
MODULE 18

RADIOGRAPHIC

INSPECTION



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MODULE 18**RADIOGRAPHIC
INSPECTION****CONTENTS**

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MODULE 18

RADIOGRAPHIC INSPECTION

Introduction

It has been pointed out in previous modules that a good visual inspection can be the most effective way of inspecting a welded product. But a visual inspection cannot, of course, detect defects below the surface of the weld. For many applications, therefore, *volumetric* nondestructive testing is required and one of the main methods for doing this is radiography.

Although the actual radiograph must be taken by a qualified technician, the inspector plays an important role in the application of radiography: verifying when and where it is to be done; checking reports and qualifications; discussing interpretation, and so forth. The inspector requires a sound knowledge of the practical aspects of applying radiography to welds and it is the intent of this module to discuss these aspects.

Objectives

After successful completion of this module you should be able to:

- Describe how radiography works
- Explain how images are formed and what controls their quality
- Discuss advantages and disadvantages of the method
- Recognize radiographic images of various defects
- Describe suitable techniques for different applications
- Discuss acceptance criteria, reports, and qualification requirements
- Describe basic safety practices.

Principles

BASICS OF RADIOGRAPHY

Since the discovery of X-rays by W. Roentgen in 1893 and gamma (γ) rays by Madame Curie and H. Becquerel in 1897, Radiographic Inspection (also called radiographic testing or 'RT') has been an invaluable aid in "seeing inside" a weld. To accomplish this, a source of ionizing radiation is placed on one side of the component and a radiographic film, enclosed within a lightproof container, is placed opposite the radiation source on the far side of the component as shown in Fig. 1. After a calculated period of time, the radiation source is removed and the film is chemically processed, revealing the status of the welded structure.

Radiographic Inspection can be performed with either X-rays or gamma rays. Both are electromagnetic waves, (see Fig. 2), the many forms of which include light, radio waves, and microwaves. The difference between the various forms is the wavelength with X- and

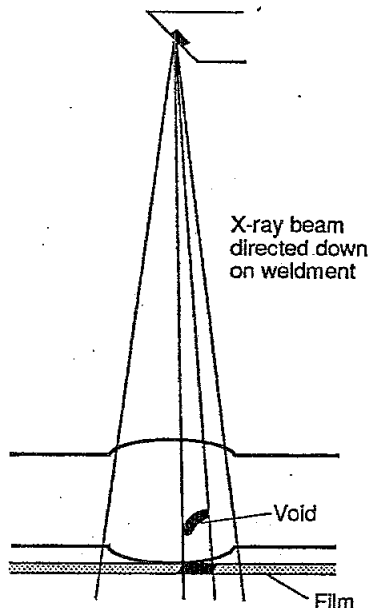


Figure 1. The radiographic principle.

Film will be darkened most under the void, and least through the thickest part of the weld.

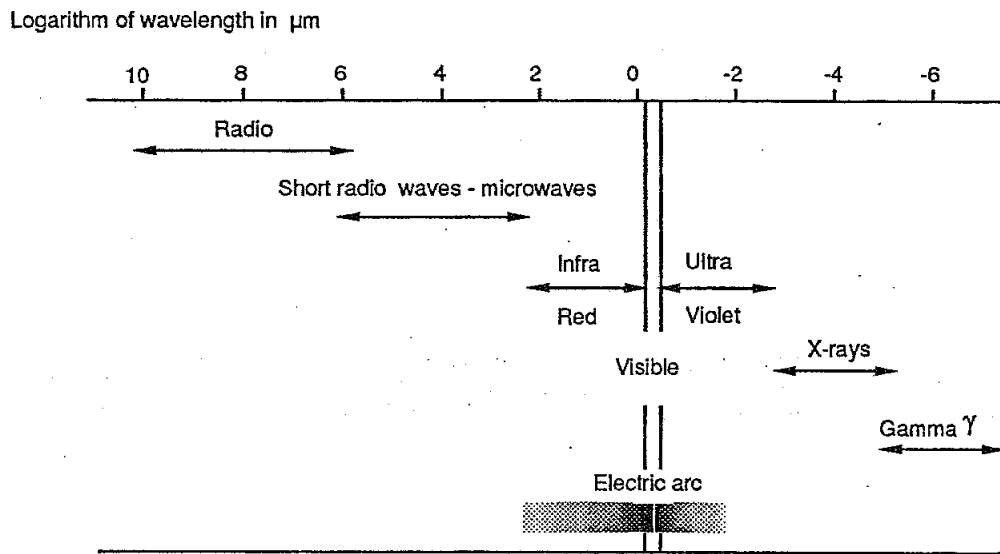


Figure 2. The electromagnetic spectrum.

Merits of radiography

gamma rays having among the shortest. This property of short wavelength enables the rays to penetrate and travel through various materials such as steel and other metals.

Compared with the other inspection methods, radiography has a number of advantages and disadvantages. The reasons for these will become apparent in the remaining sections of the module but the main ones are summarized in Table 1. It is clear from this that there will be situations where it is the preferred method of inspection but also cases where it would be a poor choice. An appreciation of the limitations, discussed in subsequent sections, is important in using the method effectively.

Table 1. Main advantages and disadvantages of radiography.

Advantages	Disadvantages
A volumetric method	Special, sometimes bulky equipment needed
Relatively quick	Safety precautions require work to stop during radiography
Provides permanent record	Some defects not reliably detected

X-ray equipment

X-rays are produced by the impact of high velocity electrons on a tungsten target. The electrons are accelerated towards the target by a high voltage (Fig. 3). The electron gun and target are sealed in a vacuum surrounded by a metallic shield with a window for the X-rays to exit. There is a control panel with adjustable controls to vary both the quantity and the quality of the X-rays and a timer to control the time (see Fig. 4). Heavy duty cables connect the panel to the X-ray tube head and

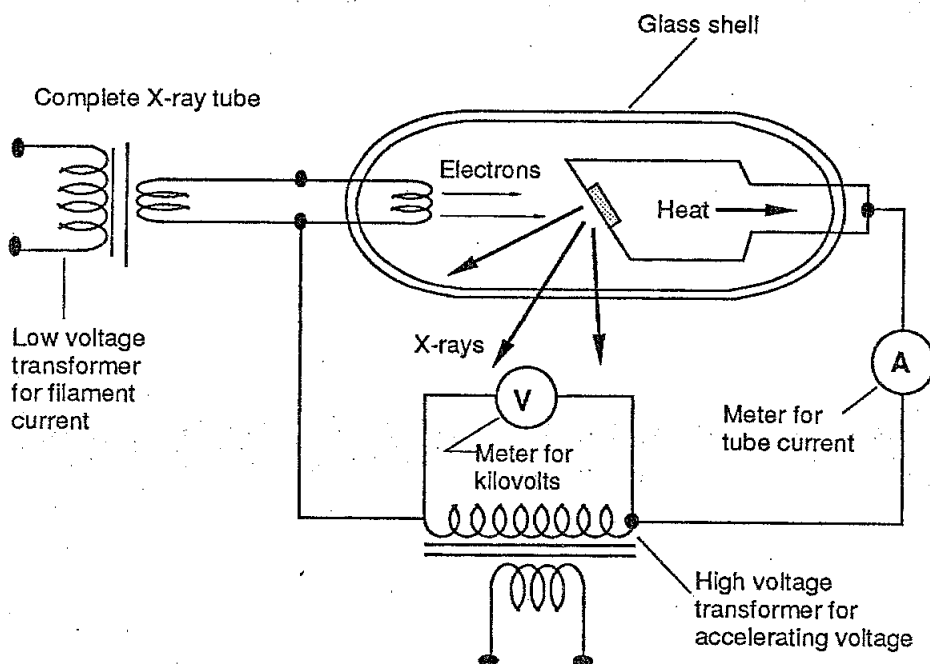


Figure 3. Principle of X-ray generation. Electrons are accelerated towards the anode when it is positive and their impact on the tungsten target generates X-rays.

the panel operates from a standard electrical supply, or in the case of site inspections, from a portable generator. The X-ray tube is supported by an adjustable stand. The main components of an X-ray machine are shown in Fig. 5.

When X-rays are generated, a substantial amount of heat is produced which must be removed. The tungsten target is embedded in a copper block to conduct heat away. Thus the overall size and weight of

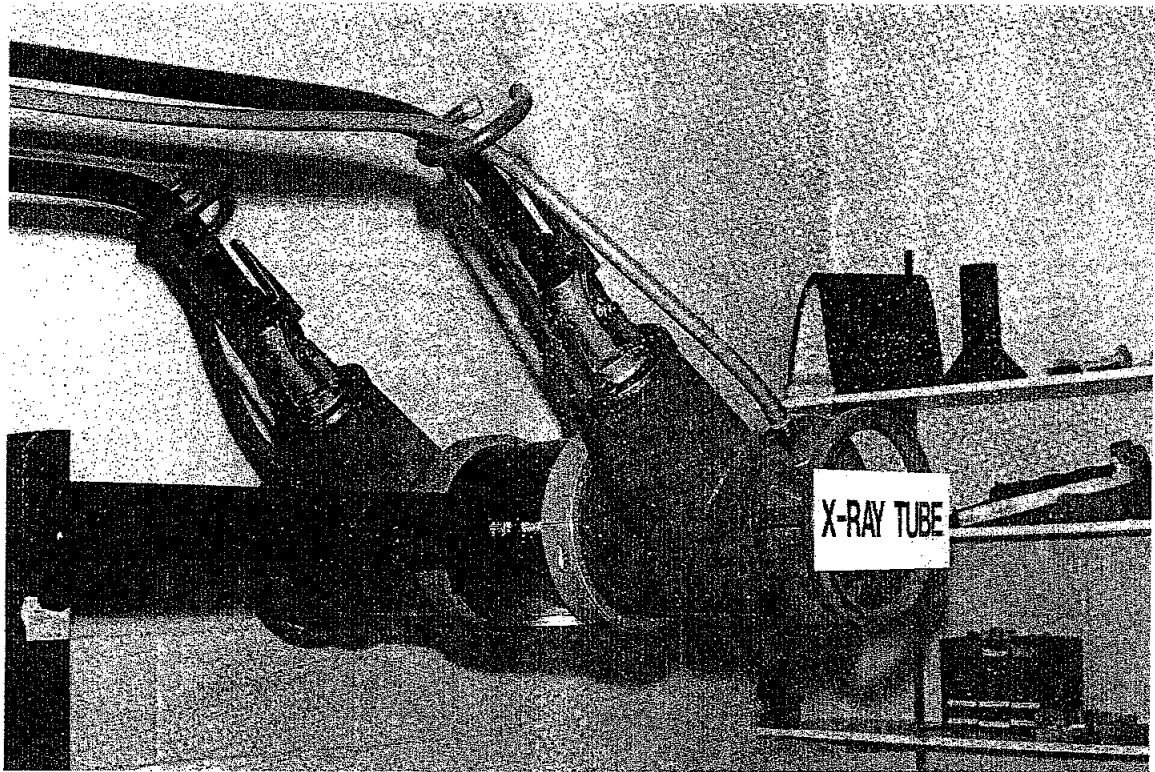


Figure 4. X-ray unit showing tube head and control panel.



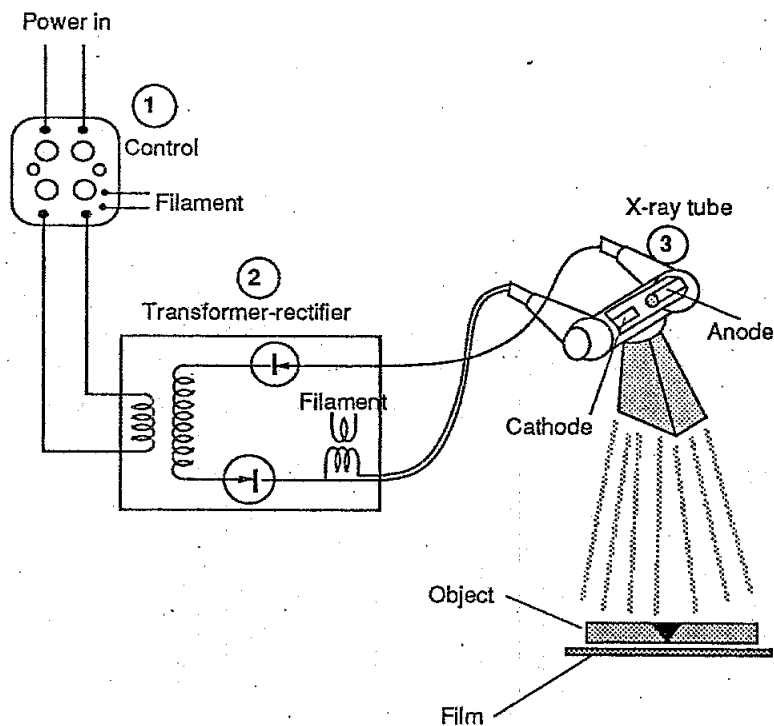


Figure 5. Diagram of an X-ray machine showing the main components.

the equipment is controlled by the cooling mechanism which can use air, oil, gas, or water. For thin materials small easily portable tubes employ air or gas inside the tube head. However, as the heat builds up with continuous use, the oil or gas expands and triggers contacts which

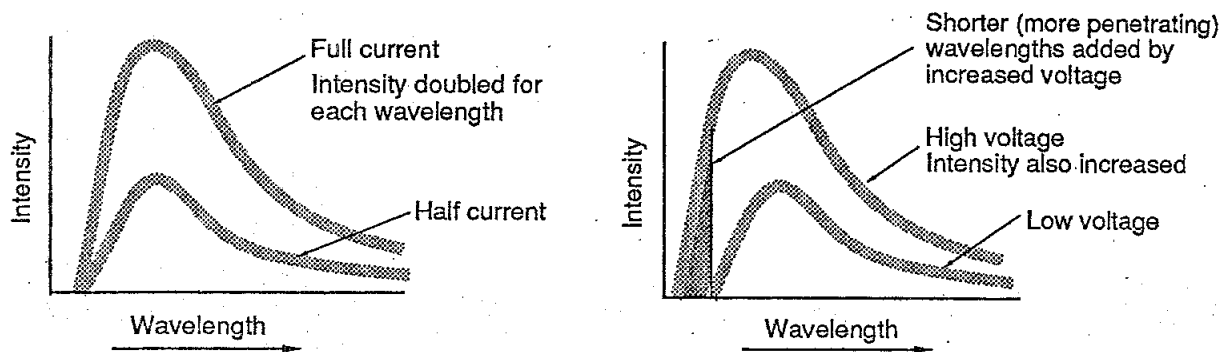


Figure 6. Effect of filament current and voltage on X-rays. Increasing the voltage decreases the wavelength which, in turn, increases the penetrating power.

automatically stop the equipment functioning until the temperature drops. With increasing thickness of materials the electrical generating requirements increase and more heat is generated thus increasing the cooling requirements. This, in turn, increases the weight of the equipment, ultimately reducing the portability.

The wavelengths produced from an X-ray tube depend largely on the voltage applied as shown in Fig. 6. Since shorter wavelengths have greater penetrating power, higher voltages are required for inspecting thicker materials. The thickness of material which can be inspected is generally related to the kilovoltage (kV) of the equipment (Table 2).

Table 2. Capacity of X-ray machines for steel.

Potential	Maximum Thickness of Steel	
80 kV	4.0 mm	0.15 in
100	7.5	0.30
150	19	0.75
200	25	1.0
250	50	2.0
400	75	3.0
1 000	125	5.0
2 000	250	10.0
15 000 to 24 000	500	20.0

Gamma ray sources

TEST QUESTION

Gamma rays are produced by the spontaneous disintegration of radioactive material. The most common industrial sources of γ -rays are radioactive isotopes of iridium (Ir^{192}) and cobalt (Co^{60}). The size of the radioactive material used is very small and consists of pellets which are encased in a stainless steel capsule. Since gamma rays cannot be switched off, the capsule is connected to a "pigtail" (Fig. 7) which is contained in a radiographic exposure device (Fig. 8). The pigtail has a mechanical adaptor at the end to connect to control cables.

The exposure device provides sufficient shielding through the use of very dense materials, such as lead or depleted uranium, to reduce the intensity of the gamma rays to an acceptable level. When the pigtail is positioned and locked within the exposure device, the device may be used as a transportation container if it is labelled in accordance with applicable provincial and federal transportation regulations.

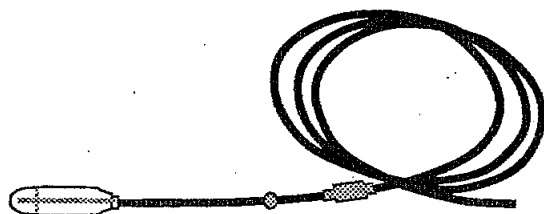


Figure 7. Typical gamma ray source with control cable.

The radiographic exposure device is a simple mechanical arrangement. The rear of the exposure device is unlocked and a projection cable can be attached to the rear of the pigtail. The length of the projection cable can vary but is generally 25 feet (7.5 m). This places the operating mechanism and the operating technician in a zone of reduced radiation intensity.

Both X- and gamma ray inspection can be carried out in specially designed facilities which incorporate thick shielding walls and electrical door interlocks where the operating technician has greater control over restricting access of non-authorized personnel, see Fig. 9. However, one of the great advantages of radiographic inspection is portability,

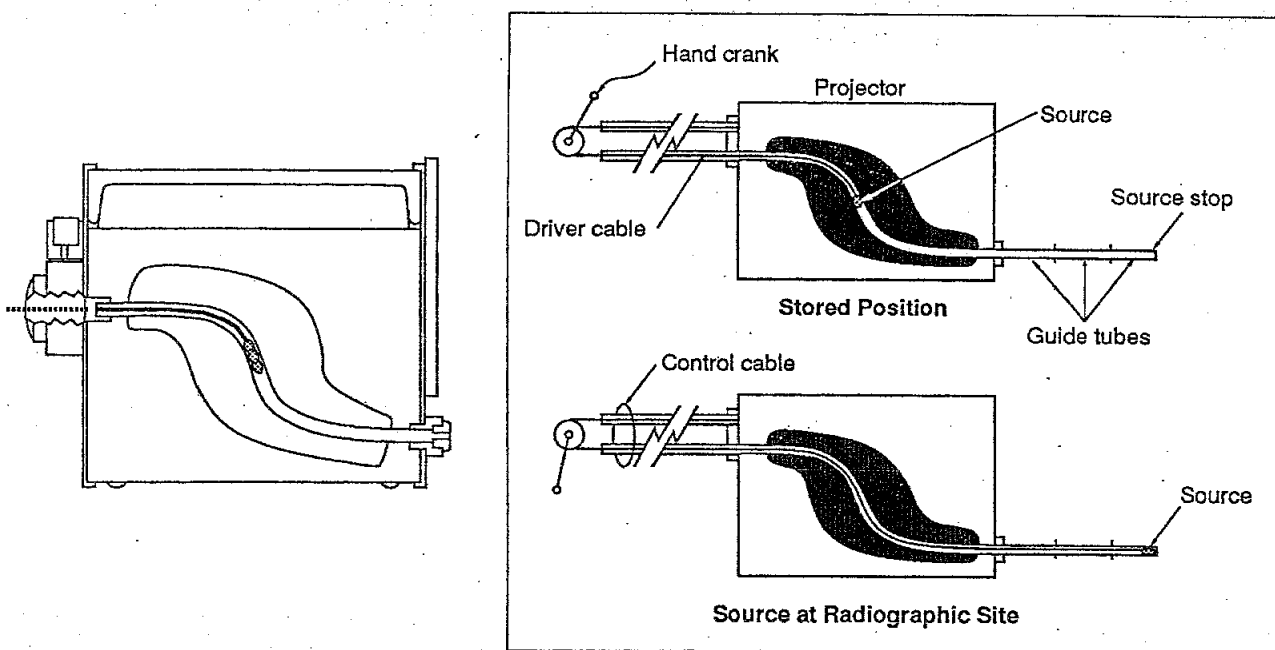


Figure 8. Example of exposure device (isotope camera) for shielding and exposing gamma ray sources.

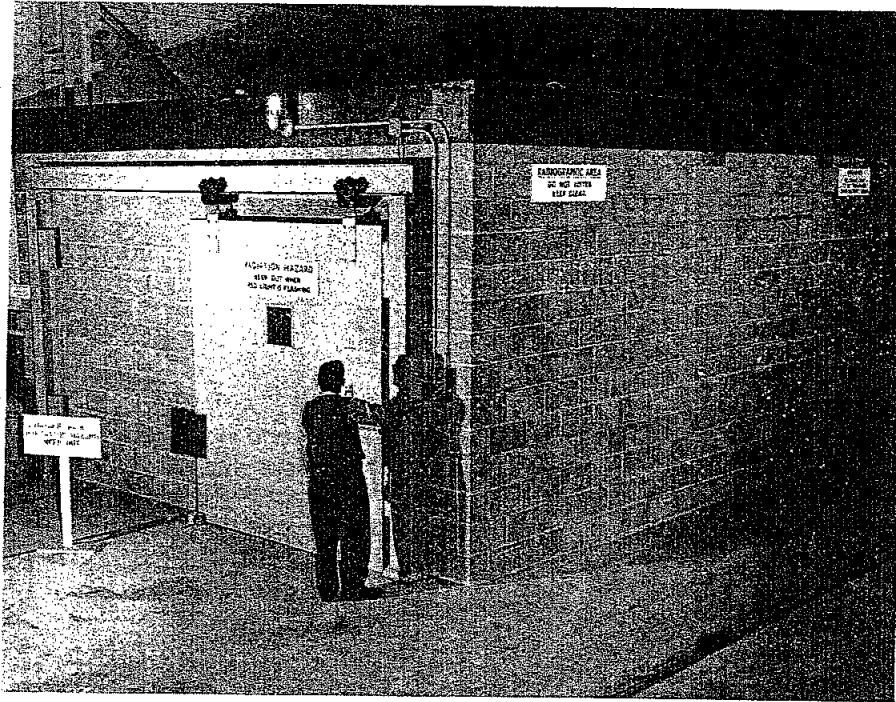


Figure 9. Shielded radiographic exposure room.

Image formation

and the same level of inspection can be carried out in fabricating shops, construction sites, or on pipelines. Gamma rays have greater penetrating capability but the sensitivity is less than for X-ray. The sidebar provides a comparison between X- and gamma ray radiography.

The value of radiography as an inspection tool depends critically on the quality of the image that is produced. It is important, therefore, to understand how the image is formed and what factors influence the quality. The image is formed by the variation in intensity of the radiation falling on different parts of the photographic film. Differences in intensity can arise because of differences in:

- the thickness of material the beam must penetrate
- the type of material through which the beam must penetrate.

Fig. 10 illustrates the two reasons for differences in intensity.

KNOW THIS PAGE

Comparison of X-rays and gamma rays

ADVANTAGES

Gamma Sources

- Small and portable
- No electric power required
- No electrical hazard
- Rugged
- Small initial cost
- High penetrating power
- Access into small areas with source tube
- Low maintenance costs

X-ray Units

- Radiation can be shut off
- Penetrating power (kV) is adjustable
- Can be used on all materials
- Provides radiographs with best contrast and sensitivity

DISADVANTAGES

Gamma Sources

- Radiation emitted continuously
- Radiation hazard
- Penetrating power cannot be adjusted
- Radioisotope decays in activity requiring replacement
- Radiographic contrast generally less than X-ray
- Cannot be used on all materials, e.g., aluminum

X-ray Units

- High initial cost
- Requires source of electrical power
- Equipment comparatively fragile
- Less portable
- Tube head usually large in size
- Electrical hazard from high voltage

Note: It is often found desirable to have both methods available. In deciding which method is to be used it is necessary to consider all the above features to decide which process best suits the application at hand.

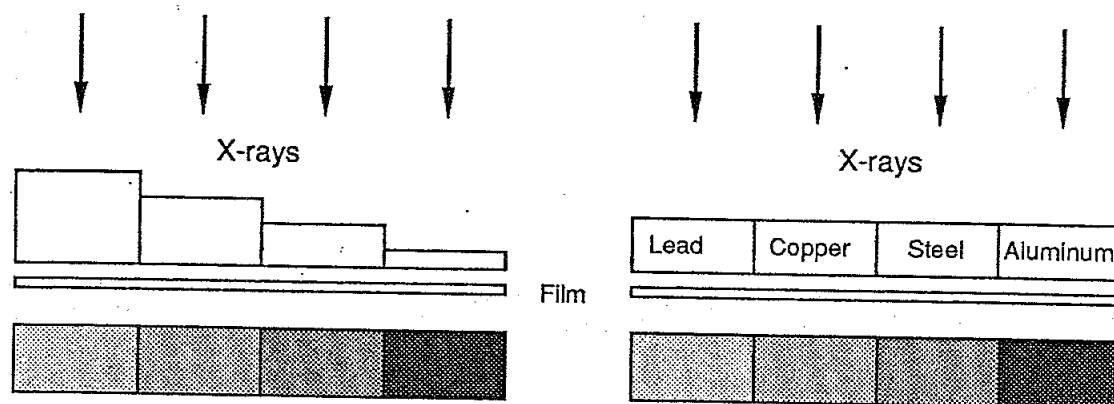


Figure 10. Variation in intensity of the beam reaching the film can result from differences in thickness or type of material.

Contrast

Thus differences in thickness or material give rise to *contrast* on the film. If the energy of the radiation, however, is too high there is little variation in the energy transmitted by different thicknesses and poor contrast results. Thus contrast is improved by using low energy levels. But a low energy increases the exposure time required for the film so in practice there is a compromise between the energy and the exposure time.

Note that the penetrating ability of the ray depends on its wavelength, the shorter wavelength having greater penetration. In an X-ray machine the wavelength is decreased by raising the voltage (kV) of the tube but this also raises the energy. Thus there is an optimum kV for each thickness to ensure penetration and achieve adequate contrast. Gamma rays have shorter wavelengths than X-rays and can be used on thicker material. But the contrast is generally poorer. Note also that the final resulting contrast also depends on the type of film used. Film contrast is the ability of the film to show a density difference for a given change in exposure. Film speed is the rate at which the film responds to radiation. A slow film speed generally results in a better quality radiograph but requires longer exposure times. The film type and speed should be specified in the radiography procedure and should be checked by the inspector.

Definition

Because the type of material through which the ray penetrates also affects contrast, the image may be able to identify certain materials in the weld. For example, a tungsten inclusion absorbs X-rays and so appears as a light disk on the film. Normal slag on the other hand, absorbs less rays than steel and therefore shows as a darker area on the film.

The second important aspect of image quality is *definition*. This is the sharpness of the edge of the image. A fuzzy image has poor definition and may not reveal the defect clearly even though the contrast is adequate. Poor definition can be caused in a number of ways. First, there is *inherent unsharpness* due to the ray passing through the photographic film itself. As the ray strikes the film, free electrons are released which affect the film in the surrounding regions. This type of unsharpness cannot be avoided.

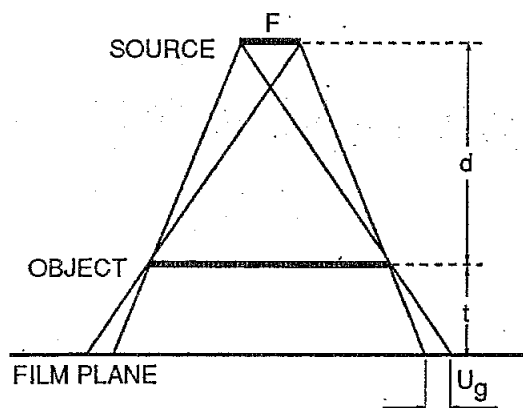


Figure 11. Geometric construction for determining geometric unsharpness(U_g).

Second, there is *geometric unsharpness*. This occurs because the source of radiation is not a true point source but has a finite size. Fig. 11 illustrates how this causes fuzziness at the edge of the image. The amount of geometric unsharpness U_g , depends on the size of the source F , the object-to-source distance d , and the object-to-film distance t , and is given by

$$U_g = \frac{Ft}{d}$$

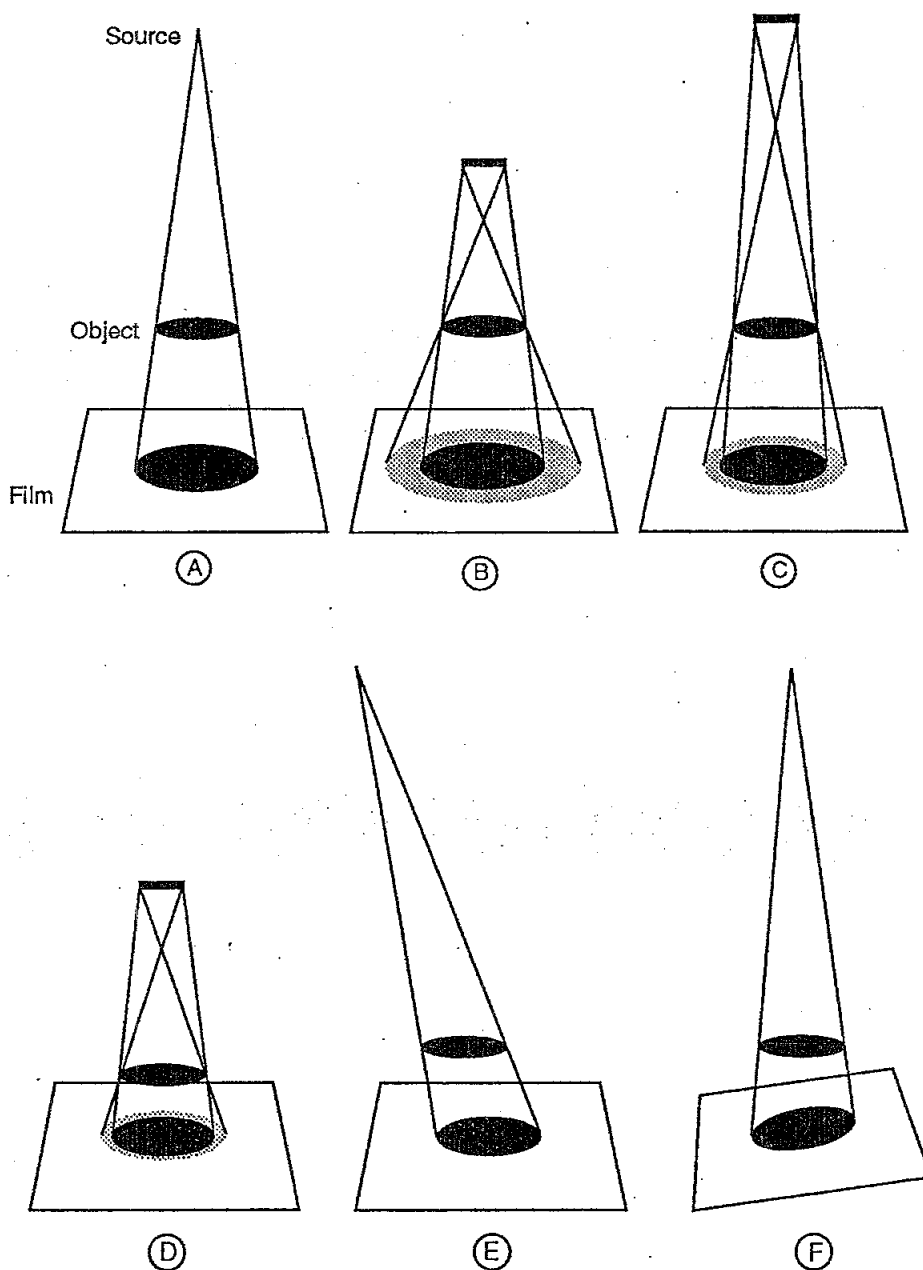


Figure 12. Illustration of the general geometric principles of shadow formation. In A the source is a point source and a sharp image is formed. In B the source has a finite size resulting in geometric unsharpness, (the fuzzy area is sometimes called 'penumbra'). In C the source is moved further away causing a decrease in the unsharpness. In D the object is closer to the film which also decreases the unsharpness. Sketches E and F illustrate the effect of an inclined beam or an inclined film on the shape of the image.

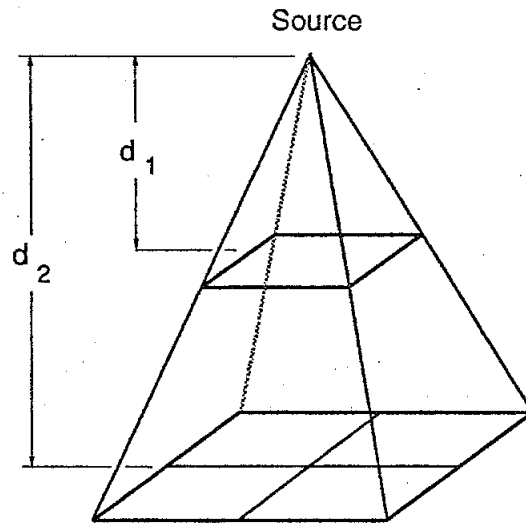
If the film is placed directly against the weld the maximum distance from the film to a defect (t) is equal to the plate thickness. Note that in thick plate a defect in the bottom of a weld close to the film will appear sharper than one at the top. Fig. 12 illustrates how geometry can affect the quality of image produced.

Table 3. Control of geometric unsharpness.

<u>CONDITION</u>	<u>CONTROL</u>
1) Physical size of the radiation source	Should be as small as possible
2) Distance from the radiation source to the side of the specimen facing the source	Should be as great as possible—within reasonable exposure time
3) Distance from the side of the specimen facing the source to the radiographic film	Should be as small as possible—dependent upon geometry of the specimen

Since the source size is determined by the equipment and the plate thickness is given, the only means of controlling the degree of geometric unsharpness is by changing the source-to-weld distance (Table 3). Increasing this reduces U_g and produces a sharper image. But it also reduces the intensity of the rays reaching the film (see Fig. 13) and increases the exposure time required. In practice, therefore, it is usual to calculate the minimum source distance required to give the specified degree of unsharpness since this gives the minimum exposure time. For example, CSA W59-89 specifies a maximum unsharpness of 0.127 mm (0.005 in.) for a thickness of 25.5 mm (1 in.). For a source size of 4 mm (0.157 in.) the minimum source distance would be

$$d = \frac{Ft}{U_g} = \frac{4 \times 25.5}{0.127} = 803 \text{ mm (32 in.)}$$



$$d_2 = 2d_1$$

$$\text{Area at } d_2 = 4 \times \text{Area at } d_1$$

$$\text{Intensity at } d_2 = 1/4 \times \text{intensity at } d_1$$

Figure 13. The effect of distance on intensity. The intensity follows the 'inverse square law.' Thus doubling the distance reduces the intensity four times.

Scattered radiation

THESE WILL BE
TEST QUESTIONS.

A further contribution to poor image quality can come from scattered radiation. Any material in the path of the beam can cause scattered rays which can affect the film and image quality (Fig. 14). Rays may be scattered from behind the weld (back scatter) or from the weld itself (forward scatter). Back scattered radiation is reduced by a lead sheet on the back side of the film and forward scattered radiation is reduced by a thin lead sheet on the front side of the film. The thin sheet of lead is not so thick as to absorb the main beam but will absorb the scattered radiation since it has a larger wavelength and lower energy.

Image intensifiers

Contrast in an image may be increased by using image intensifiers. The thin lead screens used to reduce forward scattered radiation also intensify the image by emitting electrons when struck by the radiation. Thus they serve a dual purpose. In addition, fluorescent screens intensify the image by emitting light when struck by radiation. Fluorescent image intensifiers, however, reduce the definition in the image because the light emitted is diffused through the screen.

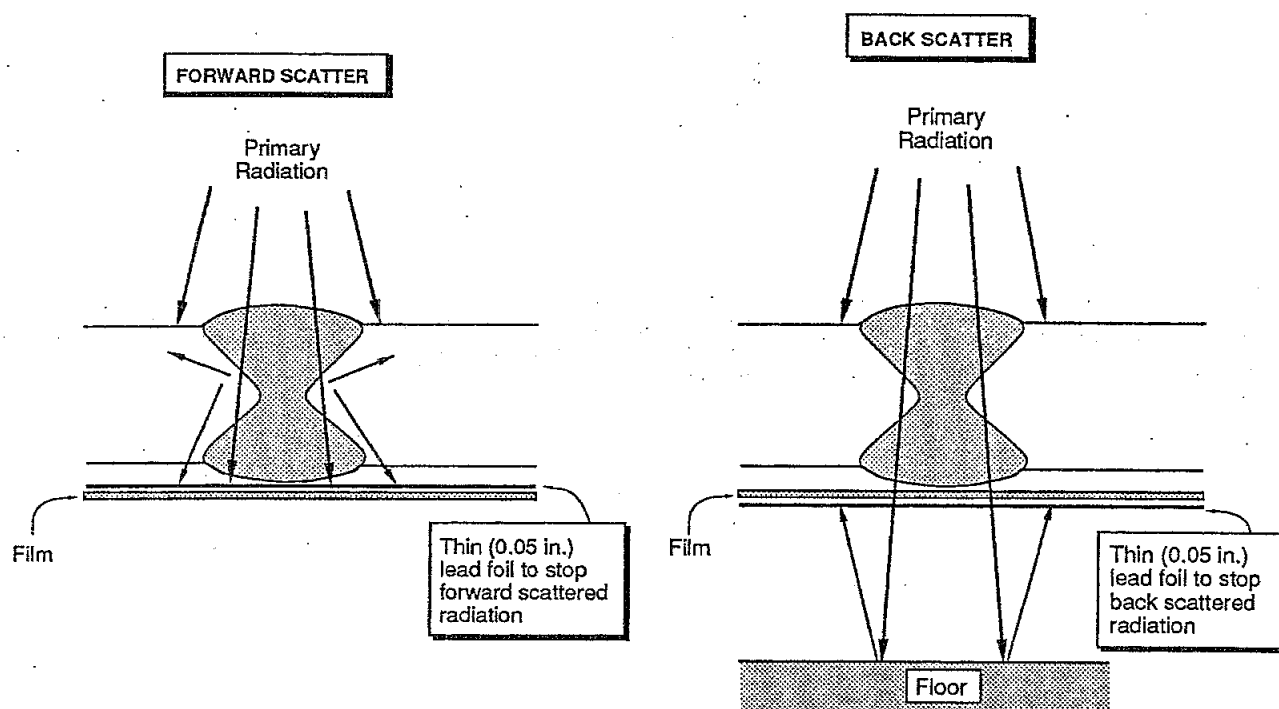


Figure 14. Scattered radiation can reduce image quality. The effects can be minimized by using thin lead sheets as shown.

Verifying image
quality

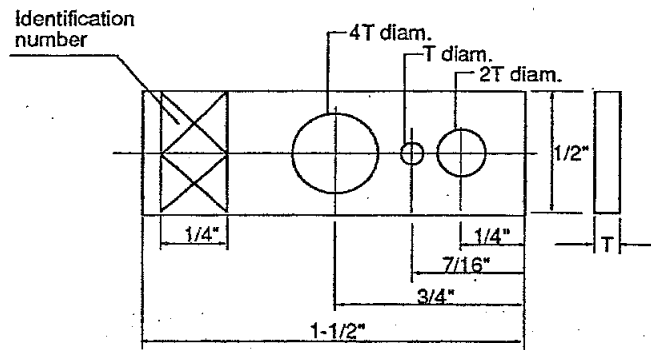
I.Q.I OR
PENETRIMETERS
WILL BE T.Q.

To verify that adequate sensitivity (i.e., contrast and definition) has been achieved in the image an Image Quality Indicator (IQI) or penetrometer is used. This device is placed alongside the weld being inspected and the radiographic image is obtained simultaneously with the weld image. The image quality indicator is made from material radiographically similar to the weld specimen. The dimensions are such that the size of the IQI is related to the thickness of the weld specimen and is generally expressed as a percentage of the specimen thickness.

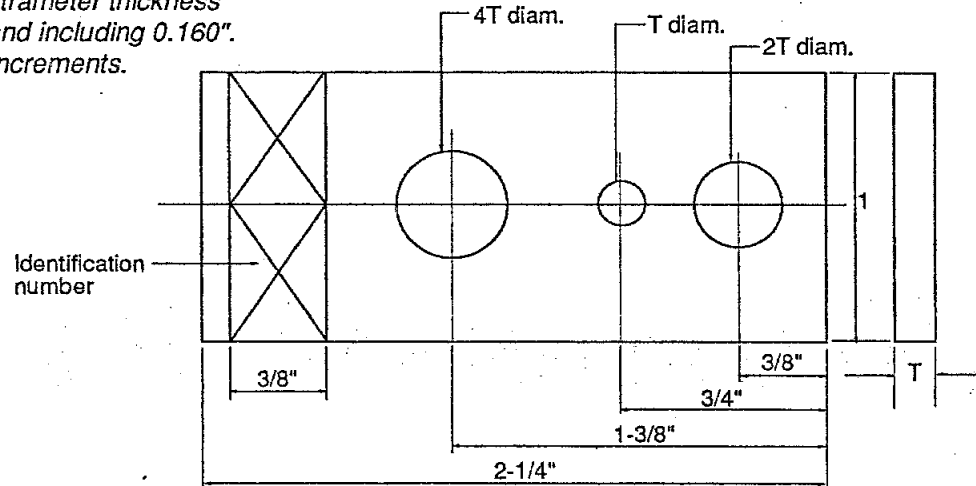
The use of the IQI fulfills the definition of radiographic sensitivity: the smallest change in specimen thickness that can be seen on a radiograph, usually expressed as a percentage of the material thickness being inspected. For example, a 2% sensitivity on 25 mm thickness means a thickness change of 0.5 mm is detectable.

The most commonly used IQI's are the ASTM plaque type and the wire type, see Fig. 15. Selection and use is governed by the applicable code or standard determined by the end use of the component.

Design for penetrameter thickness
from 0.005" and including 0.050".



Design for penetrameter thickness
from 0.060" to and including 0.160".
Made in 0.010 increments.



For details of wire
diameter see, for
example, ASTM E747

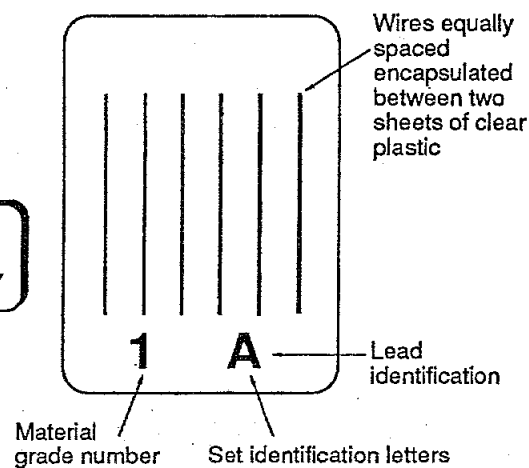


Figure 15. Image Quality Indicators (IQI) or Penetrameters (ASTM).

Radiographic Inspection

Table 4. Standard penetrameter thickness requirements (CSA W59-M89).

Material Thickness Range (mm)	Penetrameter		Essential Hole (See Notes)	
	Thickness (mm)	Number	2T (mm)	4T (mm)
Up to 13	0.255	10	0.510	1.02
Over 13 to 16	0.320	12	0.640	1.28
16 to 19	0.380	15	0.760	1.52
19 to 22	0.445	17	0.890	1.78
22 to 25	0.510	20	1.02	2.04
25 to 32	0.635	25	1.27	
32 to 38	0.760	30	1.52	
38 to 51	0.890	35	1.78	
51 to 64	1.02	40	2.04	
64 to 76	1.15	45	2.30	
76 to 102	1.27	50	2.54	
102 to 152	1.52	60	3.04	
152 to 203	2.03	80	4.06	

Notes:

- (1) For X-ray the image of the 2T hole shall appear clearly on the radiograph.
- (2) For gamma ray the steel thickness less than 32 mm the image of the 4T hole shall appear clearly on the radiograph.
- (3) For gamma ray the steel thickness equal to or greater than 32 mm the image of the 2T hole shall appear clearly on the radiograph.

The thickness of the Image Quality Indicator is selected from the appropriate table listed in the governing code and is designated by the number on the IQI which will be projected onto the film. CSA W59 requirements are shown in Table 4. The drilled holes are numerically related to the thickness of the IQI, e.g., the largest hole diameter is four times the thickness of the IQI, the next diameter is two times the thickness of the IQI with the smallest diameter being equal to the thickness of the IQI.

The sensitivity requirements specify that the outline of the IQI and the required hole must be clearly distinguished according to the applicable code.

It should be noted that the purpose of the IQI is to verify that the correct procedure and technique have been followed. It is *not* intended to judge discontinuity size. As most radiographic inspections are not performed during regular hours, thus rarely witnessed, the radiographic image of the IQI is the only verification that the inspection was carried out as intended.

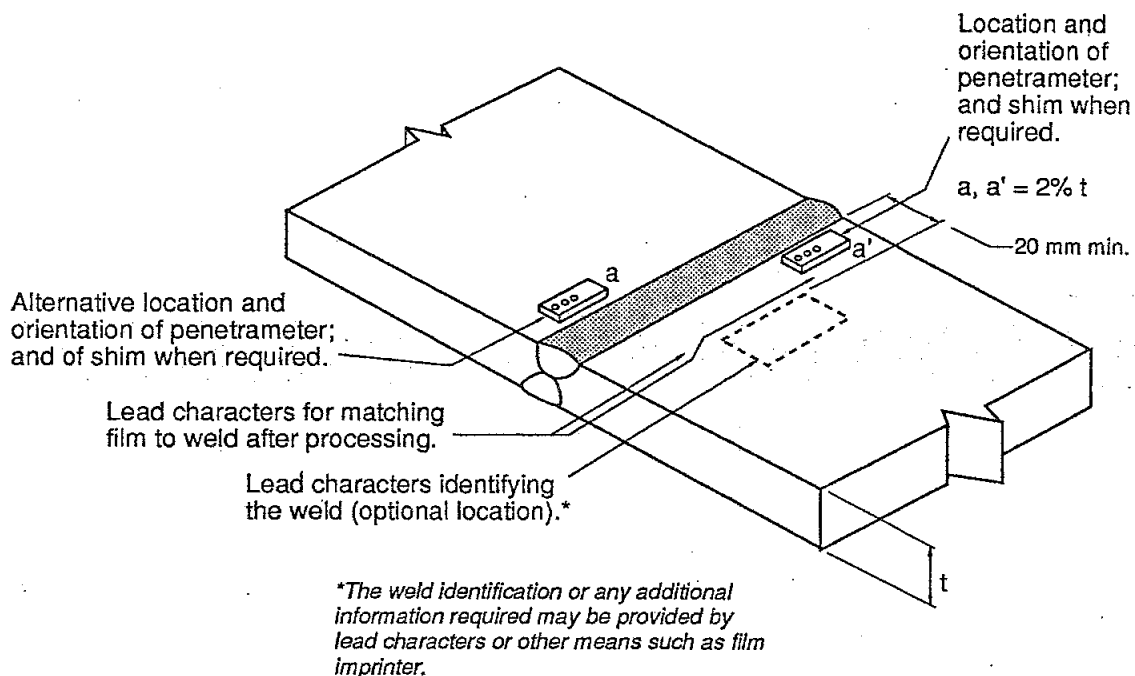


Figure 16. Location of penetrameters (CSA W59-M1989) for plates of equal thickness.

* General rules that apply to the use of IQI's are:

- Location of the IQI should be in the worst geometrical position — at the outer edge of the radiation beam. Fig. 16 shows the location as required by CSA W59-M1989.

Radiographic Inspection

QUESTION
WHERE IS THE USUAL
LOCATION FOR THE
I.Q.I.

ANSWER
ON THE SOURCE SIDE

- IQI should be made from material which is radiographically similar to the specimen material.
- IQI should be placed on the surface of the specimen facing the source of radiation. If this is not physically possible, as in the case of a contact exposure on a four inch diameter pipe weld (discussed in a later section), then the IQI may be placed on the film side of the specimen. When this situation occurs the IQI must be reduced one size.

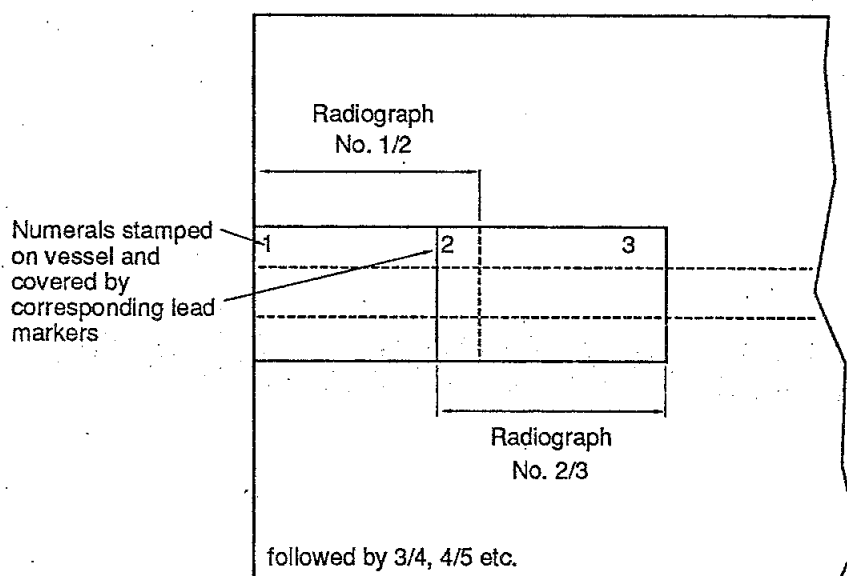


Figure 17. Method of identification of overlapping radiographs on a seam weld.

When seam welds are radiographed the individual shots must be overlapped as shown in Fig. 17. Each section must be identified on the weld and on the radiograph.

Film processing

After exposure, the film is chemically processed to develop the image on the film. Great care must be taken to follow the approved procedure as developing artifacts may be caused leading to misinterpretation. Radiographic film is sensitive to light and must be handled and processed under filtered light in a darkroom.

Film processing and handling marks

(a) DARK SHADOWS

Appearance of Defect	Probable Cause	Suggested Preventive
Finely mottled fog.	Stale film.	Use fresh film; do not hold too large a stock.
Fog on edge or corner of film.	Exposure to white light; faulty closure of good cassette or use of defective cassette.	Handle film in proper safelighting conditions; fasten cassettes properly; repair or replace faulty cassettes.
General fog with or without reflections from surface below it.	Exposure too near (or for too long) to safelight or to overbright safelight; general fog may also be due to over-development or to using old film which may have been badly stored.	Use recommended safelight under the conditions indicated by the film manufacturer. Use fresh film free from fog; develop for recommended time at recommended temperature.
Dark circular or pear-shaped marks.	Developer splashes before immersing whole film in developer.	
Dark spots or areas, sometimes, marble-like.	Insufficient fixation.	Fix for correct time. If this fails use fresh fixing solution.
Dark branched lines, dark spots.	Marks due to static electrical discharges.	Avoid rubbing or sliding one film on another or drawing film quickly from wrapping paper.
Dark lines or cracks.	Scratches or cracks in lead intensifying screens.	Replace screens.
Dark fingerprints.	Film touched before development with fingers contaminated with chemicals, for example, certain metal salts.	Handle film by the edges with clean hands and use the protective folder as long as possible.
Dark spots or streaks.	Contamination of film by metallic particles or metallic salts.	Use only stainless steel, nickel or plastic stirrers, etc. Avoid chipped enamel containers for fixing solutions.

Film processing and handling marks

(b) LIGHT SHADOWS

Appearance of Defect	Probable Cause	Suggested Preventive
Light areas usually crescent shaped.	Pressure marks due to faulty handling of film, for example, buckling or localized pressure on the film or to a residue of fixer on the hanger from previous use.	Handle film with care; moon-shaped pressure marks are avoided by handling the film by one corner and by keeping it flat. Rinse and dry hangers before using.
Light circular patches.	Air bubbles on film during development.	Agitation immediately on immersion during development.
Light fingerprints.	Film touched before development with greasy fingers.	See defect, 'Dark fingerprints.'
Circular or 'drop'-shaped light patches.	Splashes of water or fixer on film prior to development.	
Light spots or areas.	Dust or paper between the film and the intensifying screens.	
Light spots or lines.	Spots on, or cracks in, fluorescent intensifying screens.	Use new screens if marks cannot be removed by washing with a good soda-free soap.
Light spots or streaks.	Contamination of film surface with oil before development or oil in the developer.	Handle film only with clean hands; keep developer free from contaminants.

Processing takes place in three stages: first, the film is immersed in a developer—typically for five minutes at 20°C—until the image appears. Next, the developer action is halted by immersion in a stop bath. Third, the film is immersed in the fixer solution which prevents any further change in the film. After processing, all traces of chemicals are removed by immersing in a tank of clean flowing water. The film is finally immersed in a wetting agent and water solution (to prevent watermarks) then dried.

Film processing and handling marks

(c) MISCELLANEOUS

Appearance of Defect	Probable Cause	Suggested Preventive
Sharply outlined light or dark areas.	Non-uniform flow of developer over film when immersing it in the developer.	Maintain the uniform flow of developer over the film when immersing in it, and agitate the film during development.
Small depressions with black edges.	Bacterial action in processing, generally in tropical climates.	Avoid washing in water which is too warm and avoid drying in too damp an atmosphere.
Wavy marble-like marks, increased density below light areas, reduced density below dark areas.	Insufficient agitation of developer during development of film.	
Solarization (tone reversal).	Lengthy exposure to unsafe light after exposure.	Avoid light fogging: check safelights.
Reticulation (like grain of leather).	Differences in temperature between successive baths.	Keep solution temperatures uniform.
Images of wood grain, wall-bricks, etc.	Previous exposure of film to X-rays or gamma rays.	Store films away from X-ray and gamma ray sources.

Handling of film

Radiographic film must be handled carefully. Avoid moist or dirty fingers. Do not draw the film rapidly from cartons or film cassettes. Quick movements can cause friction-static which will mark the film with circular tree-like markings. Dirty hands can transfer dirt or grease to the film. All film should be handled by the corners. Film must not be crimped before *or* after exposure—this will lead to pressure marks. All film should be handled and kept on the dry side of the darkroom until ready for processing as splashes from the developer can lead to dark spots on the film.

Improperly processed films

Failure to agitate during each stage of processing can lead to streaks and uneven density. Water spots and streaks will result if a wetting agent is not used. Yellow stains can result from processing in old developer; failure to use a stop bath, or using an old bath. The most common yellow stain is from exhausted fixer.

Too high a temperature of the developer can lead to an overall fog and a low temperature can cause poor contrast. The sidebars summarize some processing and handling problems.

Viewing

Radiographs must be viewed with a proper viewer (Fig. 18), preferably with a means of controlling the light intensity. You cannot view a radiograph properly by holding it up to a light or a window! The viewer should be located in a special viewing room with subdued lighting, good ventilation, and a convenient writing area.

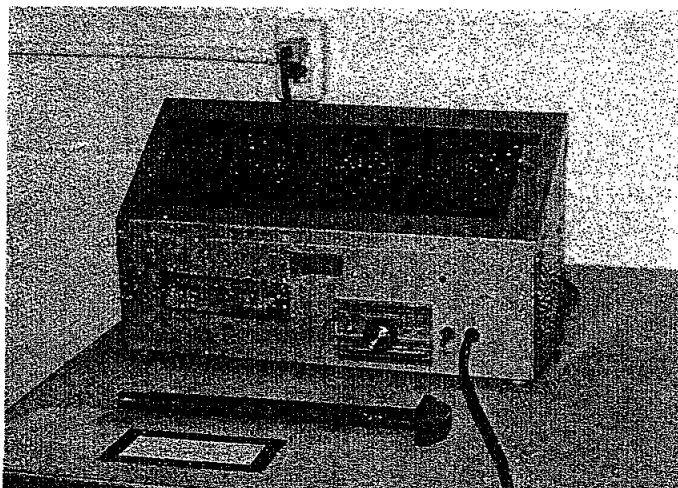


Figure 18. Typical radiograph viewer.

There are some simple rules for viewing which should be followed by the observer:

- Before removing a radiograph from the illuminator, slip another one beneath it or shut off the light source by means of a foot control. This prevents the eye from being subjected to extremely bright light.
- Cut off the glare from lighter areas and around the edges of the film by masking.

- The viewing room should be illuminated by a low intensity light source giving no front reflection from the film.
- Allow five to ten minutes for the eyes to become accustomed to the subdued lighting after coming in from full daylight.

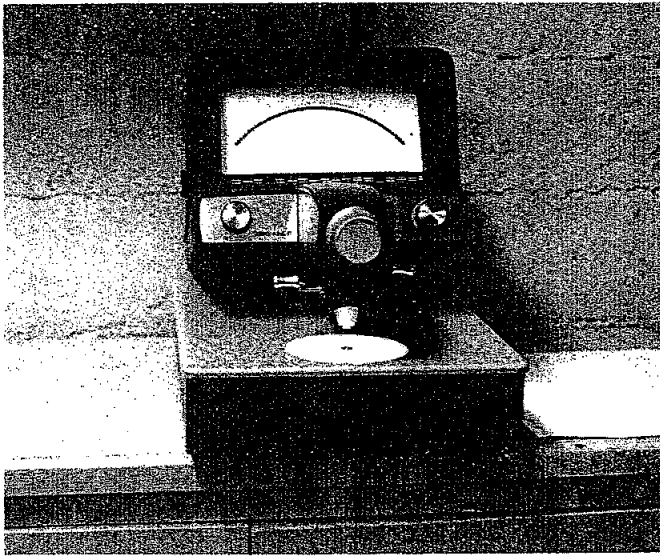


Figure 19. Densitometer for determining film density.

Q. WHAT INSTRUMENT IS USED TO DETERMINE FILM DENSITY.

A. DENSITOMETER.

Density

The degree of blackness on the film is known as the *density*. It can be measured with an instrument known as a densitometer (Fig. 19) and is expressed as a number (on a logarithmic scale). The range of acceptable density on a radiograph is usually specified. For example, CSA W59-89 requires the density to be in the range 1.5 to 3.5. The International Institute of Welding has given recommendations for the viewer brightness according to the film density. The recommendations state that the luminance of the illuminated radiograph should not be less than 30 candelas/metre² and whenever possible 100 cd/m² minimum. To achieve this the illuminator brightness must be:

For film density	1.0	brightness	=	300 cd/m ²
"	2.0	"	=	3 000 cd/m ²
"	3.0	"	=	30 000 cd/m ²

Vision requirements

Anyone interpreting a radiograph must have adequate eyesight, wearing glasses if necessary. Minimum requirements are normally detailed in the applicable standard. An inspector, even though not formally interpreting radiographs, must meet minimum vision requirements to be certified under CSA W178.2 (see Module 16).

For the interpretation of fine detail a low power (i.e., $\times 4$ to $\times 8$) magnifying glass can be used.

Interpretation of discontinuities

Interpretation of the radiograph is usually done by a certified radiographer but the inspector is often involved in reviewing radiographs and should be able to recognize the images of weld defects.

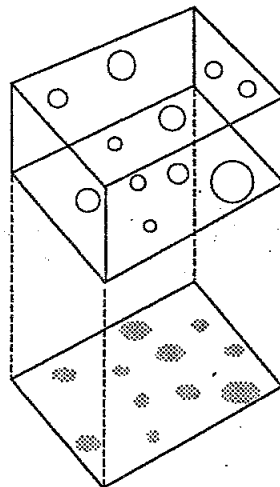


Figure 20. All discontinuities in a volume are projected onto a single plane thereby exaggerating the apparent density of flaws.

During interpretation it must be remembered that a radiograph illustrates a three-dimensional object in two dimensions, and all defects occurring throughout the complete depth of weld appear in one plane. This can exaggerate the apparent density or spacing of flaws (Fig. 20). Experience and knowledge of the welding procedure employed assists in assessing the vertical distribution of defects.

The objective of radiography is *volumetric* inspection but the interpretation of radiographs can be hampered by the images of *surface* features. Surface condition prior to radiography is therefore very important (Fig. 21).

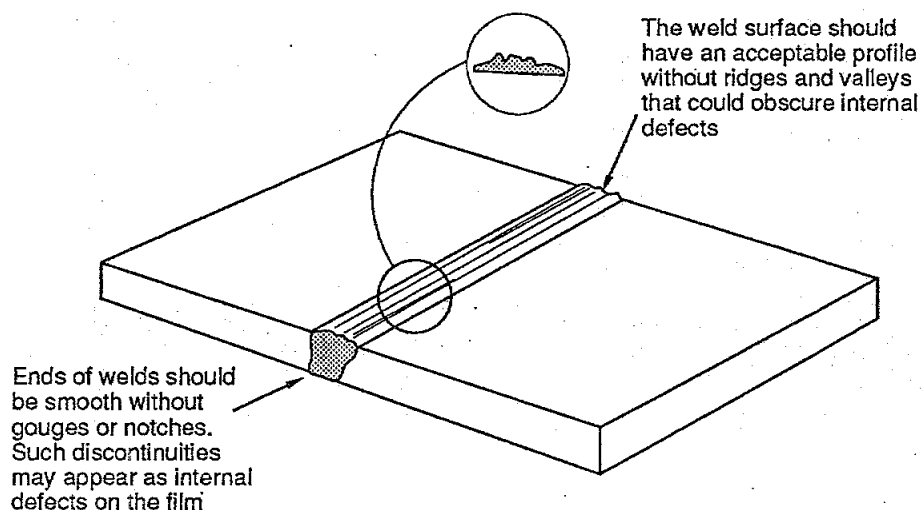


Figure 21. Surface condition prior to radiography is very important.

TEST QUESTIONS

A thorough visual inspection of the weld surface will detect the following discontinuities and will allow them to be rectified *before* radiography is performed: undercutting, incompletely filled groove, chipping or grinding marks, spatter, overlap, crater cracks, and misalignment which could result in difficulty in interpreting the radiograph.

Film indications produced by surface defects are as follows:

- Undercut produces a dark line usually broad and diffuse along one or both edges at the junction of the weld bead and the parent metal (Fig. 22).
- Weld spatter produces round light indications on the weld image and adjacent metal (Fig. 23).
- Suck-back shows as a broad darker area along the centre of the weld (Fig. 24).
- Chipping marks produce round or elongated dark spots which are easily confused with internal defects. However, chipping hammer marks usually occur on both the weld and parent plate, while internal weld defects, of course, do not.

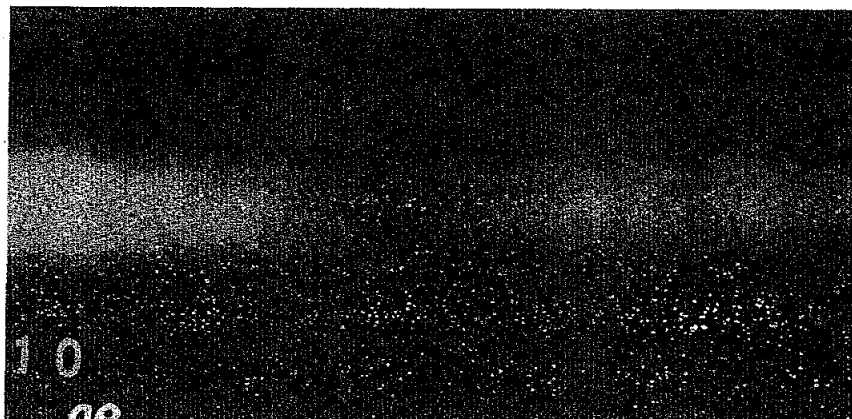


Figure 22. Radiograph showing undercut along the upper edge of the weld. Note the image of the penetrameter in the lower left corner.

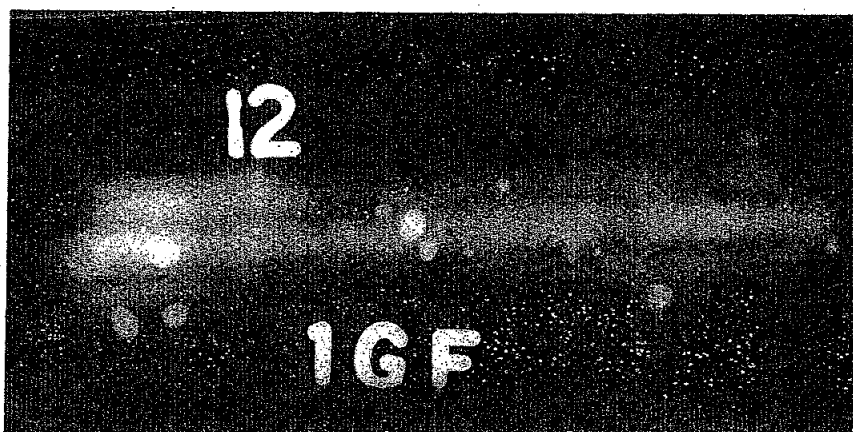


Figure 23. Radiograph showing spatter.

- Surface cracks produce a fine dark line either straight or irregular, tapering at the ends and possibly discontinuous (Fig. 26).
- Surface porosity is typified by rounded dark indications.

Some of the images formed by internal discontinuities are shown in Figs. 25 to 35.

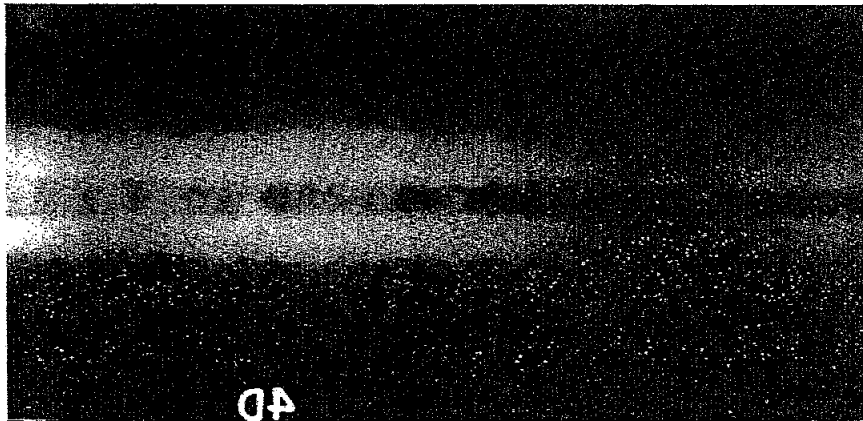


Figure 24. Radiograph of suck-back.

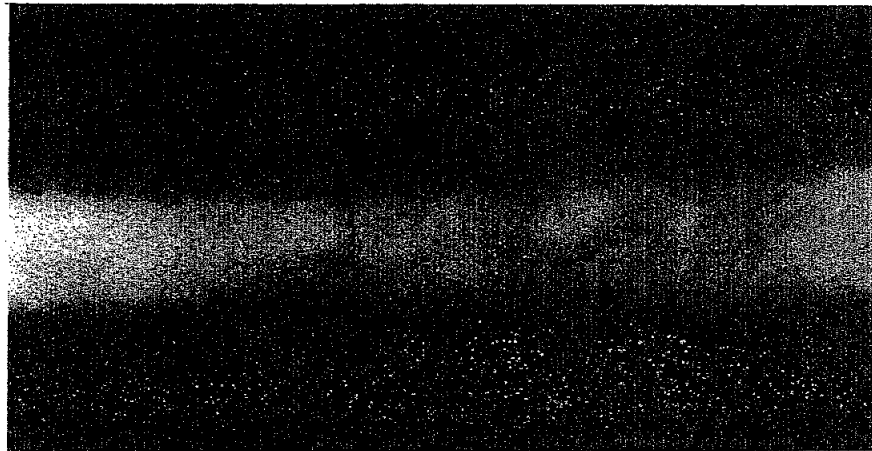


Figure 25. Radiograph of transverse crack.

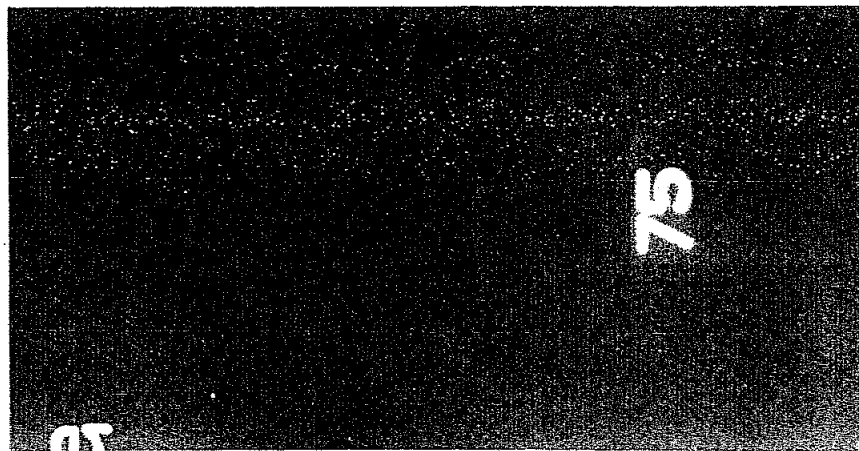


Figure 26. Radiograph of longitudinal surface crack.

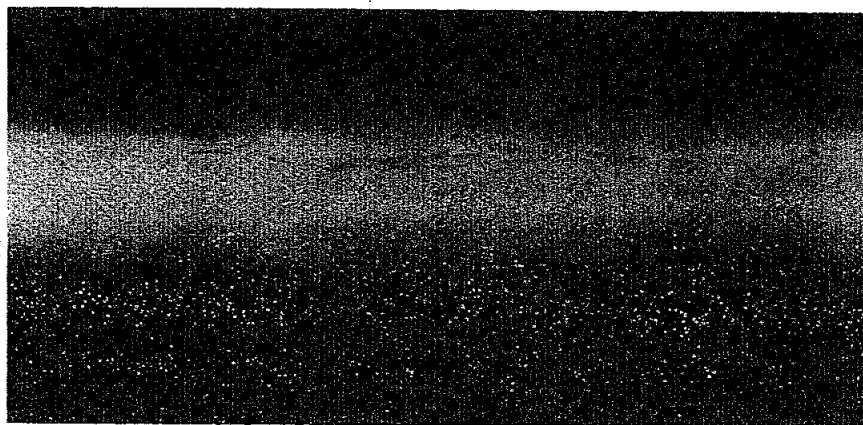


Figure 27. Radiograph of root crack.

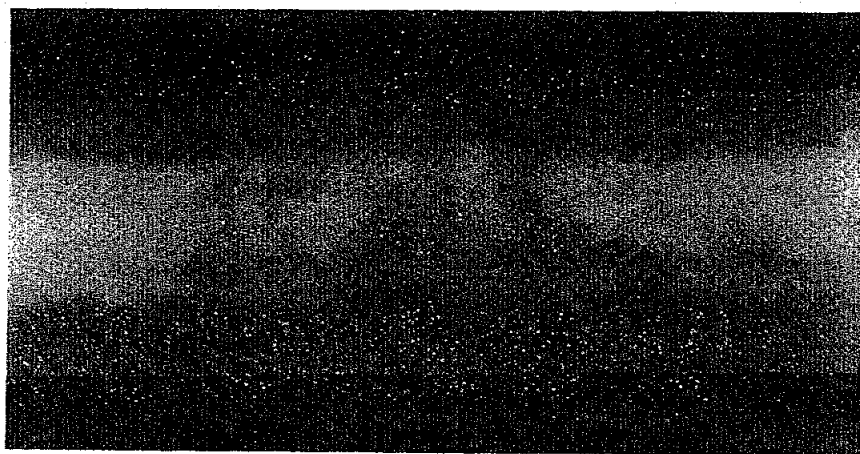


Figure 28. Radiograph of crack in parent metal adjacent to a weld.

Internal discontinuities

- Internal cracks appear as fine dark lines, either straight or irregular. Cracks are classified as longitudinal, transverse, root or crater cracks depending upon direction and location (Figs. 25 to 28).
- Porosity or gas pockets in a weld show on the radiograph as round or slightly elongated dark spots. These may be fine or coarse and may be widely scattered, in line, or grouped in a cluster. Greatly elongated holes called piping or worm holes may also occur (Figs. 29 to 31).

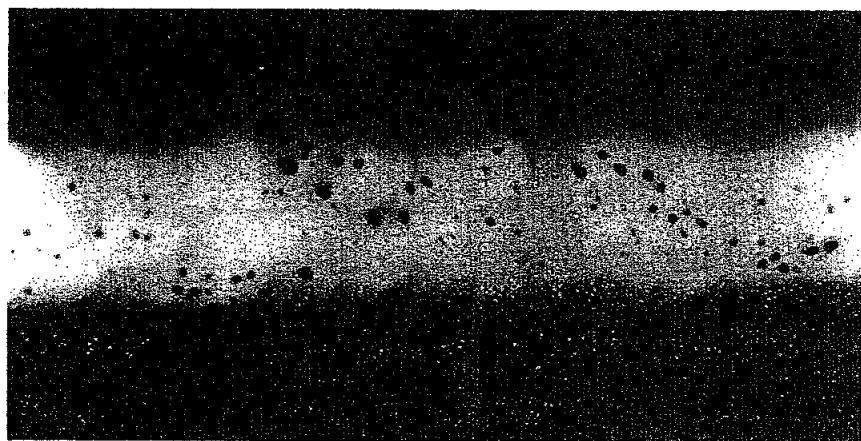


Figure 29. Radiograph showing scattered porosity.

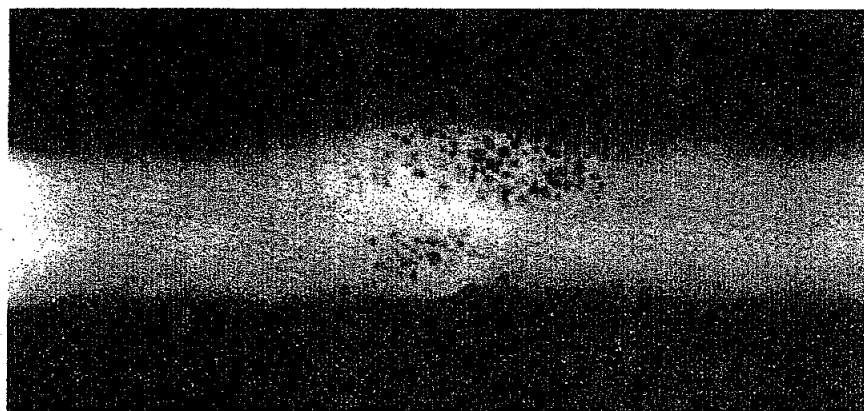


Figure 30. Radiograph showing starting porosity.

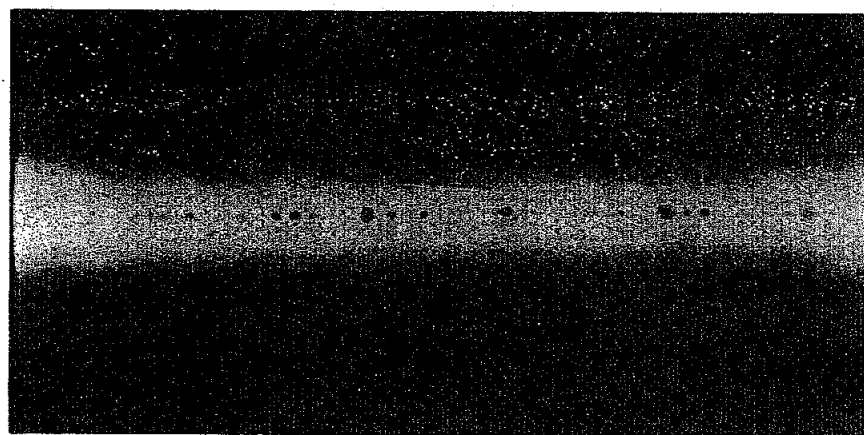


Figure 31. Radiograph showing aligned porosity at root of weld.

- Slag inclusions may occur in a variety of shapes ranging from a small single inclusion to a continuous slag line. Depending upon their form, they appear on the radiograph as irregular shaped dark areas or continuous dark lines of irregular width, parallel to the weld bead (Fig. 32).
- Lack of fusion is difficult to reveal by radiography. When detected it appears as a diffuse and wavy dark line, parallel to the weld (Fig. 33).
- Incomplete penetration appears on the radiograph as a straight dark line, continuous, or intermittent. It will run down the middle of a groove weld (Fig. 34).
- Burn-through or icicles are a result of excessive penetration. Round, light areas in the middle of the bead are typical (Fig. 35).
- Tungsten inclusions can occur when the tip of a tungsten electrode drops into the weld pool. They show as small white disks on the radiograph.

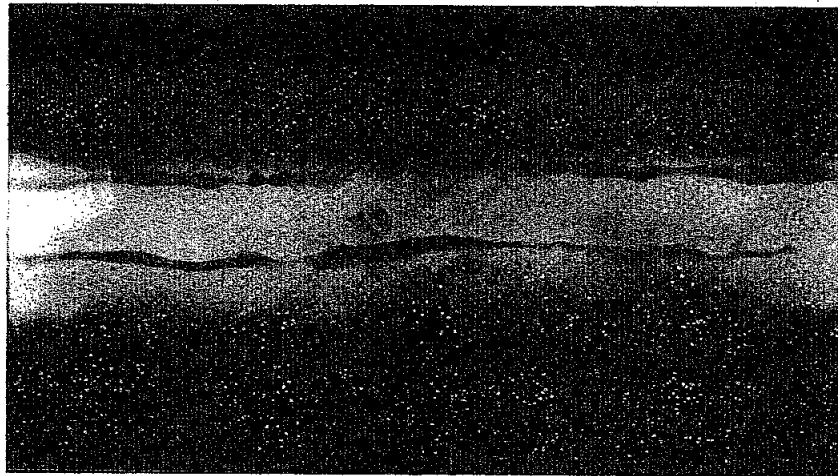


Figure 32. Radiograph showing slag lines.

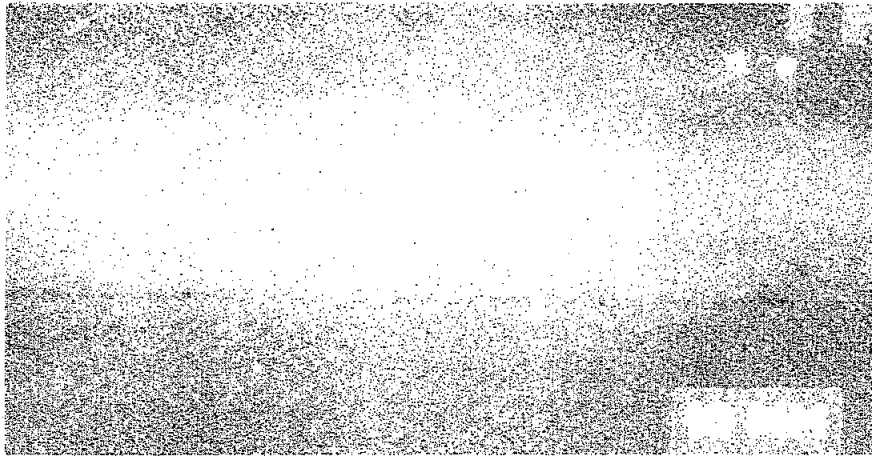


Figure 33. Radiograph showing lack of fusion.

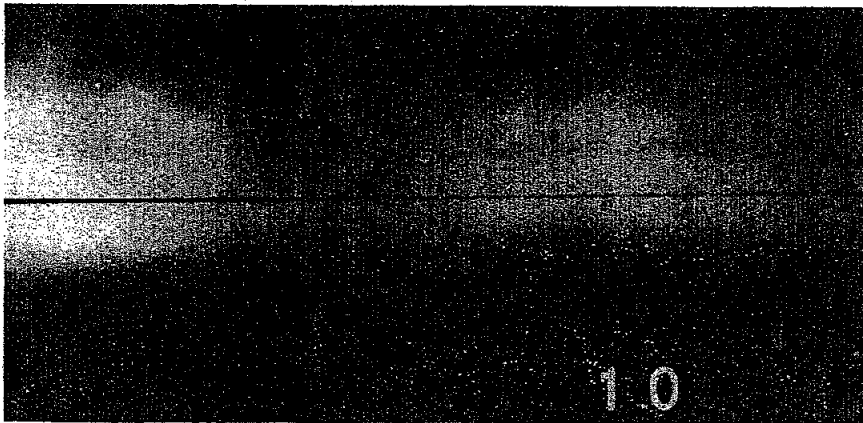


Figure 34. Radiograph showing incomplete penetration.

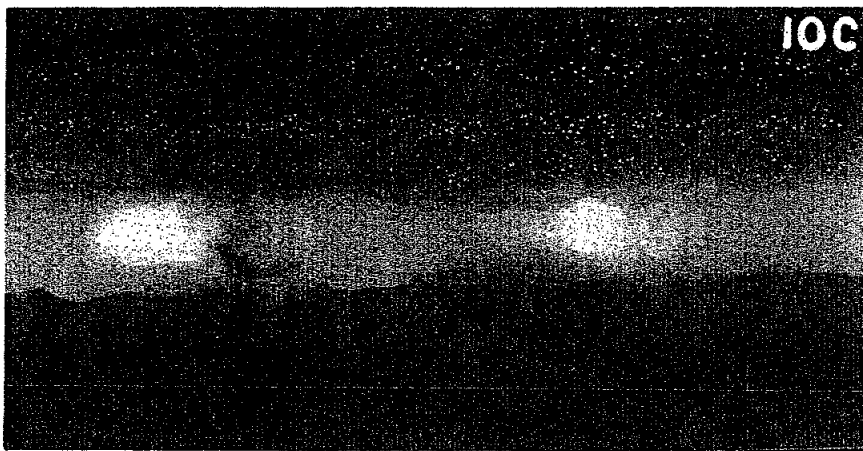


Figure 35. Radiograph showing burn-through.

TECHNIQUES

Effect of geometry

The image in a radiograph depends on detecting differences in the intensity of radiation reaching the film. Differences can be created not only by the presence of discontinuities but also by the shape of the component itself. For example, radiation passing through the round bar shown in Fig. 36 penetrates a far greater thickness of material in the centre than at the edge. If the film is correctly exposed for the middle portion it will be overexposed for the edge with no usable image. Where edge losses of this type occur additional shots are required from another angle to inspect all the material. Fig. 37 shows two shots at 90° to each other are required for a thin-walled small diameter tube.

In general, the location of the source and film should be chosen to minimize the ratio of the thickest to thinnest metal penetrated. At the same time the total distance penetrated should be minimized to increase sensitivity to internal flaws and reduce exposure times. In addition, where two or more welds are close the position of the source and film should be selected to avoid overlap of the images from the welds. With these considerations in mind a suitable angle for shooting the fillet weld

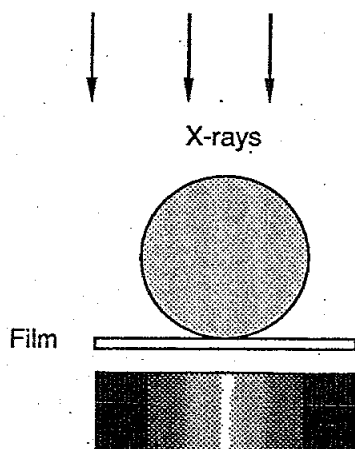


Figure 36. The shape of a component affects the image. In this example edge loss occurs because of the differences in thickness penetrated.

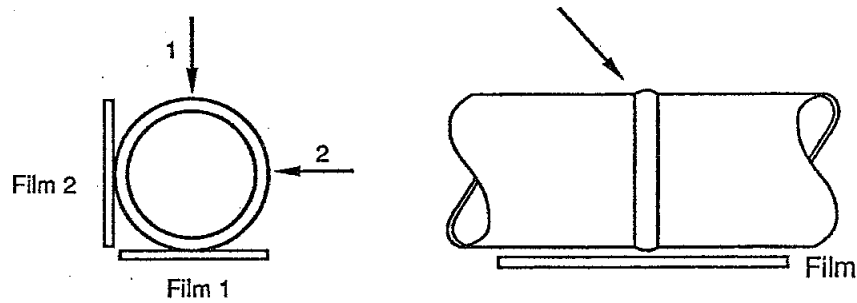


Figure 37. Using two shots to radiograph a small diameter tube producing an elliptical image.

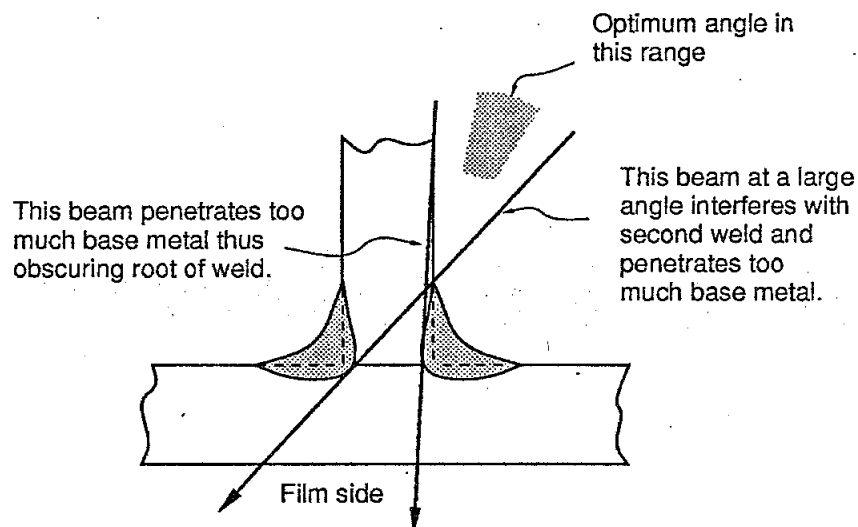


Figure 38. Optimum angle for shooting this fillet weld determined by geometrical constraints. Because of such constraints, radiography is not normally recommended for fillet welds.

illustrated in Fig. 38 would be about 15° - 20° . In general, however, radiography is not suitable for fillet welds and is not recommended by CSA W59.

Planar flaws

Many flaws, such as cracks and lack of fusion, are thin in one direction but may be long in the other directions, i.e., they are planar discontinuities. If the beam traverses the thin direction there may not be enough difference in intensity to produce an image, and the flaw is

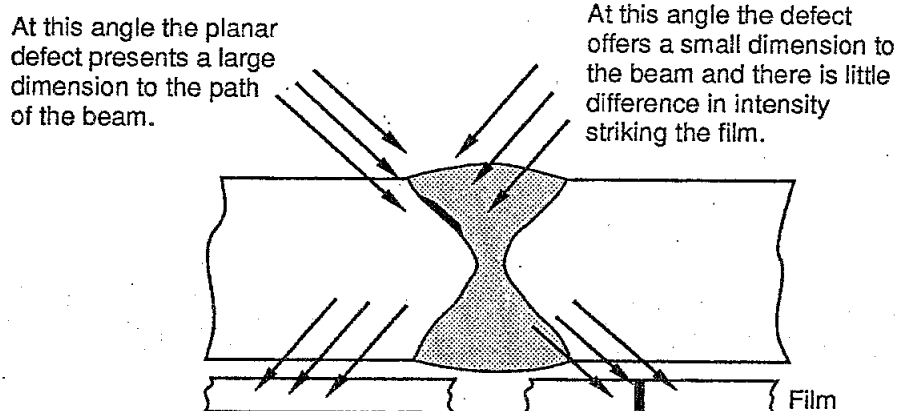


Figure 39. Planar flaws such as lack of side wall fusion may not be detected unless the beam is at a favourable angle.

not detected. Fig. 39 shows lack of fusion which may not be detected unless the beam is parallel to the long dimension. Knowledge of the welding procedure is helpful in selecting the best radiographic technique. For example, for a double V groove weld with 60° included angles, two shots at 30° either side of the normal to the plate would maximize the chance of finding lack of fusion on the side wall. Unfortunately, this effect means serious planar defects such as cracks can easily be missed with radiography and is a limitation of the method. Radiography is more effective for volumetric flaws such as porosity than for planar flaws.

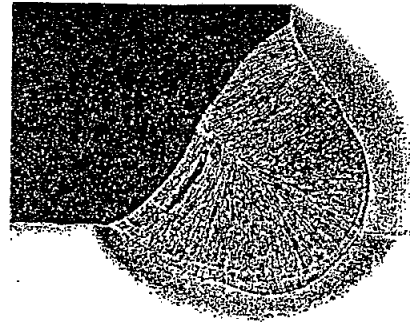
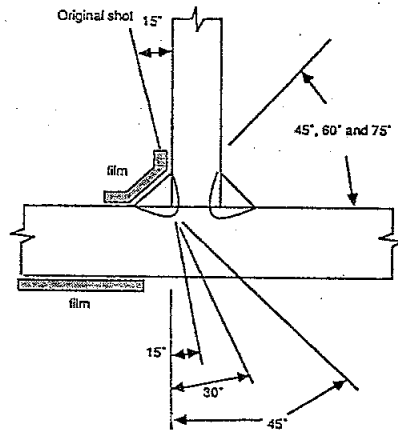
Shape of flaws

In special cases, taking shots from several angles may assist in defining the type and shape of flaws, important in assessing their significance. The sidebar shows an example where a fillet weld was radiographed from several angles to define the shape, size, and position of elongated porosity.

Estimating depth of flaws

Multiple shots are not always necessary to estimate the depth of a defect and much can be learned from single radiographs. Estimating depth from a single shot is not, however, a perfect science and other methods (such as ultrasonic examination) are usually more appropriate. The inspector is advised to seek expert advice where possible. Estimating the depth of a defect is important both in determining the type and

Example of Special Technique for Identification of Flaw Shape



Elongated porosity in the fillet weld.

Geometric arrangement for shots at various angles.

Original shot at 15°	
45° from web side	
60° from web side	
15° film on weld side	
30° film on weld side	
45° film on weld side	

Appearance of radiographs.

At 60° the flaws appear as small dots thus confirming the narrow, elongated shape of the flaws.

cause of a defect and also in planning the repair. Knowing the location through the thickness allows gouging to be done from the closest side which minimizes the cost—particularly important in thick material. It is sometimes advantageous to make a tracing of the weld which can be superimposed on the radiograph to help locate defects.

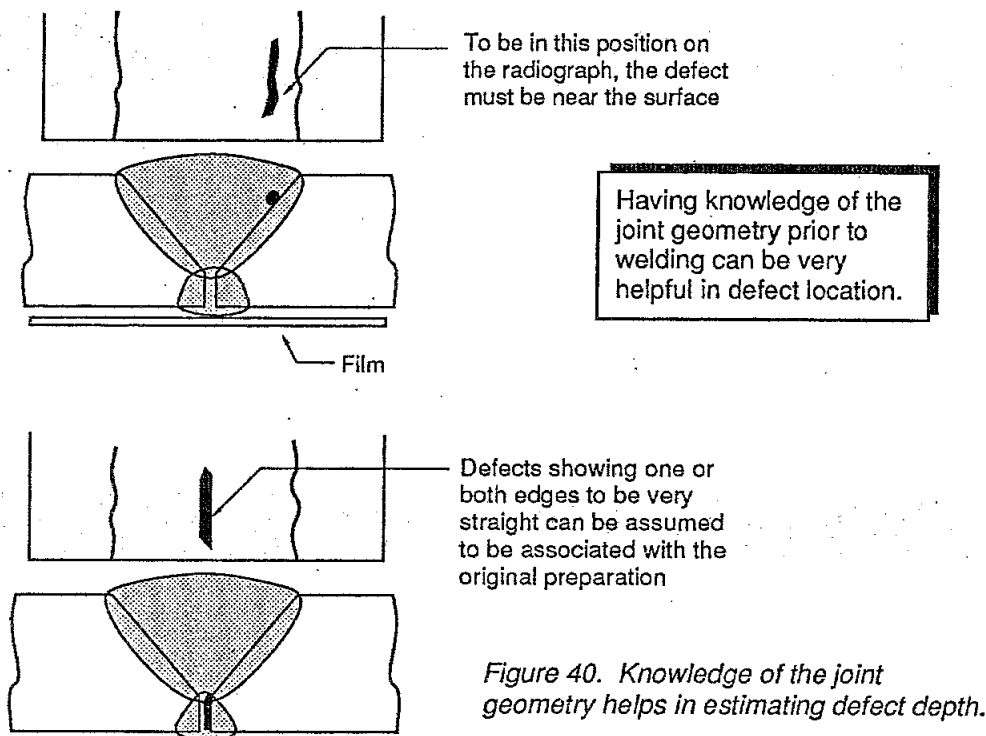


Figure 40. Knowledge of the joint geometry helps in estimating defect depth.

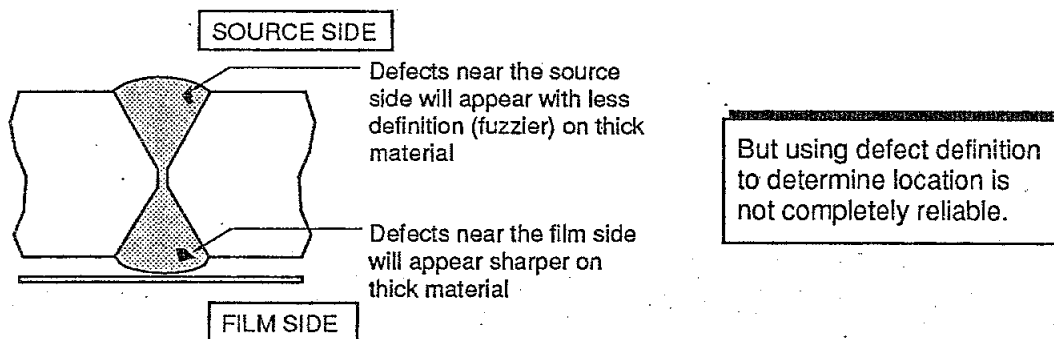


Figure 41. Defects closer to the film side of the weld appear sharper.

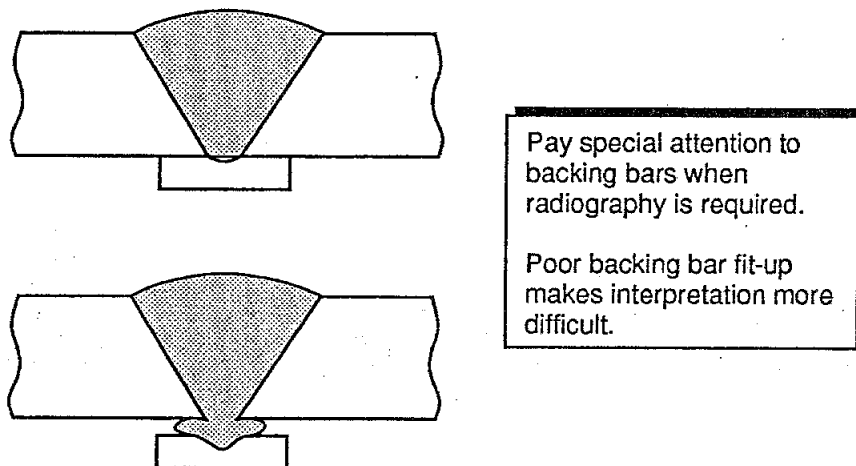


Figure 42. A poorly fitting backing bar may cause difficulty in interpreting a radiograph.

Depth may be estimated from the location of the image of the defect in relation to the joint geometry. Fig. 40 shows how a knowledge of the joint geometry prior to welding assists in defining a defect depth. It was also mentioned earlier that the images of defects closer to the film are sharper than those of shallow defects further from the film (Fig. 41). But although image definition may help in estimating depth it is not a reliable method.

According to CSA W59-89 backing bars do not have to be removed prior to radiography. They can, however, obscure defects in the weld and make interpretation difficult if the fit-up is poor (Fig. 42). Special attention should be paid to carefully fitting backing bars when radiography is required. Similarly, it is not usually necessary to remove the weld reinforcement as long as it has an acceptable profile, is smooth, and is without ridges that could obscure internal defects.

In some cases parts of a weld may be inaccessible for radiography because of the geometry and alternate inspection methods may be preferred. An example is shown in Fig. 43 where the part of a flange splice weld over the web is not easily accessible for radiography. In such a case, where 100% inspection of the splice weld is required, ultrasonic examination is better.

Backing bars

Splices in rolled section

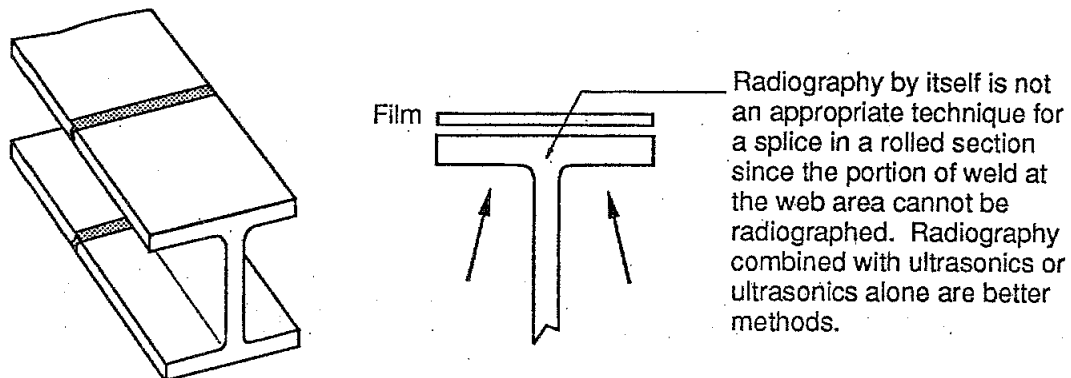


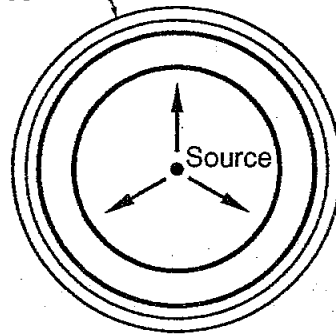
Figure 43. Flange splice weld where part of weld is inaccessible for radiography.

Hollow sections

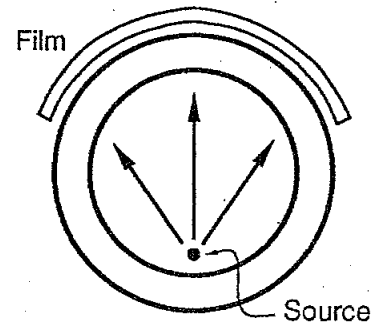
For hollow sections, pipes, cylinders, or vessels the technique employed depends on the size of the component and whether there is access to the inside. If the source can be placed inside, the beam only has to penetrate one wall thickness which is an advantage, but it may be difficult to achieve an adequate source-to-film distance. Fig. 44 shows two alternate locations for a source on the inside of a cylinder or large diameter pipe. If the diameter is too small to place the source inside but there is still access for the film, single wall welds may still be examined. Several shots will be required to examine the complete circumference.

If there is no access to the inside, both film and source are external and the beam must pass through two wall thicknesses. A typical arrangement is shown in Fig. 45. Because of the relative source-object/film-object distances the first weld that the beam passes through does not produce an image unless the diameter is small. In addition the weld can be shot at a slight angle to avoid any possible overlap or interference from the top portion of the weld. This technique requires three shots to be taken for circular sections. For rectangular hollow sections, four shots are required.

Film around complete circumference

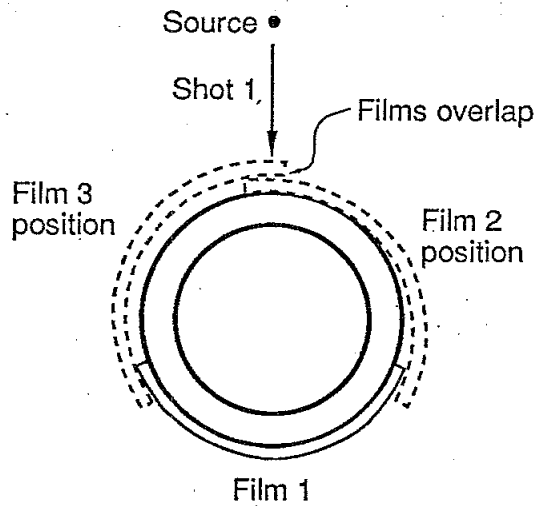


One shot required. Source-to-film distance limited to radius of pipe.



Three shots required but source-to-film distance greater.

Figure 44. Possible locations for source inside large diameter pipes or cylinders for single wall radiography.



Three shots required.

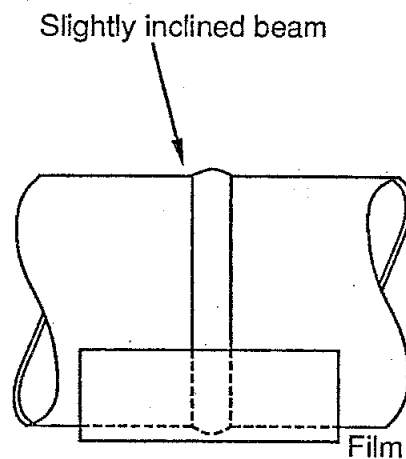


Figure 45. Possible arrangement of film and source for double wall radiography of hollow sections.

APPLICATION OF RADIOGRAPHY

The foregoing sections have shown that, although a valuable non-destructive evaluation method, radiography does have some limitations. To apply the method most effectively it should be used in conjunction with other methods, particularly visual inspection. Visual inspection and radiography should form part of an integrated inspection plan. Fig. 46 shows a typical sequence of events. Visual inspection plays an important role in determining surface defects requiring repair and ensuring that repairs have been completed prior to any radiography.

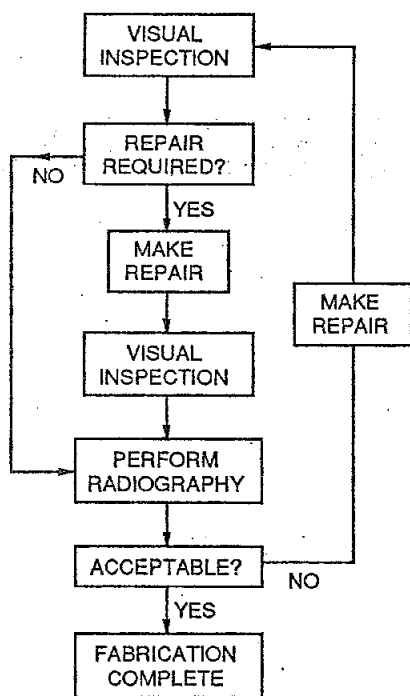


Figure 46. Visual inspection should be used as an integral part of the application of radiography.

Scheduling

As a general rule radiography (or any other NDE method) should not be applied until welding and related operations are as complete as possible. For example, if two plates spliced together are to be subsequently cut, radiograph the splice welds *after* the cutting operations.

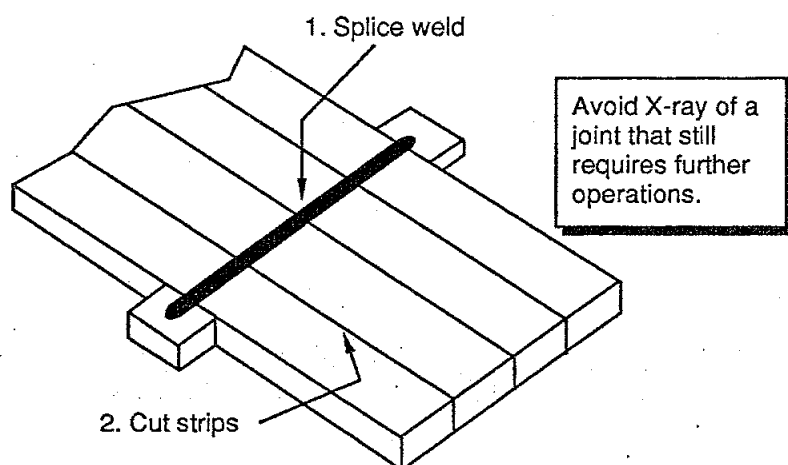


Figure 47. In general, as many operations as possible should be completed before radiography. In this example, two plates are spliced together then cut into strips. Radiograph the welds after completing all welding, cutting, and removal of run-off tabs.

Delay after welding

Similarly, flange splices should be radiographed after completion of all welding with run-off tabs removed (Fig. 47). Exceptions to this might be where subsequent operations make access to the weld more difficult or prevent an effective repair being undertaken.

Radiography should not be performed until several hours after the weld has cooled to ambient temperature. In the case of high restraint joints W59-89 recommends a minimum of 48 hours before doing any radiography. The reason for this is that some types of defects, such as hydrogen cracks, may not form until several hours after the weld has cooled. At normal shop temperatures cracking is not likely to be delayed more than 48 hours, but research has shown that when welding at low temperatures cracking may be delayed many days.

Post-weld heat treatment

Many products, such as pressure vessels and piping, often require a post-weld heat treatment. For some materials the ASME code allows radiography to be performed before the post-weld heat treatment. This is often done to avoid repeating an expensive heat treatment in the event that repairs are necessary. But client specifications may require radiography on the final product after post-weld heat treatment implying that radiography is done before and after. In such cases it is very

Spot radiography

important that the exact same procedure and set-up is used in both cases if difficulties in interpretation are to be avoided. Small differences in procedure and radiographic sensitivity could mean a borderline indication deemed acceptable before heat treatment becomes rejectable after simply because the inspection sensitivity has changed.

It is quite common for specifications to call for spot radiography, i.e., examination of a percentage of the total weld length (typically 10%) selected by the client. Spot radiography may be specified to include intersections of horizontal and vertical welds, thus providing a sample of two welds on one radiograph. CSA W59-89 requires each spot radiograph to show at least 100 mm (4 in.) of weld length. If the radiograph shows a defect, the defect must be traced for repair. Two additional spots on the same unit length of weld must be selected and if these show a defect the entire unit length of weld must be radiographed or totally removed (Fig. 48).

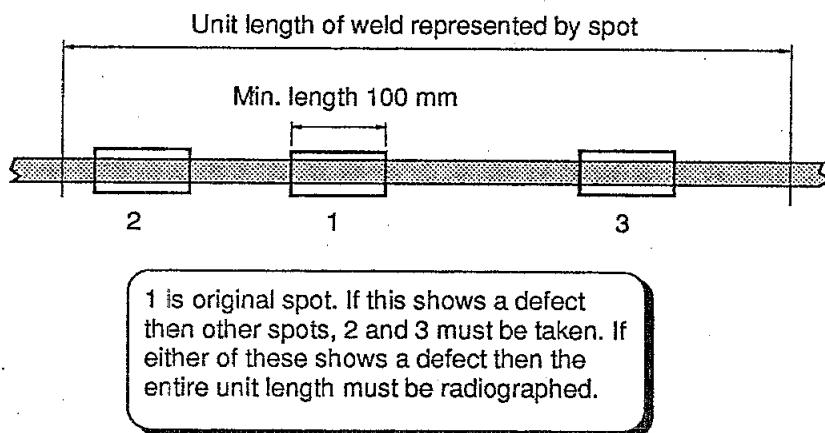


Figure 48. Spot radiography. If the spot shows a defect two additional spots must be radiographed (CSA W59).

Field radiography

In field practice, radiography must be coordinated with production welding. For safety reasons the immediate area must be clear of all personnel so it is common practice to schedule radiography between shifts or during breaks. To assist with speedy set-up prior to and between exposures, the radiographer uses canvas and cardboard cassettes, flexible envelopes into which the unexposed film is loaded under darkroom conditions. The cassettes are placed on the weld and held there with masking tape or magnetic clamps. Accurate location of defects is often done by making a tracing of the defect on the radiograph and transferring it to the weld.

Qualifications

Radiography must only be carried out by certified technicians and the qualifications of personnel should be checked by the inspector. Certification is to the Canadian General Standards Board (CGSB) 48-GP-4M "Certification of Nondestructive Testing Personnel (Industrial Radiography Method)." Personnel may be certified at three levels. An example of a wallet-size certificate is shown in Fig. 49.

 Energy, Mines and Resources Canada		Énergie, Mines et Ressources Canada	
INDUSTRIAL RADIOGRAPHY - RAYONNEMENTS IONISANTS			
This certifies that Bobby Shaftoe			
La présente atteste que			
has qualified according to the C.G.S.B. Standard 48-GP-4M, as: définit la certification suivante selon la norme ONGC-48-GP-4M:			
LEVEL 1	11/68		
LEVEL 2	GENERAL 11/72	AIRCRAFT STRUCTURES 7/80	
NIVEAU 2	GÉNÉRALE	STRUCTURES AÉRONAUTIQUES	
LEVEL 2	LACF 11/72	WW 7/72	HWCF 11/72
NIVEAU 2	PCFAL	S & AS	PCFAL
LEVEL 3	GENERAL	AIRCRAFT STRUCTURES	
NIVEAU 3	GÉNÉRALE	STRUCTURES AÉRONAUTIQUES	
SEE REVERSE FOR PERIOD OF VALIDITY LE VERSO INDIQUE LA PÉRIODE DE VALÉITÉ		REG. NO. 209 N° MATRICULE	<i>J. Newbury</i>

Figure 49. Example of radiographic certificate.

Procedures

Many factors influence the quality of a radiograph and it is essential that they are all controlled in practice. There should be written procedures for radiography that include such details as: equipment, type of source, geometric arrangement, source-to-film distance, type of film and processing. The inspector should carefully review radio-

Radiographic Inspection

NONDESTRUCTIVE EXAMINATION PROCEDURE

ABC Company
Central Branch
Canada

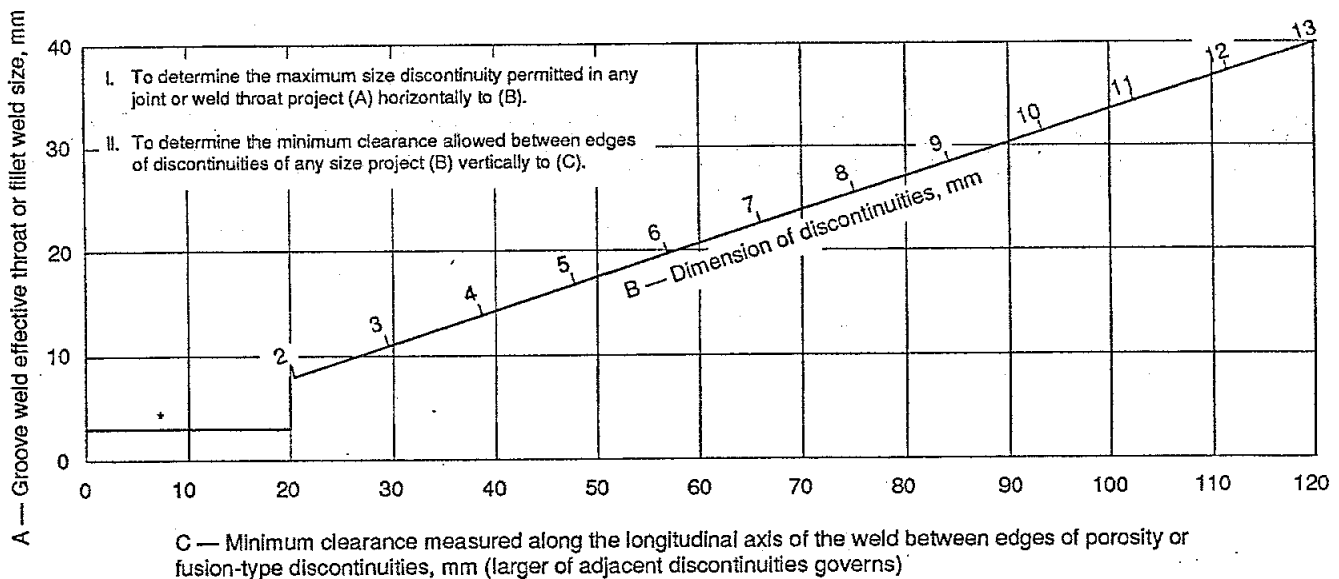
SUBJECT RADIOGRAPHIC PROCEDURE FOR THE EXAMINATION OF WELDS TO W59	PROCEDURE NO. S-RE-W W59 Page 3 of 11
<u>SCOPE</u> This procedure describes the radiographic testing of groove butt welds in accordance with C.S.A. Standard W59. The geometries covered by this procedure are Butt, Corner Weld and Tee Joints. Any special configurations will be covered by a supplement to this procedure. <u>SOURCE OF RADIATION</u> Tech/Ops Gamma Ray 1R192. <u>GEOMETRIC ARRANGEMENT</u> The geometric arrangement of the source weld and film are shown in Figures 1, 2 and 3. <u>FILM IDENTIFICATION</u> Identification of film shall be made by a film Identification Printer, and location markers which will appear on the film, will be by lead location markers. <u>SAFETY</u> All radiographic work carried out under this procedure shall be done under protected conditions whereby the radiographer, and non-radiation workers in the area, will not receive a radiation dose that exceeds that permitted by the Radiation Protection Branch of the Department of Health and Welfare. <u>FILM PROCESSING</u> Films will be machine processed through a Kodak X-omatic Film Processor Model B. <u>FILM</u> Fine grain Industrial Film will be used for all radiographs. <u>INTENSIFYING SCREENS</u> Lead screens of .010 thickness shall be used front and back. <u>SURFACE PREPARATION</u> All weld ripples and surface irregularities on both sides of the weld shall be removed to a degree that the resultant radiographic image, and these irregularities will not mask defects indicated with the radiographic image, and these irregularities will not mask defects indicated with the radiographic image.	

Figure 50. Part of a typical procedure for radiography.

Acceptance criteria

graphic procedures to ensure such details are documented. Of particular value in a procedure is a sketch showing the relative location of the film and source together with details of penetrameter and identification locations. Part of a typical example is illustrated in Fig. 50.

The criteria for acceptance or rejection of welds based on radiographs are given in the particular standard governing fabrication. For example, CSA W59-89 provides separate acceptance criteria for statically loaded and dynamically loaded structures. As an example, Fig. 51 shows the requirements for tension members in a dynamically loaded structure. The diagram gives the maximum size and minimum spacing of porosity and fusion defects (cracks are not permitted). For example, the maximum size of a single pore in a 25 mm thick groove weld is 8 mm. There can be no other pores 2 mm or greater within a distance 75 mm either side of the pore.



*The maximum size of the defect located within this distance from an edge of plate shall be less than 2 mm. The sum of defects located within this distance from the edge shall not exceed 5 mm.

Adjacent discontinuities, spaced less than the minimum spacing required by the above figure, shall be measured as one length, equal to the sum of the total length of the discontinuities plus the length of the space between them, and evaluated as a single discontinuity by the above figure.

Figure 51. Radiographic acceptance criteria for welds in tension in dynamically (fatigue) loaded structures (CSA W59-M1989). Refer to the original for use.

Radiographic Inspection

Report of Radiographic Examination of Welds

Project:
 Quality Requirements: Section No.
 Reported to:

[illegible]

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of Clause 8.1 of CSA Standard W59-M, Welded Steel Construction (Metal Arc Welding).

Manufacturer or Contractor

Authorized by

Date

Radiographer(s) Interpreter

Figure 52. Typical format for a radiographic inspection report.

Inspection records and reports

The results of radiography and the interpretation should be documented in a report. A typical format is illustrated in Fig. 52 which includes a sketch, details of technique, and results of interpretation. This report together with the radiographs would usually be submitted to the client.

Once the interpretation and the required documentation has been completed, many industries, especially the nuclear industry, require completed radiographs to be kept for periods up to 40 years. This is referred to as Archival Quality. Commercial Quality refers to the storage of radiographs for a period of between 3 and 10 years. Therefore, close attention must be paid to *all* aspects of the processing procedure. The image on poorly processed film will begin to fade within a relatively short period of time. Radiographs should be in storage packets made from acid-free paper and kept in a clean, dry environment. Stacking should be on the film edge rather than flat.

Safety

RADIATION SAFETY

Both X-rays and gamma rays are ionizing electromagnetic radiations that pose a potential hazard to both the radiographic technician, fellow workers, and the public. Ionizing radiation can damage human blood cells and tissues resulting in acute or long-term health effects. Strict safety precautions are therefore required when radiography is performed. Radiographic inspection must only be performed by trained and qualified personnel, and the radiographic technician is not only responsible for his or her own safety but also the safety of all ancillary personnel in the surrounding area.

Licensing and use of ionizing radiation equipment is governed by strict regulations. In Canada the use of gamma ray inspection is controlled by the federal government through the Atomic Energy

Table 5. Maximum permissible doses.*

Column I Organ or tissue	Column II Atomic radiation workers		Column III Any other person
	Rems/quarter of a year	Rems/year	Rems/year
Whole body, gonads, bone marrow	3*	5*	0.5
Bone, skin, thyroid	15	30	3*
Any tissue of hands, forearms, feet and ankles	38	75	7.5
Lungs and other single organs or tissues	8	15	1.5

*Refer to original document—Atomic Energy Control Regulations, Schedule II, 'Maximum permissible doses and exposures' Table I, for details (currently under revision).

Warning signs

Control Board and its regulations are applicable in all provinces. The use of industrial X-ray machines is a provincial government concern and is controlled by the provincial ministry responsible for the respective Industrial and Occupational Health and Safety Act. All regulations state maximum permissible doses of radiation which must not be exceeded by either qualified personnel or non-qualified personnel (see Table 5).

To limit the risk of exposure to radiation a restricted area is designated around the site where radiography is being undertaken. This restricted area is marked by physical barriers, warning lights and signs bearing the international radiation hazard sign (Fig. 53). It is imperative that non-radiographic personnel do not enter the restricted area at any time.

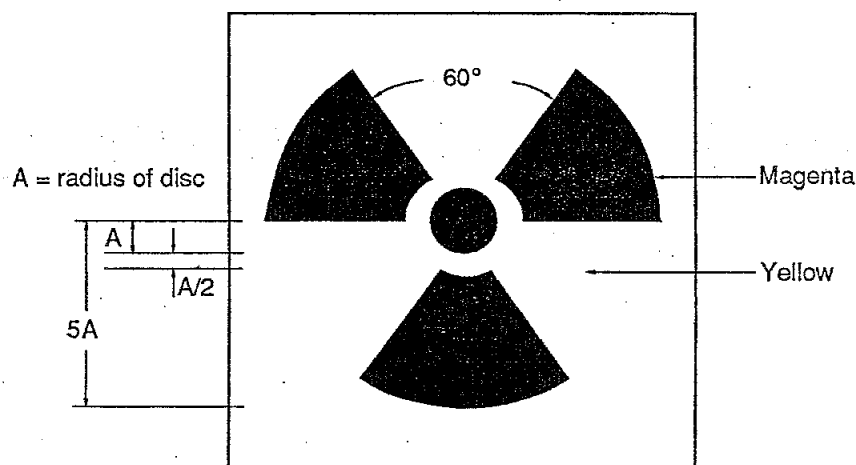


Figure 53. Trefoil — radiation hazard sign.

The sign in Fig. 53 is used for radiation in general including both X-rays and gamma rays. Another sign used in Canada specifically for X-rays is shown in Fig. 54. An important feature of X-ray equipment is that X-rays can only be emitted when the machine is turned on. This is in contrast to gamma rays that are continuously emitted from a radioactive isotope.

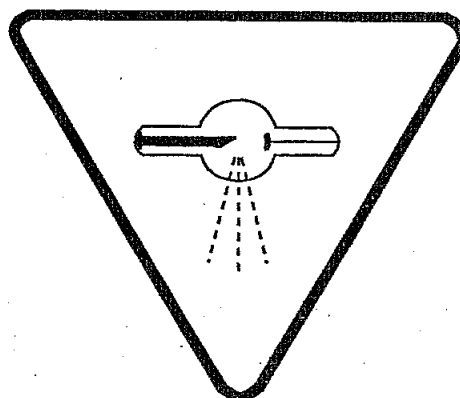


Figure 54. The warning sign used in Canada to indicate the presence of a hazard from X-rays.

Controlling exposure

There are several steps that can be taken to reduce radiation levels and these follow a few basic principles:

- Reduce *exposure times* by using the fastest film speed that gives the required sensitivity and the shortest source-to-film distance (SFD) that meets unsharpness requirements.
- *Distance*. Radiation follows the Inverse Square law (see Fig. 13). Thus doubling the distance from a source reduces the radiation intensity four times.

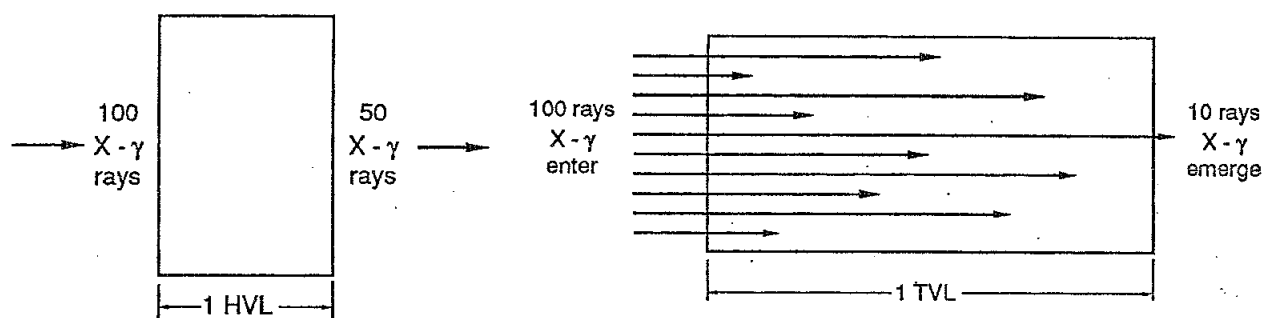


Figure 55. Definition of HVL and TVL terms to denote shielding ability of materials.

Detecting and measuring radiation

- *Shielding.* Heavy materials, such as lead or depleted uranium, absorb radiation. For a given thickness of the material the intensity is reduced by a given fraction. Thus the Half Value Layer (HVL) is the thickness of material that reduces the intensity of a beam to half its original intensity. Similarly, the Tenth Value Layer (TVL) reduces it to one tenth (Fig. 55).
- *Collimator.* This is a device surrounding a radiation source that helps to minimize scattered radiation and direct the primary beam onto a localized area.
- *Safety interrupt switches.* For X-ray equipment interrupt switches may be attached to the door into an X-ray cell so that the machine is automatically turned off if the door is opened during radiography.

X-rays and gamma rays cannot be detected by any of the human senses so various instruments must be used to measure the doses received by radiographic personnel, (the units of radiation are explained in the sidebar). For measuring the level of radiation around a radiography site a radiation survey meter (Fig. 56) may be used. The intensity of the field is indicated on a meter dial but no permanent record is

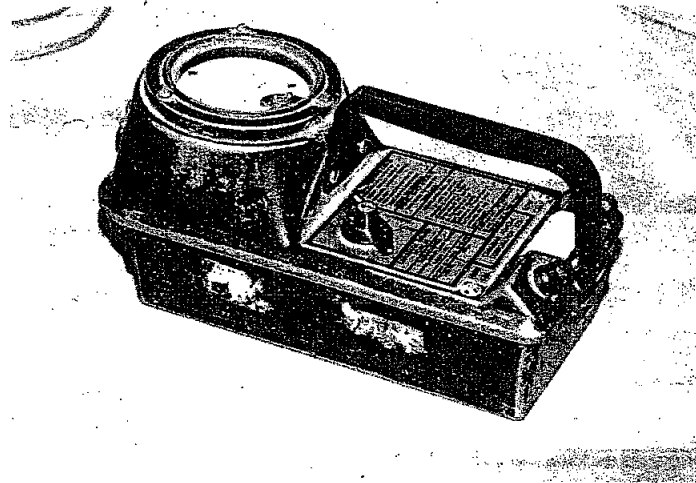


Figure 56. Typical radiation survey meter.

Units of radiation

	Customary units	S.I. units	Conversion
<u>Radiation Intensity</u> The intensity of X- and γ rays is measured by the ability to create ions. One Roentgen is the amount of radiation that will create 2.08×10^9 ion pairs in one cc of air at STP.	Roentgen (R)	Coulomb per kilogram (c/kg)	$1 \text{ R} = 2.58 \times 10^{-4} \text{ c/kg}$
<u>Radiation Activity</u> The strength of a radioactive source is determined by the rate of disintegration. One curie is 37×10^9 disintegrations per second. As the source decays the activity decreases. The time for the activity to decrease to one half the original is the half life. Half life of $\text{Ir}^{192} = 74$ days Half life of $\text{Co}^{60} = 5.3$ years	Curie	Becquerel (Bq) (one disintegration per second)	1 curie = 37 gigabecquerels (GBq)
<u>Radiation Absorbed Dose (RAD)</u> Measure of radiation energy absorbed by living tissue.	rad	Gray (Gy) (Joules per kilogram, J/kg)	$1 \text{ rad} = 10 \text{ mGy}$ $1 \text{ Gray} = 100 \text{ rads}$
<u>Roentgen Equivalent Man (REM)</u> X- and γ rays do the same amount of damage for the same energy absorbed. The amount of potential damage-causing radiation absorbed is thus the same as the RAD. For other types of radiation there is a different factor.	rem ($=1 \times \text{rad}$) millirem $= \text{rem}/1000$	Sievert (Sv)	$1 \text{ Sv} = 100 \text{ rem}$ $1 \text{ rem} = 10 \text{ mSv}$

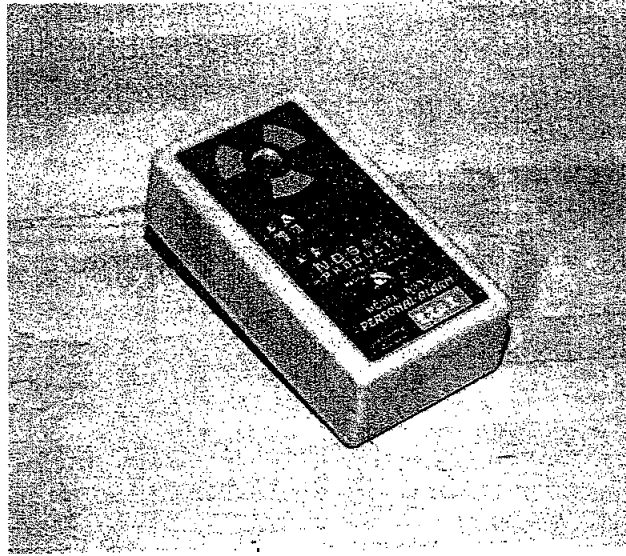


Figure 57. Typical audible alarm.

provided. An audible alarm can also be used to detect radiation fields (Fig. 57). This small electronic device is battery powered and usually worn on a belt. In a radiation field the device emits a loud beeping noise and as the intensity of radiation increases the time between beeps get shorter until in a high radiation field the device emits a continuous high-pitched noise.

Thermoluminescent
dosimeter

TEST
QUESTION

Personal dose records are obtained by using a thermoluminescent dosimeter (TLD). This device traps radiation energy which can later be released by gently heating. The released energy is measured and a permanent record obtained of the total exposure to radiation. It is a small, personal device (Fig. 58) and has replaced the use of the film badge in Canada. The film badge was simply a holder containing a small piece of film which could be developed and the degree of blackening on the film used as a measure of exposure.

In Canada the monitoring of radiation exposure is controlled by the Federal Government through the Department of Health and Welfare. The TLD's are issued and read and a lifelong history of radiation doses received is maintained by the Bureau of Radiation and Medical Devices.

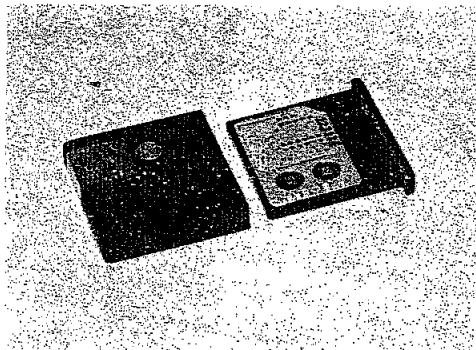
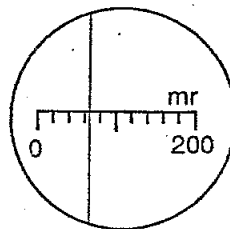
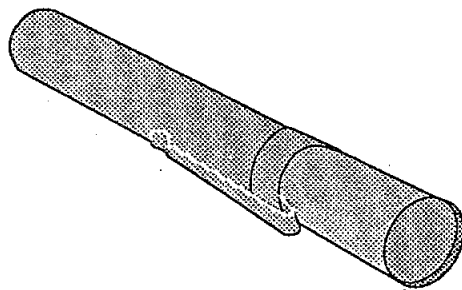


Figure 58. A thermoluminescent dosimeter.

Direct Reading Dosimeter (DRD)

For an immediate indication of personal radiation dose a device known as a Direct Reading Dosimeter (DRD) is used (Fig. 59). The DRD is about the size of a fountain pen containing a charged quartz fibre which moves when struck by radiation. The movement can be read directly against a scale thus providing an immediate indication of personal radiation dose although it is not highly accurate.



View through eyepiece

Figure 59. Direct reading dosimeter (DRD).

Summary

Radiography is a powerful tool for the volumetric inspection of welds but it has its limitations. It is best used in conjunction with good visual inspection and may be supplemented with other methods such as ultrasonics. Although radiography is carried out by certified technicians, inspectors, supervisors and others also require a good knowledge of the method.

In this module we have discussed the basics of radiography and shown how an image is formed and what controls the quality. Location of the source and the distance from the film to the source is important. Because radiography depends on density differences in the path of the beam it may not reveal defects such as cracks that are narrow in one dimension. Techniques for improving the ability to detect flaws and methods for locating their position in the weld are discussed. The appearance of typical defects on a radiograph is covered.

The application of radiography involves checking operator qualifications, procedures, and correct reporting. The interpretation is done in accordance with the acceptance criteria defined in the applicable standard. We have also drawn attention to the need for careful planning so that radiography is incorporated into an overall schedule.

Finally we have discussed some aspects of the important subject of safety in radiography. The correct safety procedures must be known, understood, and applied by all personnel involved in radiography or near an inspection site whether or not they are actually carrying out the radiography. With communication and cooperation among inspection personnel, technicians, and the client, radiographic inspection will continue to be a safe and valuable nondestructive testing method for welded structures.

GUIDES AND EXERCISES

MODULE 18

RADIOGRAPHIC INSPECTION

RADIOGRAPHIC INSPECTION

MODULE 18

Guides & Exercises

To obtain maximum benefit from this module we suggest that you follow this guide and complete the exercises as indicated. It is important that you work through the text methodically, studying each section thoroughly before moving on. The exercises are designed to give you an indication of whether you have learned the material and can move on or whether you need to go back and study the section again.

Do the exercises honestly. They will not help you unless you take them seriously. If you get a question wrong go back through the text until you understand where you have gone wrong and know the correct answer.

The length of time required to complete the module will vary from student to student. Find your own pace. Do not rush. Remember you are trying to learn something, not win a race.

Some people like to underline sections when they read a text. We suggest that you use caution if you do this. What you think is important first time you read it may be different after reading it three times. We suggest you read a section three times thoroughly before highlighting anything.

The last exercise is designed to give you an indication of whether you are ready to take the WIC closed-book exams. The exercise questions are of a similar standard to the official exams. Do not take the exam until you feel you are ready and you may wish to study several Modules before taking the exams on each. The details of the examination procedures are on a separate sheet.

If you have any difficulties with this Module do not hesitate to ask for help. You may find you learn more by attending seminars which are given periodically, and you should also contact your local WIC Chapter to see if they can be of assistance. Remember, if you fail the examination you can always try again later.

After working through each guide, check your answers (starting on page 65) for accuracy. If any of your answers are wrong, re-study the guide subject matter in the text until you understand it before moving on to the next guide.

Guide 1

Read carefully pages 1 to 9 and answer the following questions:

1. True or false?
"X-rays are a type of electromagnetic wave but γ rays are beams of tiny charged particles."
2. List three disadvantages of radiography over other inspection methods.
3. Sketch the main components of an X-ray machine then compare your sketch with that shown in Fig. 5.
4. The effect of increasing the voltage (kV) in an X-ray machine is to—
 - a) increase the X-ray beam intensity without changing its wavelength
 - b) decrease the intensity and shorten the wavelength
 - c) increase the intensity and shorten the wavelength
5. Do γ rays generally have a greater or lesser ability to penetrate thick steel than X-rays?
6. List three disadvantages of γ ray over X-ray radiography.

Guide 2

Read carefully pages 9 to 16 and answer the following questions:

1. For a given intensity of X-rays striking a specimen, what are the two main factors that affect the intensity that emerges from the specimen to strike the film?
2. Which of the following conditions gives the better image contrast?
 - a) A low energy level with an adequately long exposure time
 - b) A high energy level with a shorter exposure time
3. Place the following in order of increasing absorption of X-rays:
 - a) Steel
 - b) Tungsten
 - c) Welding slag

Radiographic Inspection

Guide 5

1. True
2. 48 hours
3. So that borderline indications are not interpreted differently before and after stress relief
4. 100 mm
5. Canadian General Standards Board
6. Some would be: a sketch, governing standard, equipment, type of source, geometric arrangement, source-to-film distance, type of film and processing
7. No

Guide 6

1. Atomic Energy Control Board
2. See page 51
3. True
4. 10
5. 16 times lower
6. Sievert (Sv)

Guide 4

Read carefully pages 34 to 41 and answer the following questions:

1. True or false?

"Radiography is not recommended by CSA W59 for fillet welds."

2. Which of the following defects could most likely be missed by radiography:

- a) A crack
- b) Porosity
- c) Slag inclusions

3. A single Vee groove (60° included angle) weld in 25.4 mm thick plate is radiographed. On the radiograph an indication thought to represent slag appears about 7~8 mm in from the edge of the weld. Estimate the location of the slag through the thickness.

4. True or false?

"According to CSA W59-M1989 all backing bars must be removed prior to radiography."

5. Give two reasons why the source is not always placed inside cylinders or pipes when radiographing welds.
6. How many shots would be required to radiograph a splice weld in a rectangular hollow structural section where there is no access to the inside?

Guide 5

Read carefully pages 42 to 49 and answer the following questions:

1. True or false?

"Good visual inspection should always be used in conjunction with radiography."

2. What is the recommended delay after welding before doing radiography on high restraint joints (according to CSA W59-M1989)?
3. If a product is to be stress relieved why is it important to use exactly the same procedure for radiography after stress relief as is used before?

Radiographic Inspection

6. How large is the hole in the IQI that must be clearly distinguished on an X-ray according to CSA W59-M1989?
- a) 2T (where T is the weld thickness)
 - b) 2T (where T is the thickness of the IQI)
 - c) 0.255 mm
 - d) T (where T is the thickness of the IQI)
 - e) 1 mm
7. A dark narrow area 2~3 mm wide appears on a radiograph all the way along the edge of the area representing the weld. The joint was a 60° double Vee groove. What does this dark area most likely represent?
- a) Undercut
 - b) Slag entrapment
 - c) A root crack
 - d) Incomplete penetration
 - e) Lack of side wall fusion
8. Which of the following statements is correct?
- a) CSA W59-M1989 requires all backing bars to be removed before radiography
 - b) Backing bars need not be removed since they have no effect at all on the quality of the radiographic image
 - c) CSA W59-M1989 does not require backing bars to be removed but a badly fitted backing bar could interfere with interpretation of the radiograph
 - d) Backing bars must always be removed to make room for the IQI
 - e) Backing bars must never be removed since they are an integral part of the weld and must therefore be radiographed
9. What is the minimum length of weld that each spot must show when doing spot radiography to CSA W59-M1989?
- a) No minimum
 - b) 50 mm
 - c) 2T (T is the plate thickness)
 - d) 200 mm
 - e) 100 mm
10. What device is now commonly used for measuring the personal radiation dose of radiographic workers?
- a) Radiation survey meter
 - b) Thermoluminescent dosimeter (TLD)
 - c) There is no method for measuring personal dose
 - d) Personal audible alarm
 - e) A collimator

ANSWERS

Guide 1

1. False
2. Bulky equipment, special safety precautions, some defects not reliably detected
3. See Fig. 5 on page 6 and Fig. 3 on page 4
4. c)
5. Greater
6. See the sidebar on page 10

Guide 2

1. Thickness and type of material
2. a)
3. Welding slag, steel, tungsten
4. False, fuzziness is also caused by inherent unsharpness and scattering
5. Source size, F ; object-to-source distance, d ; thickness, t

$$U_g = \frac{F \times t}{d}$$

6. Increase the object(plate)-to-source distance

Guide 3

1. False
2. Outline of the IQI and the 2T hole
3. a)
4. Scratches or cracks in the lead intensifying screens. Possible other causes are listed in the sidebars on pages 21 to 23
5. 1.5 to 3.5
6. False
7. Spatter appears white or light and may cover the base metal as well as the weld. Porosity is normally confined to the weld metal and appears dark
8. It is difficult to get an accurate value but roughly 2~3% is a reasonable estimate

Guide 4

1. True
2. a)
3. Mid-thickness (about 12.7 mm deep)
4. False
5. There may not be access to the inside; it may not be possible to get adequate source-to-film distance inside
6. Four

**Welding Institute of Canada
Test Key
Module 18**

Compare your answer sheet to this key.

QUESTION	ANSWER				
1	a	b	c	d	(e)
2	a	(b)	c	d	e
3	a	b	(c)	d	e
4	(a)	b	c	d	e
5	a	b	c	(d)	e
6	a	(b)	c	d	e
7	(a)	b	c	d	e
8	a	b	(c)	d	e
9	a	b	c	d	(e)
10	a	(b)	c	d	e

MODULE 18

TEST

This test is designed to determine whether you are ready to attempt the formal examination.

Complete the ANSWER SHEET and compare the results with the TEST KEY. If you score less than 70% we suggest you re-study the material.

1. How would you shorten the wavelength of X-rays emitted by an X-ray machine?
 - a) Use faster film
 - b) Increase the filament current
 - c) Use lead screens
 - d) Place the source closer to the workpiece
 - e) Increase the voltage on the machine (measured in kV)
2. How do γ rays compare with X-rays when applied to radiography of welds?
 - a) X-rays can be used on thicker sections than γ rays
 - b) γ rays have greater penetrating ability but generally give poorer contrast
 - c) γ rays always require longer exposures on thin sections
 - d) γ rays are less penetrating but give a better image
 - e) The wavelength of γ rays gets longer as the source gets old whereas the wavelength of an X-ray machine is fixed
3. Which of the following has the least absorption for X-rays?
 - a) Mild steel weld metal
 - b) Lead
 - c) Most welding slags
 - d) Tungsten
 - e) Low alloy steel plate
4. Given a source size of 4 mm, a weld thickness of 25.4 mm, and a plate-to-source distance of 900 mm, what is the geometrical unsharpness?
 - a) 0.113 mm
 - b) 141.7 mm
 - c) 0.007 mm
 - d) 0.0044 mm
 - e) 0.0282 mm
5. What range of density should a radiograph have according to CSA W59-M1989?
 - a) 7.3 to 8.2
 - b) It should be calculated from the source size, thickness, and object-to-source distance
 - c) 2T to 4T (T is plate thickness)
 - d) 1.5 to 3.5
 - e) 300 to 3 000 cd/m²

Welding Institute of Canada Answer Sheet Module 18

Complete the "Answer Sheet" and compare your answers with those in the "Test Key." If you score less than 70% we suggest you re-study the material.

Please circle only ONE letter corresponding to the answer you think is most correct.

QUESTION	ANSWER				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

The answer sheet below is provided in the event you wish to re-test yourself.

QUESTION	ANSWER				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e