. For this purpose, it is good practice for the radiographer to prepare a transparent skin that is overlaid on the radiographic image; then, with a wax pencil, the identification numbers are marked on the skin, as well as the outline and location of the discontinuity. This permits an accurate marking of the discontinuity on the actual part and facilitates precise repair. After repair, the region that originally contained the discontinuity must be reexamined to assure that the discontinuity has been completely removed.

It is essential that the entire evaluation process be entered on a radiographic report form. Report forms differ in format with each individual company. It would be extremely beneficial to the radiographic industry if a consistent, generic report form could be adopted. To this end, sample radiographic report forms for welds and castings are offered (see Figure 6-29).

VII. APPLICATIONS

Although the majority of applications in radiographic testing appear to involve welds and castings, it has been effectively applied to many other product forms spanning a



Customer ____________________
Part ID/ Location ____________________
Weld ID/Location ____________________

PART DATA

Base Mat'l Thickness ____________________
Weld thickness ____________________
Material Type ____________________
Welding Process ____________________
Weld Status ____________________
Type of Weld Joint ____________________
Diameter or Weld Length ____________________
RT Procedure ____________ Rev. _______
Acceptance Criteria

RT Report # ____________ Date ______________

TECHNIQUE DATA

IQI# _____ ☐ s/s ☐ f/s
Shim Thickness __________
Film Mfr. & Type __________
Film Size ______________
# of Film /Cassette ________
Radiation Type: ☐ Isotope _____ ____ ci. ☐ X-Ray _____kV
Exposure: __________ ci-min /__________ mam
f = ______ t = ______ d = ______ Ug = ________
Film Processing: ☐ Manual ☐ Automatic

Screen Type ____________
Front Thickness ____________
Inner Thickness ____________
Back Thickness ____________

SHOOTING SKETCH

(Show location and orientation of radiation source, part, film, IQI & location markers)

INTERPRETATION DATA

EXPOSURE: ☐ Single wall ☐ Double wall VIEW: ☐ Single wall ☐ Double wall

Part #	Weld #	Location #	Acc	Rej	Disc. Code	Quality	Density	Artifiacts	Remarks

DISCONTINUITY CODES

POR - Porosity
SI - Slag Inclusion
ESI - Elong. Slag Inclusion
IP - Incomplete Penetration
IF - Incomplete Fusion
BT - Burn Through

SP - Spatter
AS - Arc Strike
CX. - Convexity
CV. - Concavity
HiLo - High Low

DT - Drop Through
W - Tungsten Inclusion
CR(L) - Longitudinal Crack
CR(T) - Transverse Crack
CR(C) - Crater Crack

EUC - External Undercut
IUC - Internal Undercut
UI - Unconsumed Insert
SO - Surface Oxidation
SURF - Surface
UF - Underfill

Interpreted by: ______________________________ NDT Level _____ Date ________

Customer: ______________________________ Date ________

(a)

FIGURE 6-29 Radiographic report form for (a) welds. (*Continues*)

Customer ______________________________
Part ID/ Location ______________________
Casting ID/Location ____________________

PART DATA

Mat'l Thickness ____________________
Material Type _______________________
RT Procedure ______________ Rev. _______
Acceptance Criteria ____________________

RT Report # ___________ Page ___ of ___ Date _______

TECHNIQUE DATA

IQI# ______ ☐ s/s ☐ f/s Screen Type ___________
Shim Thickness __________ Front Thickness __________
Film Mfr. & Type _________ Inner Thickness __________
Film Size _______________ Back Thickness __________
# of Film /Cassette ________
Radiation Type: ☐ Isotope _____ ____ ci. ☐ X-Ray _____kV
Exposure: __________ ci-min /___________ mam
f = ______ t = ______ d = ______ Ug = _________
Film Processing: ☐ Manual ☐ Automatic

SHOOTING SKETCH

(Show location and orientation of radiation source, part, film, IQI & location markers)

INTERPRETATION DATA

EXPOSURE: ☐ Single wall ☐ Double wall VIEW: ☐ Single wall ☐ Double wall

Part #	Casting #	Location #	Acc	Rej	Disc. Code	Quality	Density	Artifiacts	Remarks

DISCONTINUITY CODES

CR - Crack
MP - Microporosity
POR - Porosity
WP - Worm Hole Porosity
BH - Blow Hole
SI - Sand Inclusion
INC - Inclusion
DI - Dense Inclusion
SS - Sponge Shrinkage
MS - Micro Shrinkage
SH - Shrinkage
DR - Dross
HT - Hot Tear
MR - Misrun
COL - Cold Shut
UC - Unfused Chaplet
UCL - Unfused Chill
CS - Core Shift
SURF - Surface
SEG - Segregation

Interpreted by: ____ NDT Level _____ Date _________

Customer: ____ Date _________

(b)

FIGURE 6-29 (*Continued*) Radiographic report form for (b) castings.

wide variety of industries. The major industries include but are not limited to the following.

1. *Power Generation.* A wide range of weld configurations, thicknesses, and materials are used at power plants. Radiographic testing requires radiation sources that are capable of providing energies from the low end of the spectrum to the highest commercially available. Pressure vessels are complex structures that require high-quality initial examinations. The associated piping systems, with their many weld joint geometries, provide continual challenges for the radiographer. Cast valve bodies are usually radiographed at the foundry. In-service examinations offer even greater challenges. There are other conditions the radiographer must deal with, such as accessibility, the environment (temperature; in the case of nuclear power plants, radiation, air quality, and circulation, etc.), the transporting and positioning of equipment, the concern for the security of radiation areas, and the weather when examinations are to be conducted outdoors. There are other nonconventional applications for RT in power plants. There are ongoing concerns regarding the degradation of structures and components as a result of corrosion, vibration, and wear. Many times, the areas are covered with insulation or are very difficult to reach. There are portable RT units that provide for the examination of these conditions and provide contour data through the insulation. When there are similar concerns for the internal conditions of valves, or for the determination of the position of the mechanical components, a higher-energy source may be necessary.
2. *Aerospace.* There are countless uses for RT in the aerospace industry. The critical components in the aircraft engine itself call for thousands of radiographs. The airframe and other related structures depend greatly on radiography for initial and in-service inspection. Water ingress in honeycomb cells can cause problems due to freezing when the aircraft is airborne. Radiographic techniques can effectively detect this condition in most cases.
3. *Petrochemical.* Radiography is of great importance in the initial construction of petrochemical plants. Considering the many service conditions under which this type of complex operates, establishing a baseline through radiography is of extreme importance. Just as with power plants, in-service inspection is necessary and RT plays a key role. The detection of areas of degradation, corrosion, erosion, wear, and other conditions that develop through the extended operation should be detected and corrected before an unplanned shutdown becomes necessary. Other than the cost of initial construction, unplanned outages are the most costly events in this industry. It should be noted that this also applies to most other major industries.
4. *Nonmetals.* This category includes a wide variety of materials that are inspected by radiography, including plastics, rubber, propellants, ceramics, graphite, concrete, explosives, and many more. Perhaps the electronic industry, because there are some metals involved, also belongs in this industry segment.
5. *Medicine.* There are numerous applications in medicine that do not involve the examination of living creatures. On occasion, foreign objects or contaminants have inadvertently found their way into various drugs and medicines during processing. These elements most usually have densities that are quite different from the products into which they have become included. This makes their examination an ideal application for RT. A prerequisite of course, must dictate that the product will not be affected by exposure to radiation. When a large quantity of product is involved, real-time radiography may be the most cost-effective approach. This provides for a two-dimensional image to be displayed on a monitor almost immediately, as a result of the conversion of the radiation into an electronic or optical signal.
6. *Law Enforcement and Security.* Radiography is especially adaptable and useful for the detection of hidden contraband and weapons and for the examination of explosive de-

vices such as shells and projectiles. Sealed boxes, envelopes, and other packages have been found to contain devices that were potentially hazardous if they had not been detected. When passing through the security area in an airport, carry-on articles are subjected to real-time radiographic inspection.

7. *Food.* Various food products are examined with some form of RT for the purpose of detecting foreign objects that may have been introduced during processing. In some cases, food items may be inspected for content, distribution of additives (such as nuts, candy, etc. in ice cream), or for quantity. Again, the fastest approach would include fluoroscopy or some other real-time technique.

8. *Objects of Art or Historic Value.* This industry is perhaps the most unusual and most interesting for radiographers. Famous paintings have been radiographed (using low-energy, high-contrast techniques) to disclose hidden paintings or images beneath their outer layer. Mummies, usually of some very prominent ruler or an individual with some historic significance, have been inspected to evaluate the condition of the remains. Statues, vases, old pottery, figureheads from historic seagoing vessels, and the famous Liberty Bell have all been subjected to radiographic inspections. Entire jet engines, cars, and complicated assemblies have been examined, many times with a single exposure.

Summary

The uses of radiography are limited only by the principles inherent in the process and the human mind. There are those that would say that the world of radiography has reached its peak. It is easy to dispute such a narrow opinion when considering the many recent developments and innovations, including industrial computed tomography, real-time radiography, flash (high-speed) imaging, in-motion radiography, microfocus radiography, digital imaging, and the photostimulable luminescence (PSL) process, also known as storage phosphor plates, for capturing radiographic images.

The future of radiography will continue to offer new and exciting techniques that will expand its world of applications and opportunities. Certainly, Wilhelm Conrad Roentgen and Marie and Pierre Curie would have been proud.

VIII. ADVANTAGES AND LIMITATIONS OF RADIOGRAPHY

Advantages

Radiographic testing has many advantages, some of the most significant of which are listed below. It:

1. Provides an extremely accurate and permanent record
2. Is very versatile and can be used to examine many shapes and sizes
3. Is quite sensitive, assuming the discontinuity causes a reasonable reduction of cross section thickness
4. Permits discontinuity characterization
5. Is widely used and time-proven
6. Is a volumetric NDT method

Limitations

1. There are safety hazards with the use of radiation devices
2. RT has thickness limitations, based on material density and energy used
3. RT can be time-consuming
4. RT is very costly in initial equipment and expendable materials
5. It is also very dependent on discontinuity orientation
6. RT requires extensive experience and training of the personnel taking the radiographs and during the interpretation

Safety Considerations

Radiation ionizes matter through the ejection of electrons from their orbit, thereby changing the electrical characteristics of the atoms. It is this process that results in biological effects to humans. Living tissue will be damaged to an extent determined by the dose received. Absorption of radiation by a human is expressed in REM (roentgen equivalent man). It is the product of roentgens or milliroentgens (mR) and the Quality Factor (QF) of the radiation type. Since x- and gamma rays have a QF value of 1, the exposure as measured in Roentgens will be the dose received in units of REM. The age-old rules of protection against radiation exposure involve time, distance, and shielding.

Time. The shorter the exposure, the better. Every effort should be made to keep personnel exposure time as close to zero as possible. When performing radiography in the field, zero exposure is virtually impossible. So every attempt should be made to minimize the time of exposure to the body to as short a time as possible.

Distance. The further an individual is from a radiation source, the less the exposure. Recall the inverse square law and how radiation intensity varies inversely proportional to the distance. If there is an intensity of 200 mR/hour at a certain distance from a radiation source, simply doubling the distance will decrease the intensity by a factor of one-fourth, or 50 mR. Doubling the distance again will reduce the intensity to 12.5 mR, and so on. Using the inverse square law will permit the radiographer to calculate the approximate exposure at any distance.

Shielding. The greater the thickness and density of the shielding material, the less the radiation exposure. This is a function of the half- and tenth-value layers, as discussed in Section II. Lead, of course, makes an excellent shielding material because of its high density.

To summarize, the exposure to radiation should be kept as short as possible, the distance from the radiation as far as reasonable, and the shielding as thick as practical.

There are many excellent references regarding the biological effects of radiation exposure. Unfortunately, there is not a great deal of data to support the effects of radiation on humans. The limited data from the end of the Second World War and some of the more notable accidents involving radiation have been the primary source for the exposure effects still referred to today. The ALARA (as low as reasonably achievable) concept is the most appropriate way to treat the issue of radiation exposure. If every person working with radiation took every precaution and made every effort to minimize exposures, needless damage would not occur to nearly the same extent as it does.

Since humans cannot sense radiation, it is essential, and in many industries a requirement, that personnel-monitoring devices be used. Such devices include:

1. *Film badges* are small plastic holders that contain a special film, which are worn during the time working in or near a radiation area. The film is quite sensitive and can de-

tect as low as several mR of low-energy x-rays and up to as high as 2000 R. They usually contain small metallic filters that enable the type and energy range of the radiation to be identified. After a period of time, they are sent to a laboratory for processing and reading. This is the main source of data that are entered on a lifetime radiographic exposure history report that should be maintained for all radiation workers.

2. *Ionization chambers* are sometimes referred to as pocket dosimeters. They are small, lightweight, and are capable of being read directly from a scale inside the chamber.
3. *Thermoluminescent dosimeters,* referred to as TLDs, are widely used due to their rapid readout response time and broad range, which is quite linear. They can be reused and are excellent under field conditions.
4. *Photoluminescent glasses* are useful down to about 1 R. They build up fluorescent centers when exposed to radiation and emit visible light when viewed with ultraviolet light. The intensity of the light is proportional to the exposure of radiation.

In addition, area monitors should always be employed whenever radiographic activities are in process. Some of the monitors, or survey meters commonly used include:

- Ionization chambers
- Geiger—Mueller (G–M) counters
- Scintillation instruments

(Note: Two survey meters are better than one in the event of a failure.)

Radiation should never be taken for granted. One cannot be too cautious when dealing with this potentially hazardous form of electromagnetic energy. And yet, it can be safely and effectively used in radiography by following the rules and being familiar with the regulations. Personnel who do not respect radiation and try to do things their way cause most accidents and overexposures. Radiation does deserve respect!

IX. COMPENDIUM OF RADIOGRAPHS

Examples (Figures 6.30–6.44) of a number of conditions (artifacts) and discontinuities are included in the following pages as a guide. It must be stressed that discontinuities are unique and no two are alike. There are many other types that are not covered in this chapter. A thorough knowledge of the materials, how they were processed, the radiographic techniques employed, and an understanding of the variables involved in radiographic interpretation are all essential to effective evaluation.

Figures 6-30–6-33 illustrate artifacts; Figures 6-34–6-42 illustrate weld discontinuities; and Figures 6-43 and 6-44 illustrate casting discontinuities. (*Note.* For an example of Radiographs showing other casting discontinuities, refer to Chapter 2: hot tear—Figure 2-5b, sand and slag inclusions—Figure 2-20, and an additional example of shrinkage, Figure 2-5a.)

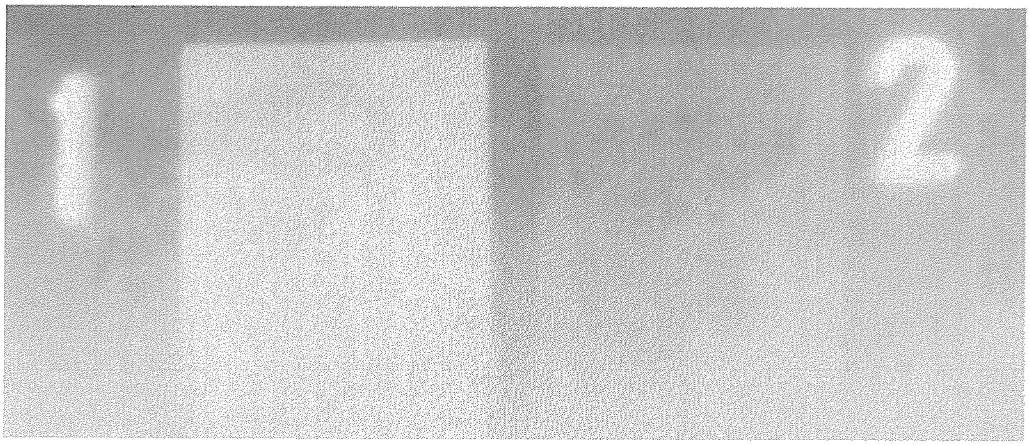


FIGURE 6-30 Chemical stains. (Courtesy Charles J. Hellier.)

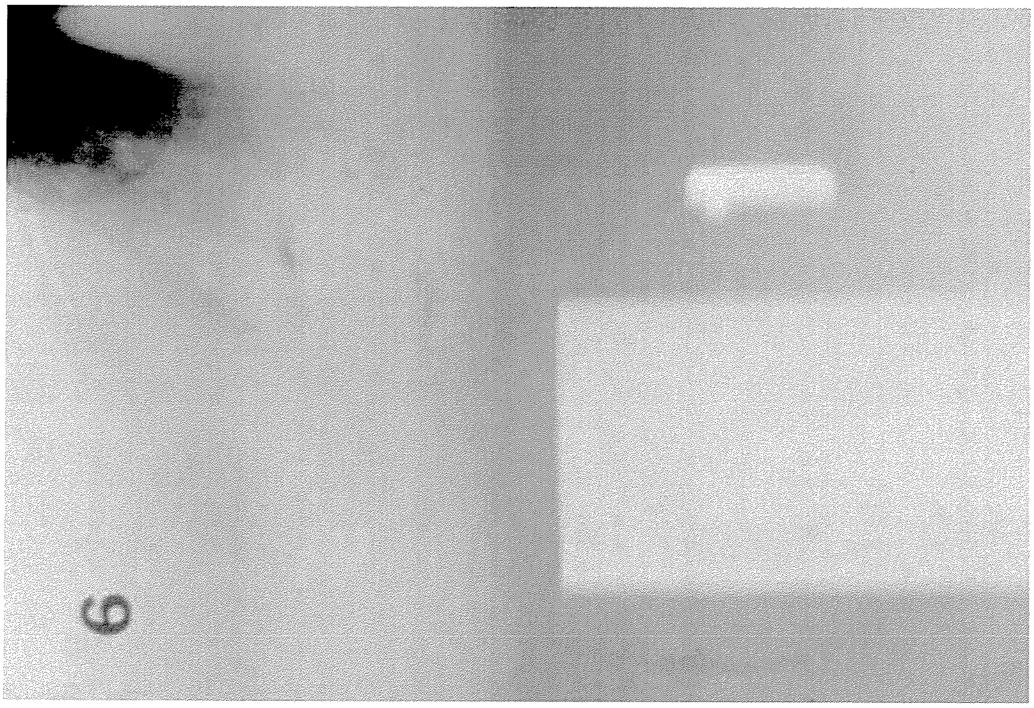


FIGURE 6-31 Light leaks. (Courtesy Charles J. Hellier.)

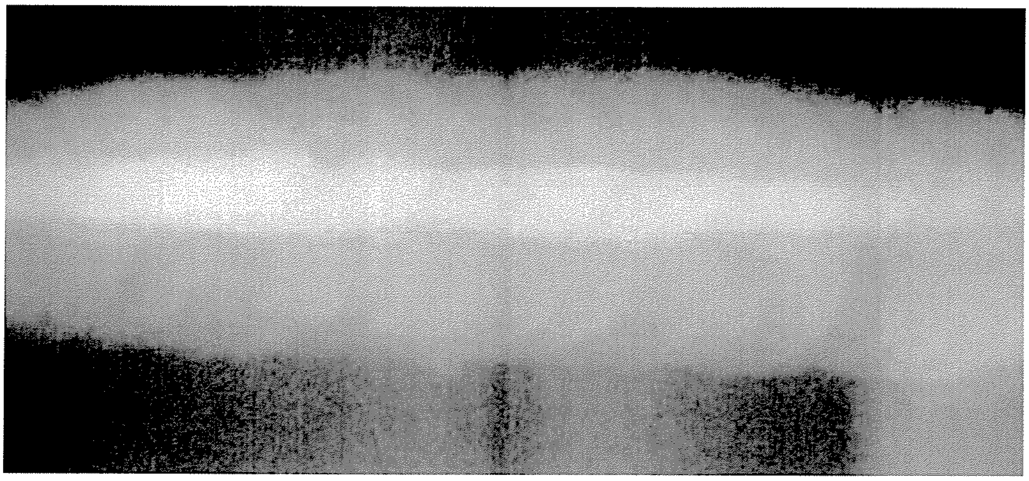


FIGURE 6-32 Pi lines. (Courtesy Charles J. Hellier.)

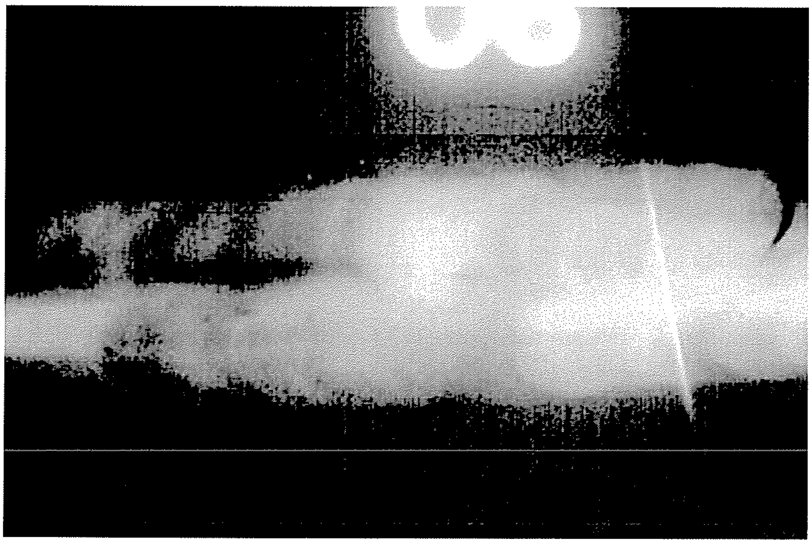


FIGURE 6-33 Sliver of paper (located between the lead intensifying screen and the film). (Courtesy Charles J. Hellier.)

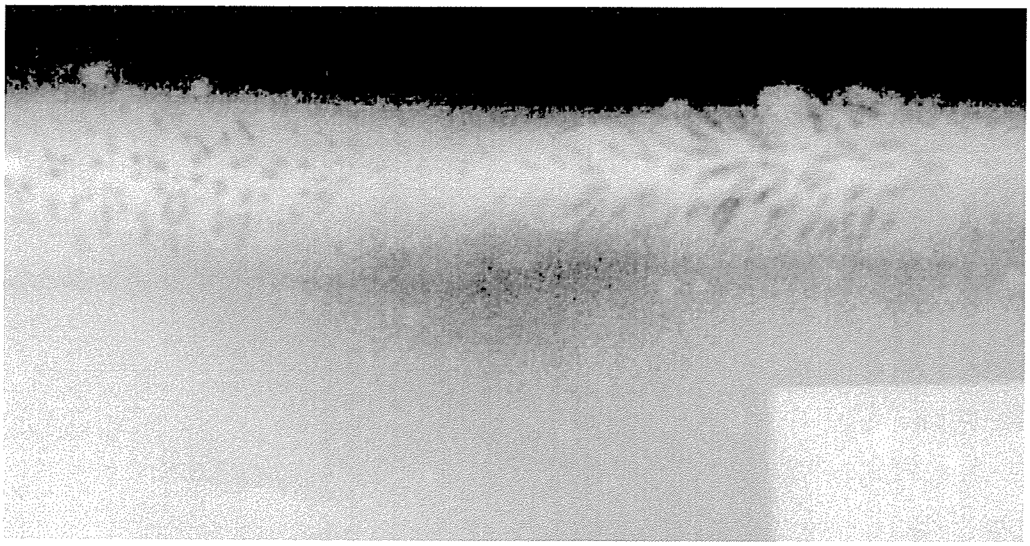


FIGURE 6-34 Porosity. (Courtesy of Quality Consulting Company, Inc.)

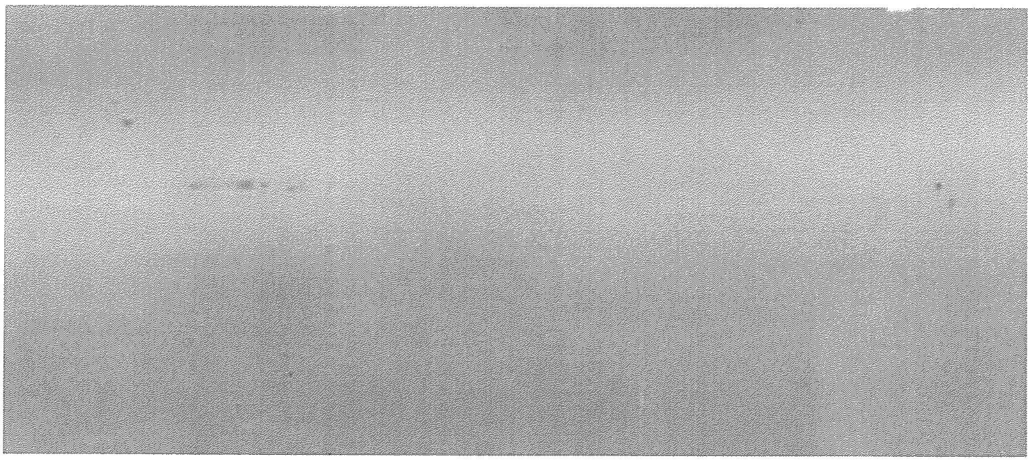


FIGURE 6-35 Slag inclusions. (Courtesy Charles J. Hellier.)

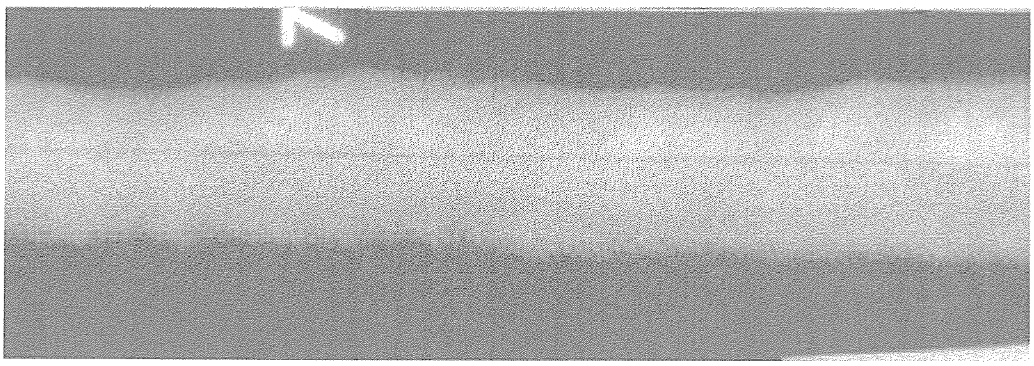


FIGURE 6-36 Incomplete penetration. (Courtesy Charles J. Hellier.)

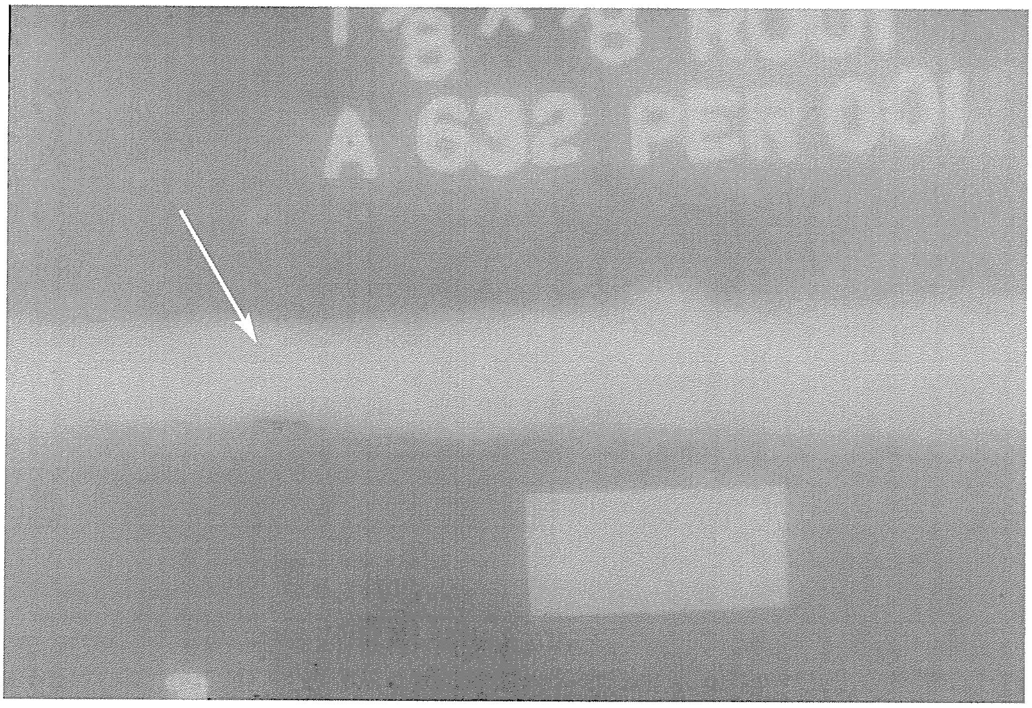


FIGURE 6-37 Lack of fusion (arrow) and undercut (at edge of weld). (Courtesy Charles J. Hellier.)

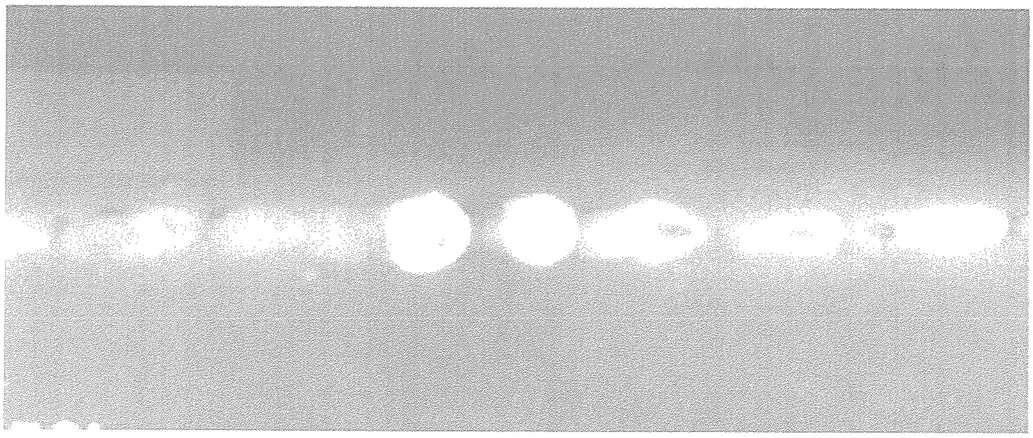


FIGURE 6-38 Icicles and burnthrough. (Courtesy Charles J. Hellier.)

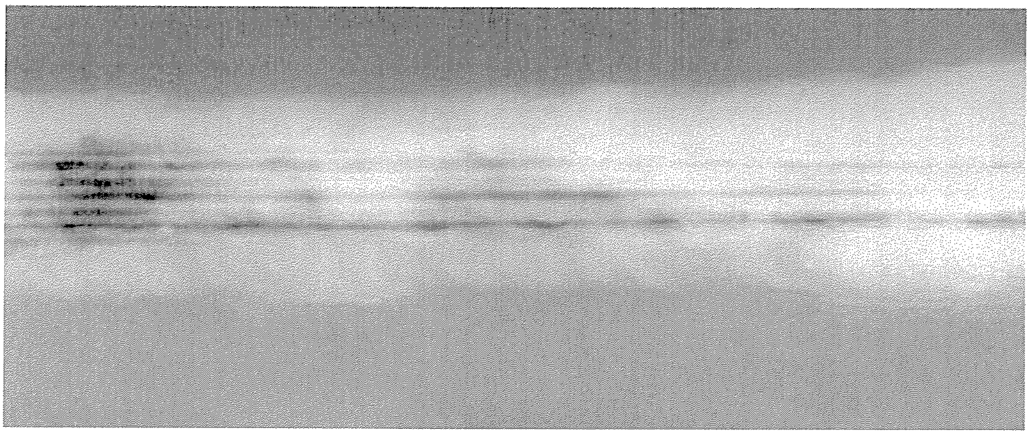


FIGURE 6-39 Slugging (weld rods placed in weld groove). (Courtesy Charles J. Hellier.)

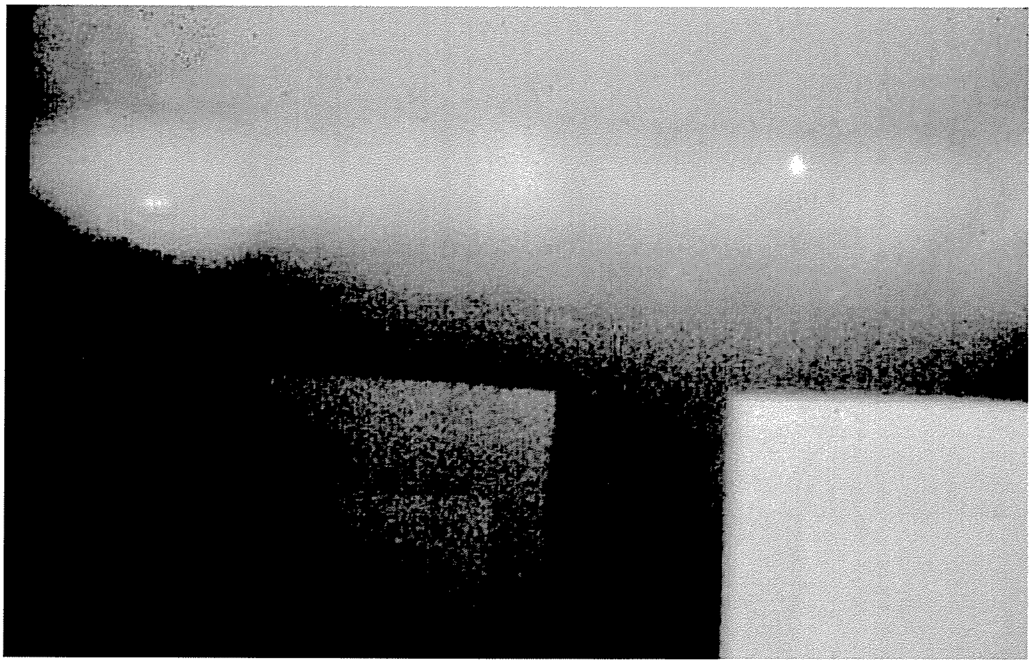


FIGURE 6-40 Tungsten inclusion (Courtesy of Quality Consulting Company, Inc.)

FIGURE 6-41 Tungsten inclusion (double wall double view ellipse technique). (Courtesy Charles J. Hellier.)

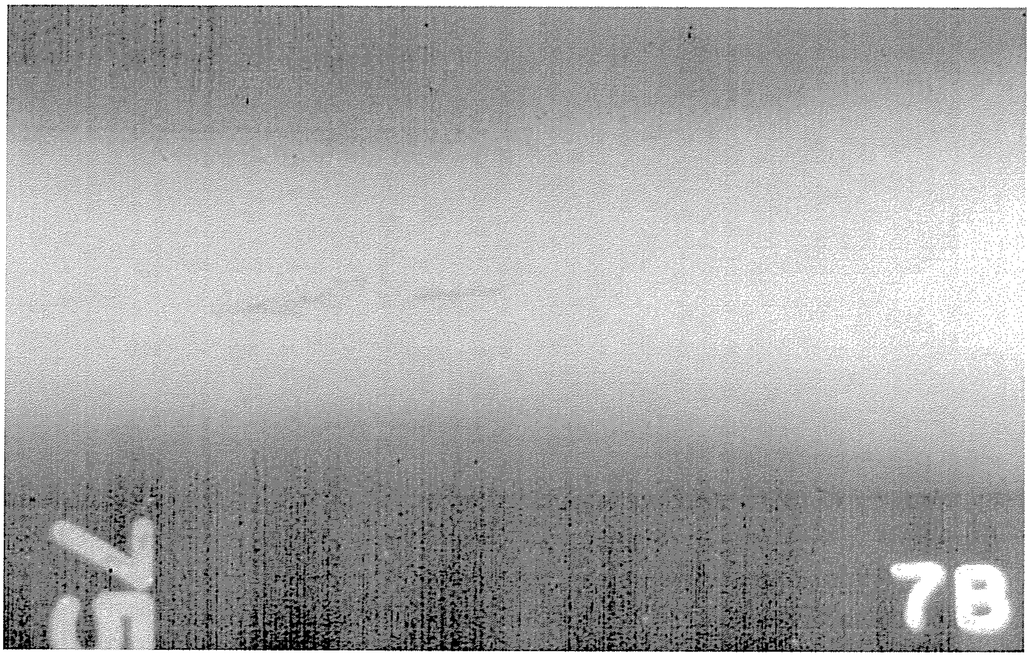


FIGURE 6-42 Cracks. (Courtesy Charles J. Hellier.)

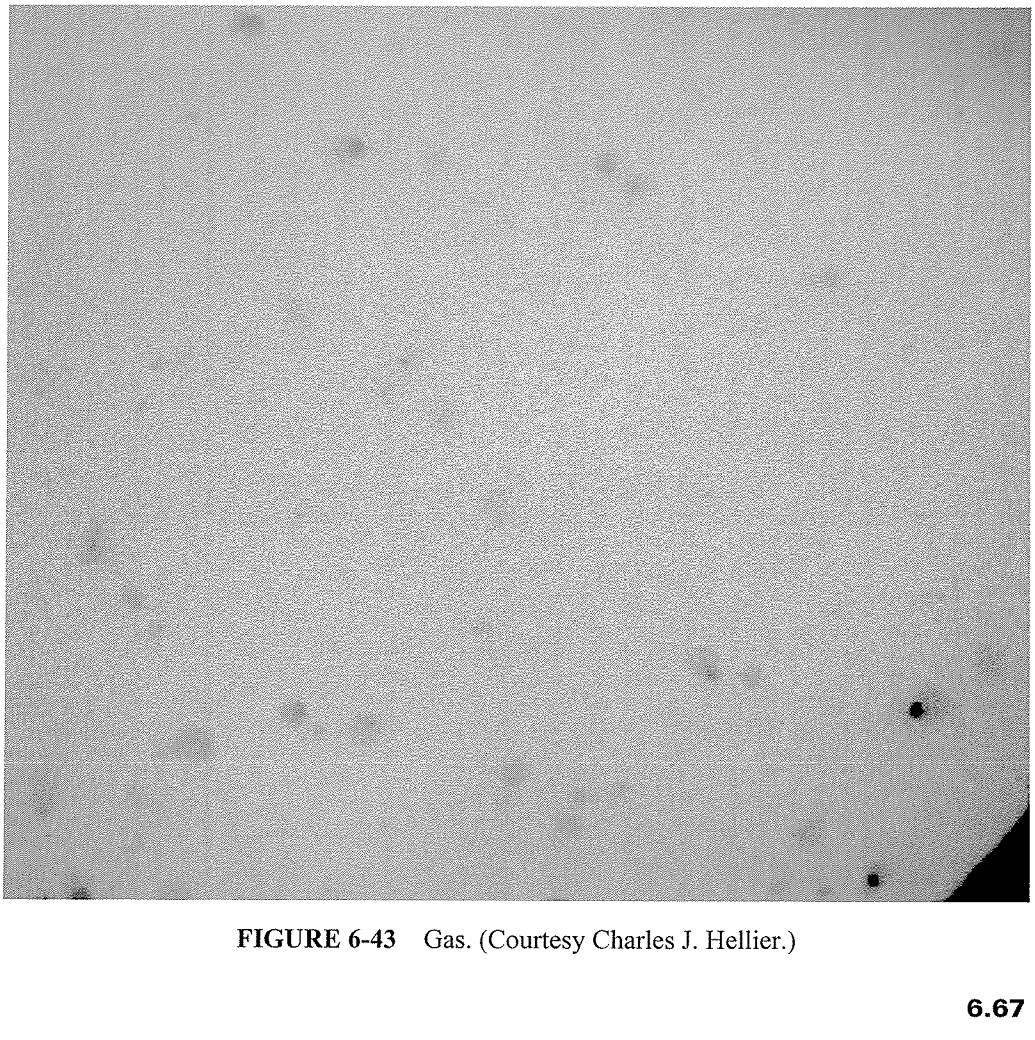


FIGURE 6-43 Gas. (Courtesy Charles J. Hellier.)

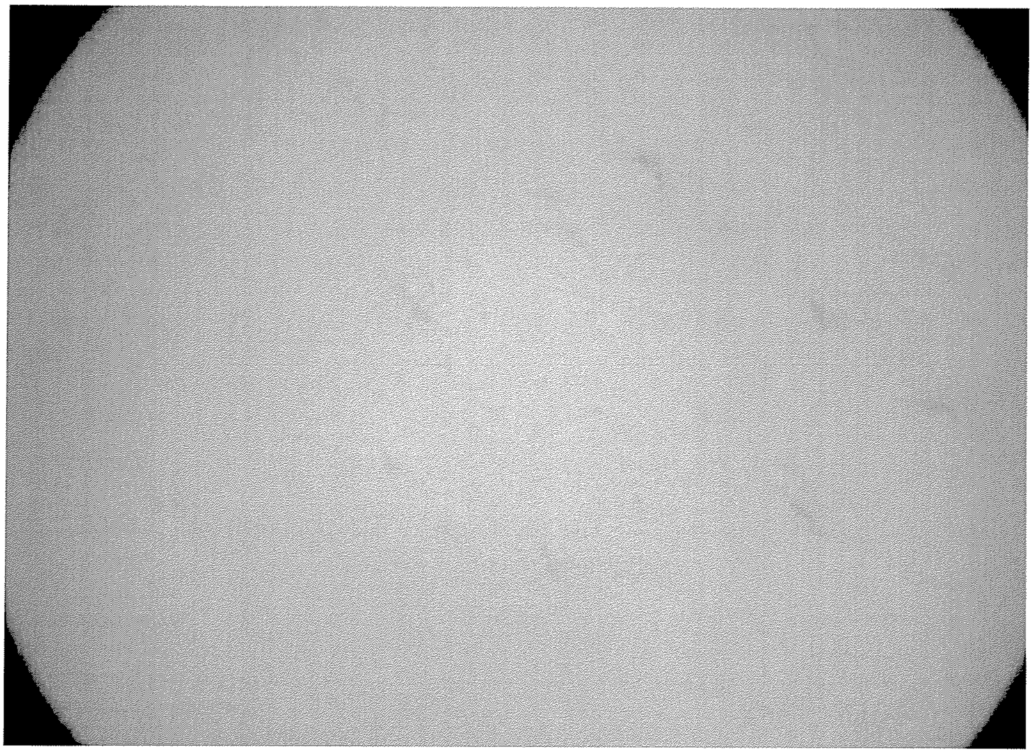


FIGURE 6-44 Shrinkage. (Courtesy Charles J. Hellier.)

X. GLOSSARY

Absorption—The process whereby photons of radiation are reduced in number or energy as they pass through matter.

Angstrom unit (Å)—A unit of length that is used to express the wavelength of electromagnetic radiation (i.e., light, x-rays, gamma rays). One angstrom unit is equal to 0.1 nanometers (1 nm = 10^{-9} m).

anode—The positive electrode of a discharge tube. In an x-ray tube, the anode contains the target.

artifact—A false indication on a radiograph arising from, but not limited to, faulty manufacture of the film, storage, handling, exposure, or processing.

cassette—A light-tight packet or container for holding radiographic film during exposure; may include intensifying or conversion screens.

collimator—A device made of radiation absorbent material intended for defining the direction and angular divergence of the radiation beam.

composite viewing—The viewing of two or more superimposed radiographs from a multiple film exposure. The film may be the same or different speeds.

constant potential x-ray unit—An x-ray system that operates on full-wave rectified current.

contrast sensitivity—A measure of the minimum percentage change in an object that produces a perceptible density/brightness change in the radiographic image.

definition, image—The sharpness of delineation of an image in a radiograph. Generally used qualitatively.

densitometer—A device for measuring the density of radiographic film.

density, radiographic—The quantitative measure of film blackening when light is transmitted.

duty cycle—The usable time of a device versus the time that it has to rest when operating "continuously."

equivalent penetrameter sensitivity—That thickness of penetrameter, expressed as a percentage of the part thickness radiographed, in which a 2T hole would be visible under the same radiographic conditions.

exposure table—A summary of values of radiographic exposures suitable for the different thicknesses of a specific material.

film contrast—A qualitative expression of the slope or steepness of the characteristic curve of a film; that property of a photographic material that is related to the magnitude of the density difference resulting from a given exposure difference.

film speed—A numerical value expressing the response of a radiographic image film to the energy of penetrating radiation under specified conditions.

filter—Uniform layer of material, usually of higher atomic number than the specimen, placed between the radiation source and the film for the purpose of preferentially absorbing the lower-energy radiation.

focal spot—In x-ray tubes, the area of the anode that emits x-rays when bombarded with electrons.

fog—A general term used to denote any increase in optical density of a processed photographic emulsion caused by anything other than direct action of the image-forming radiation.

gamma radiography—A technique of producing radiographs using a radioactive source emitting gamma rays.

geometric unsharpness—The penumbral shadow in a radiographic image that is dependent upon 1) the radiation source dimensions, 2) the source to object distance, and 3) the object to film distance.

graininess—The visual impression of irregularity of silver deposit in a processed film.

half-life—The time required for a radioactive isotope to decay to one-half of its original activity.

half-value layer (HVL)—The thickness of a material required to reduce the intensity of a beam of incident radiation to one-half its original intensity.

image quality indicator (IQI)—A device or combination of devices whose demonstrated image or images provide visual or quantitative data, or both, to determine the radiographic quality and sensitivity. Also known as penetrameter. (*Note:* it is not intended for use in judging size or establishing acceptance limits of discontinuities.)

intensifying screen—A material that converts a part of the radiation into light or electrons and that, when in contact with a recording medium during exposure, improves the quality of the radiograph or reduces the exposure time required to produce an image, or both.

IQI sensitivity—The minimum discernible image and the designated hole in the shim-type or the designated wire image in the wire-type image quality indicator.

isotope—One of a group of atoms that have the same atomic number (same chemical characteristics) but have a different mass number. The nuclei have the same numbers of protons but different number of neutrons, resulting in differing values of atomic mass.

Kinetic energy—The energy of a body with respect to its motion.

latent image—A chemical change in the film emulsion as a result of a condition produced and persisting in the image receptor by exposure to radiation. It can to be converted into a visible image by processing.

location marker—A number or letter made of lead or other high-density material that is placed on an object to provide traceability between a specific area on the radiograph and the part.

material density—A material's mass per unit volume.

milliamperes (mA)—The current applied to the filament in the cathode portion of an x-ray tube that controls the intensity of the x-rays.

object to film distance—The distance between the surface of the source side of the object and the film.

photon—A "packet" of electromagnetic radiation.

primary radiation—Radiation coming directly from the source.

radiographic contrast—The difference in density between an image and an adjacent area on a radiograph.

radiographic quality—A qualitative term used to describe the capability of a radiograph to show changes in the area under examination.

radiographic sensitivity—A general or qualitative term referring to the size of the smallest change in a test part that can be displayed on a radiograph.

secondary radiation—Radiation emitted by any substance as the result of radiation exposure by the primary source.

source—A machine or radioactive material that emits penetrating radiation.

source to film distance—The distance between the radiation-producing area of the source and the film.

step wedge comparison film—A strip of processed film carrying a stepwise array of increasing photographic density for comparison to radiographs for the purpose of estimating density.

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

target—That part of the anode of an x-ray tube that emits x-rays as a result of impingement of electrons from the filament.

transmitted film density—The density of radiographic film determined by measuring the transmitted light, usually through the use of a densitometer.

tube current—The current, measured in milliamperes, passing from the cathode to the anode during the operation of an x-ray tube.

XI. BIBILIOGRAPHY

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