

RADIOGRAPHIC TESTING

module 5

Introduction

Industrial radiography is a method of non-destructive testing where many types of manufactured components can be examined to verify the internal structure and integrity of the specimen. Industrial Radiography can be performed utilizing either X-rays or gamma rays. Both are forms of electromagnetic radiation. The difference between various forms of electromagnetic energy is related to the wavelength. X and gamma rays have the shortest wavelength and this property leads to the ability to penetrate, travel through, and exit various materials such as carbon steel and other metals.

The vast majority of radiography concerns the testing and grading of welds on pressurized piping, pressure vessels, high-capacity storage containers, pipelines, and some structural welds.

Radiographic Testing (RT)

Definition:

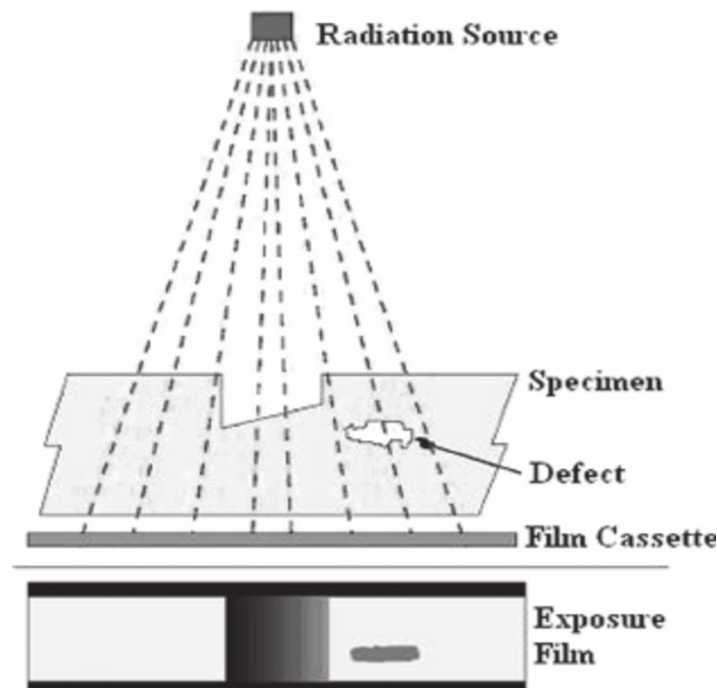
An NDT method that utilizes x-rays or gamma radiation to detect discontinuities in materials, and to present their images on recording medium.

Principle

X-rays are generated in an X-ray tube when a beam of electrons is accelerated on to a target by a high voltage and stopped suddenly on striking the target. The X-rays produced have different wavelengths and different penetrating powers according to the accelerating voltage. Gamma-rays have the same physical nature as X-rays and are emitted by certain radioactive substances.

In radiography a source of penetrating radiation (X or gamma) is placed on one side of a specimen and a detector of radiation on the other side. In passing through the specimen the radiation is attenuated as a function of thickness, so that through the thinner parts of the specimen more radiation penetrates and a greater effect is produced at the detector.

Therefore, if a near-point source of radiation is used at a distance from the specimen, a spatial image is produced of the thickness variations in the specimen whether these are due to external thickness changes, internal cavities or inclusions. In most applications the detector is a sheet of photographic film.



X-rays make up X-radiation, a form of electromagnetic radiation. Most X-rays have a wavelength ranging from 0.01 to 10 nanometres , corresponding to frequencies in the range 30 petahertz to 30 exahertz (3×10^{16} Hz to 3×10^{19} Hz) and energies in the range 100 eV to 100 keV. X-ray wavelengths are shorter than those of UV rays and typically longer than those of gamma rays. In many languages, X-radiation is referred to with terms meaning Röntgen radiation.

X-Ray Source

An X-ray tube is a vacuum tube that converts electrical input power into X-rays. It receives electrical energy and converts it into two terms. I.e. X-Radiation and heat.

X-ray tube consists of a glass bulb under vacuum enclosing a positive electrode and a negative electrode. The cathode provides a source of electrons and the anode acts as the target to electrons and releases X Rays.

The energy required for this process is provided from the generator which is connected to an electrical circuit system. A rectifier is also provided in the electrical system, to convert the electrical energy from the generator into the DC, which is being the adequate form to be applied to X Ray tube.

Normally X-rays are produced when fast moving electrons are suddenly brought to rest by colliding with matter. During collision, the accelerated electrons therefore lose their kinetic energy very rapidly at the surface of the metal plate and energy conversion consequently occurs.

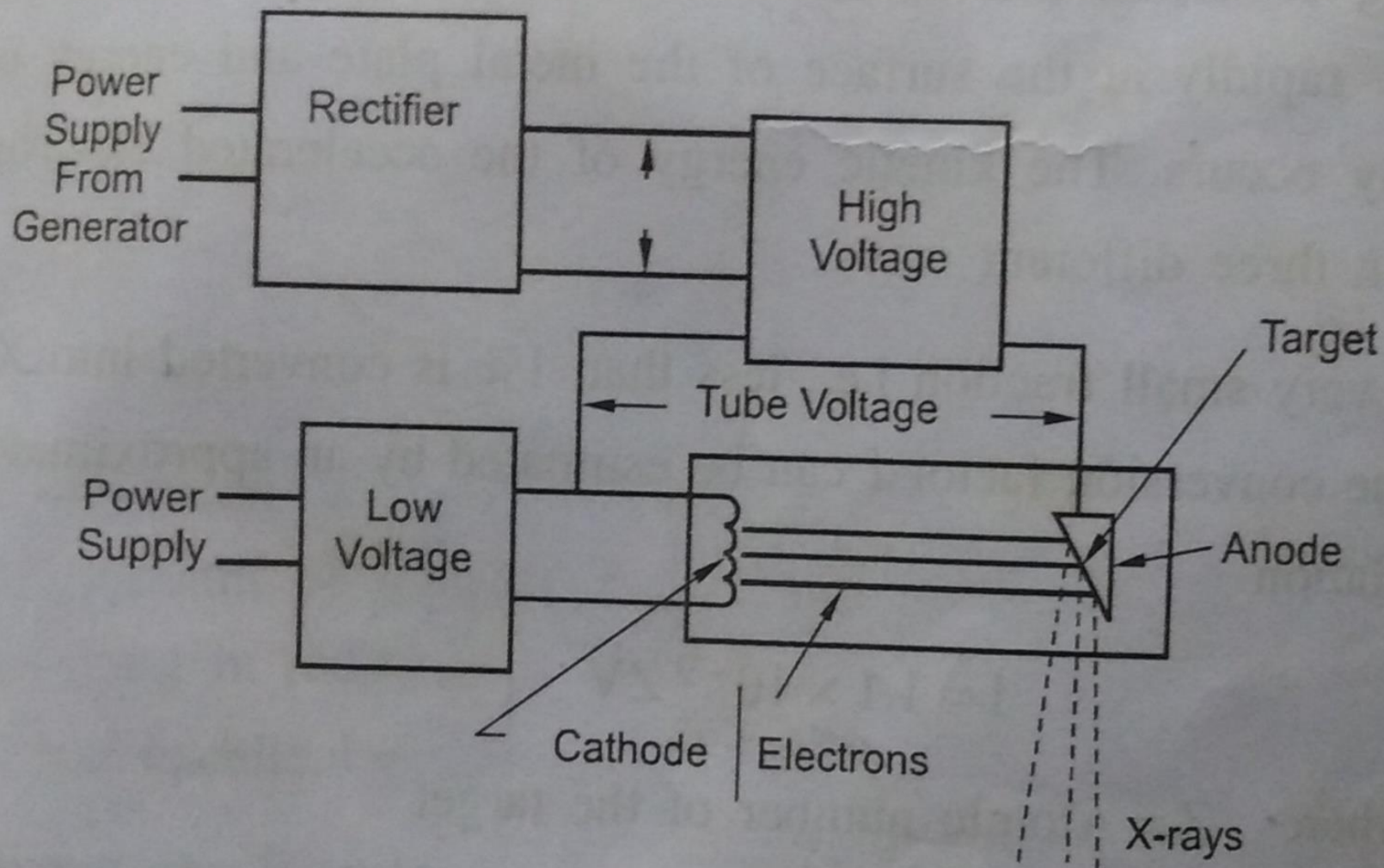


Fig. 5.2: Schematic setup of X-ray tube and circuit

The kinetic energy of the accelerated electrons can be converted in three ways

- 1) A very small fraction. I.e. less than 1% is converted into X-radiation.
- 2) Approx. 99% of energy of electrons is converted into heat by increasing the thermal vibrations of the atoms of the target
- 3) Some of the electrons have sufficient energy to eject orbital electrons from the atoms of the target material which are ionised.

Gamma Ray Source

Gamma rays are electromagnetic radiation emitted from an unstable nucleus. It was first observed by a French chemist Paul Villard

The name gamma ray was proposed by physicist Ernest Rutherford, after the discovery of alpha and beta ray.

Gamma rays can be produced by four different nuclear reactions namely fusion, fission, alpha decay and gamma decay

Properties of X rays and Gamma Ray

- They are invisible and travels at the speed of the light.
- They propagate in a straight line and pass through space
- They are not affected by electric and magnetic fields
- They are capable of ionizing gases and also changes the electrical properties of solids and liquids
- They are capable of blackening photographic film
- They can damage and kill living cells and produce genetic mutations
- They exhibit wave properties and are reflected, refracted, diffracted & polarized

Inspection techniques in Radiography

Single wall single image (SWSI) Technique

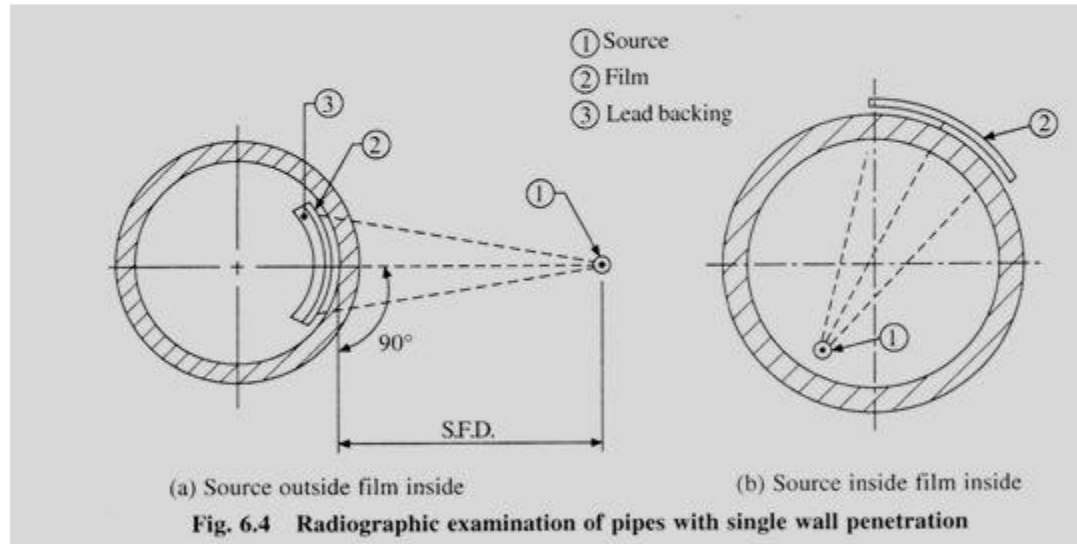
This applicable in case when the material to be inspected in in the form of cylinders

Eg:- pipes, shells, etc. there are two ways to do the inspection. They are

- 1.To keep the radiographic source outside and the film inside- Flat technique
- 2.To keep the radiographic source inside and the film outside- Panoramic technique

Inspection Techniques

- **Single Wall Single Image Techniques**
 - Both sides of the specimen are accessible
 - Used for plates, cylinders, shells and large diameters pipes
 - Source outside and the film inside or vice versa

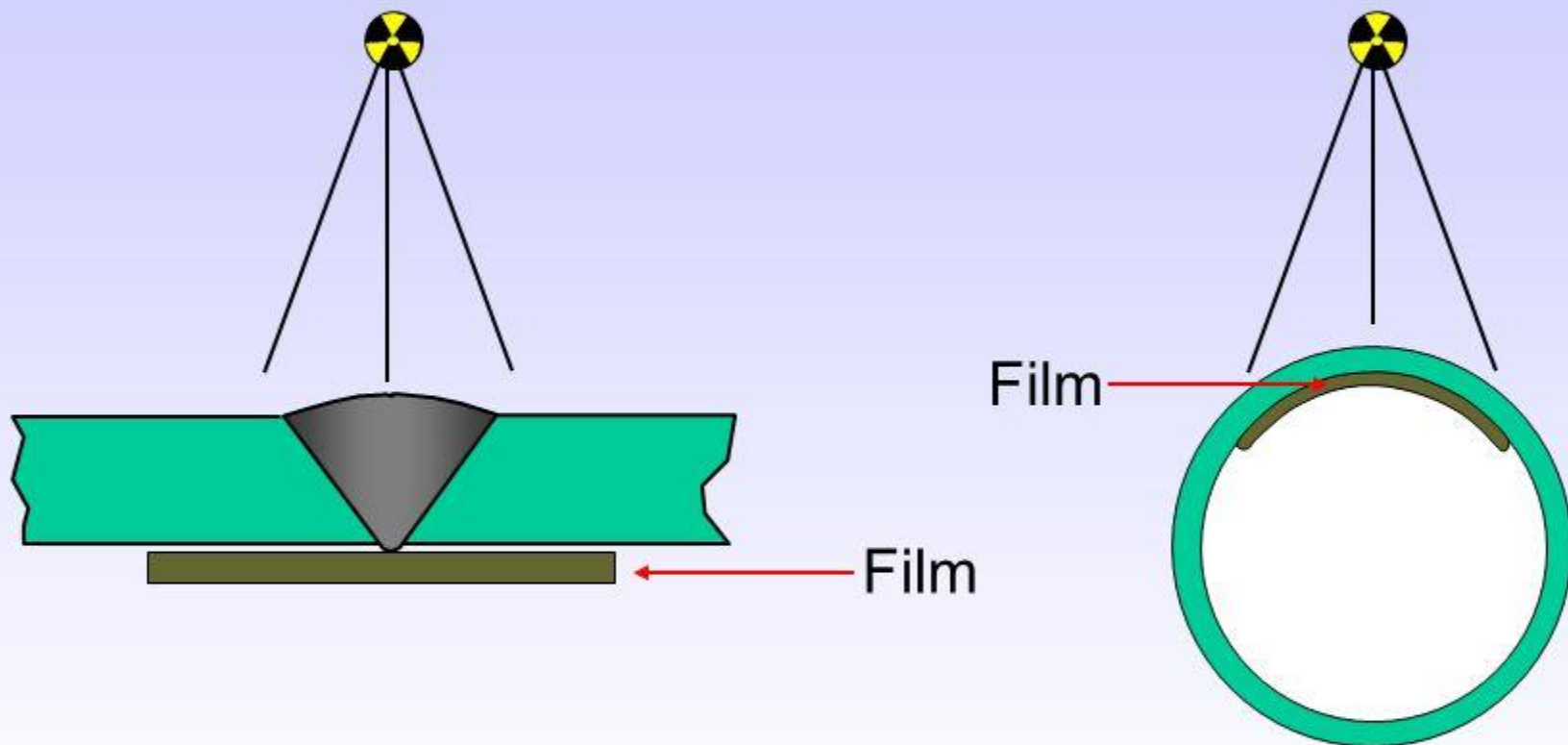


Panaromic Technique

Radiation source is kept in the centre of the pipe and the film is fixed around the weld on the outer surface of the pipe

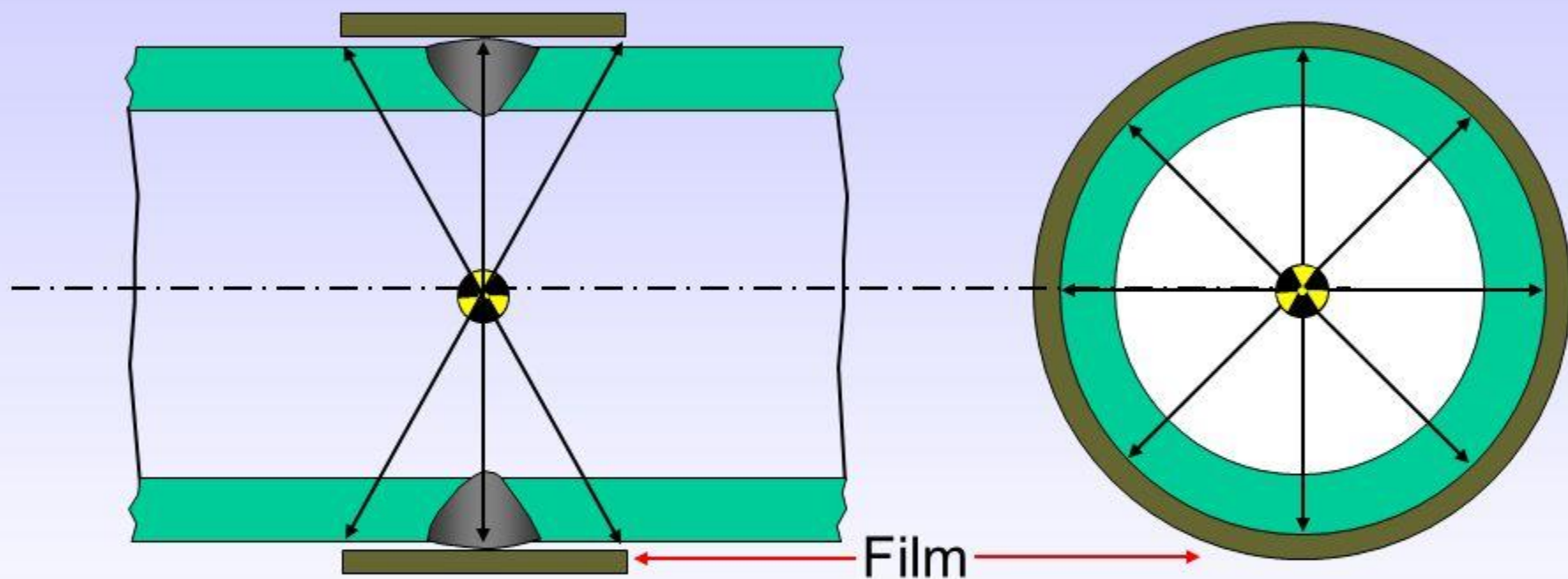
Reduces the examination time, IQI can be placed either on source side or film side and SFD is sufficient enough to ensure the proper sensitivity

Single wall single image SWSI



IQI's should be placed source side

Single wall single image SWSI panoramic

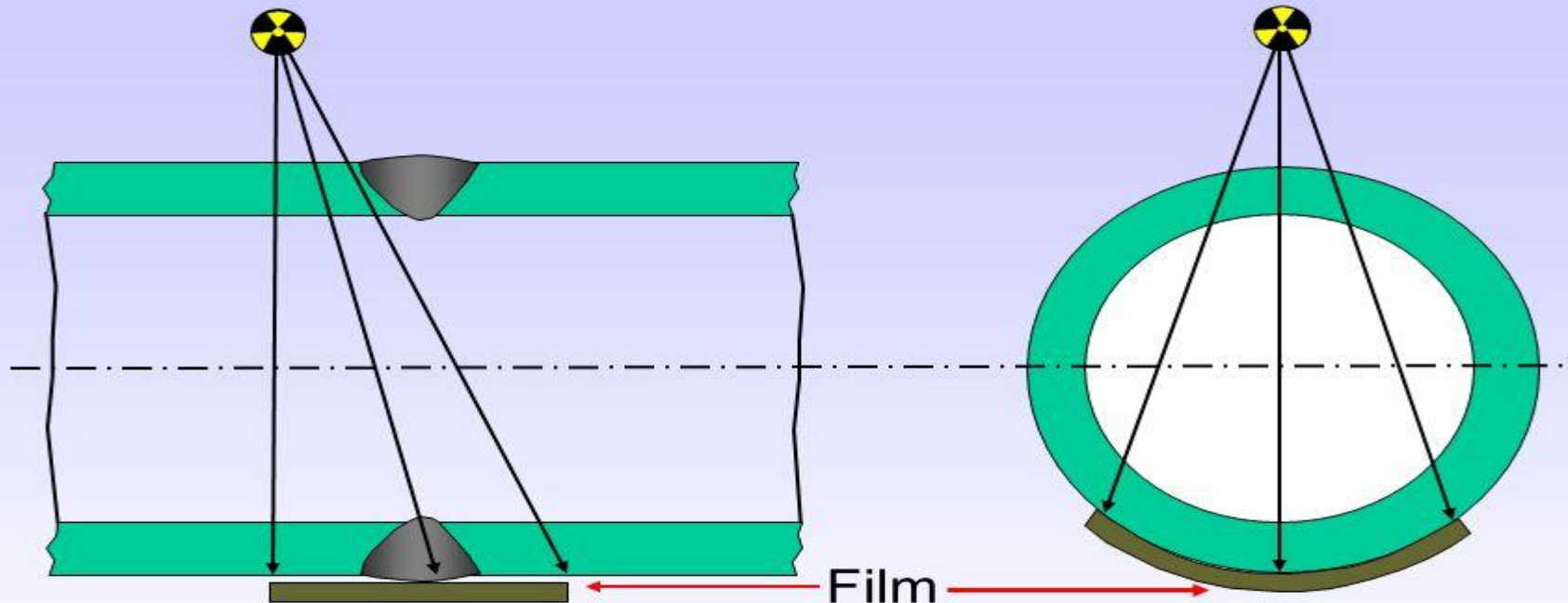


- IQI's are placed on the film side
- Source inside film outside (single exposure)

2. Double wall single image



Double wall single image DWSI

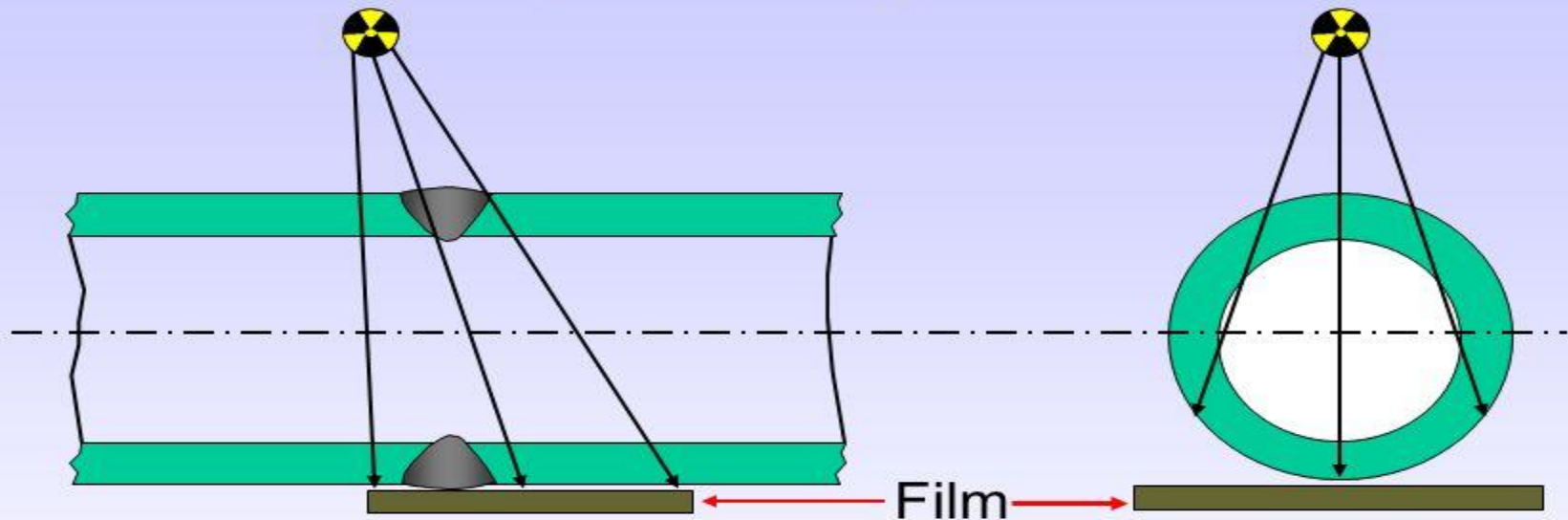


- IQI's are placed on the film side
- Source outside film outside (multiple exposure)
- This technique is intended for pipe diameters over 100mm

3. Double wall double image(DWDI)



Double wall double image DWDI elliptical exposure

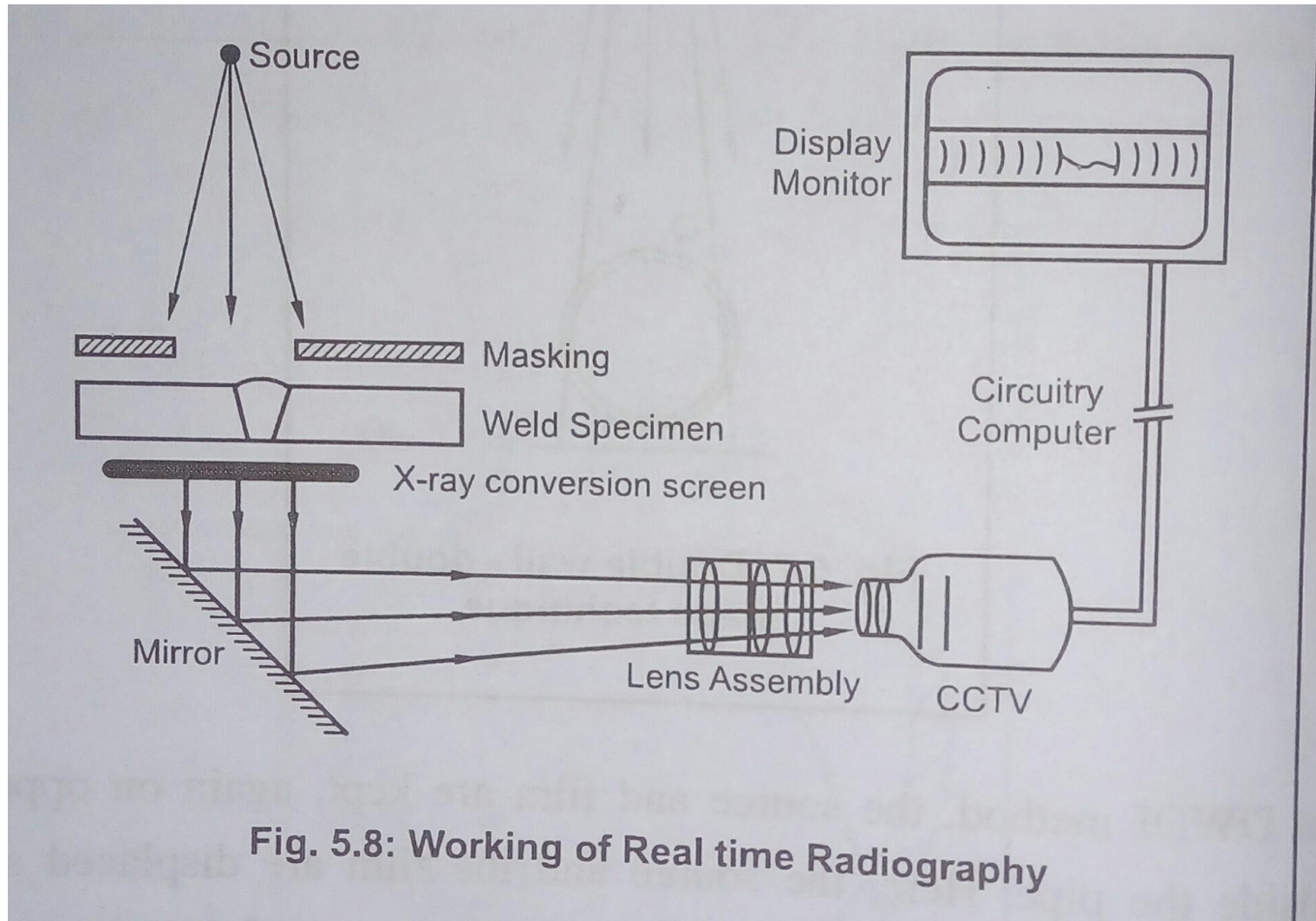


- IQI's are placed on the source or film side
- Source outside film outside (multiple exposure)
- A minimum of two exposures
- This technique is intended for pipe diameters less than 100mm

Real Time Radiography

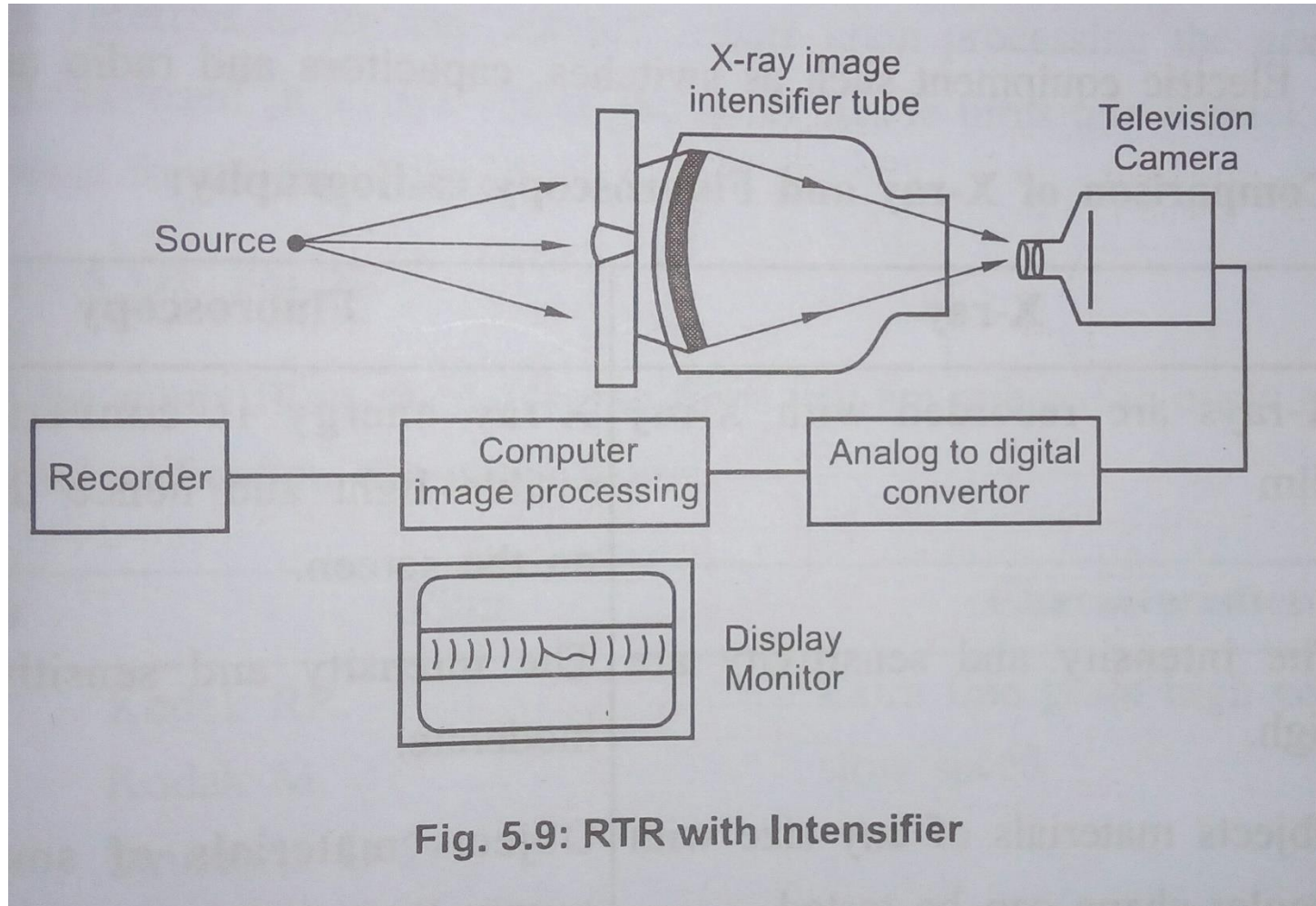
- Real time radiography also known as fluoroscopy, is a technique in which the X-ray radiation is converted into light by using a fluorescent screen in the place of the film.
- The process of the image of the object by converting the X-rays into light on the fluorescent screen is known as fluoroscopy or real time radiography.

Arrangement and working principle



- In this method, the radiation after passing through the material is recorded on the fluorescent screen. The image of the test piece which is obtained by the fluorescent screen, is received by CCTV and is then amplified using the amplification circuit associated with the camera.
- The amplified circuit is then processed by the computer. The processed image is then displayed on the monitor. The monitor is operated by means of a remote from the X-ray source to avoid the exposure to radiation.
- The image obtained using this method is usually faint and the sensitivity is very low. Therefore, to improve the quality of image, should employ the image intensifier equipment.

The image intensifier is a large glass enclosed electron tube. The function of image intensifier is to convert radiation to light, light to electron for intensification and electron back to light for viewing. The use of Fluoroscopic units in conjunction with these image intensifying system greatly enhances the versatility and sensitivity of the real-time radiographic setup



Advantages of RTR

- Can take place at high speed
- Low cost

Disadvantages of RTR

- Cost of the equipment is high
- Not portable to gamma ray
- Special cabinet is required to keep exposure radiation within regulations

Applications of RTR

- Laser weld in thin wall sections
- Electron beam weld in thin pipes

Films used in industrial Radiography

- X-ray films for general radiography consist of an emulsion-gelatin containing radiation sensitive silver halide crystals, such as silver bromide or silver chloride, and a flexible, transparent, blue-tinted base. The emulsion is different from those used in other types of photography films to account for the distinct characteristics of gamma rays and x-rays, but X-ray films are sensitive to light. Usually, the emulsion is coated on both sides of the base in layers about 0.0005 inch thick.
- Putting emulsion on both sides of the base doubles the amount of radiation-sensitive silver halide, and thus increases the film speed. The emulsion layers are thin enough so developing, fixing, and drying can be accomplished in a reasonable time. A few of the films used for radiography only have emulsion on one side which produces the greatest detail in the image.

Types of film

Class	Film	Characteristics
Class I	Kodak R R	Extra fine grain high contrast,low speed
	Kodak M	
	Structurix D 2	
Class II	Kodak A A	fine grain high contrast, medium speed
	Structurix D 4	
	Structurix D 7	
Class III	Kodak kodirex X	High Speed
	Structurix D 10	
Class IV	These are screen type films used in conjunction with fluorescent screens and are not recommended in industrial radiography	

Speed of the film

The film speed is an important parameter in film radiography. Based on the grain size and exposure time, films are classified in two ways.

1) *High speed films:* A film is called high speed film when its grain would begin reacting to the exposure considerably sooner than other films and have larger grains may not be able to produce the minute detail.

2) *Low speed films:* A film is called low speed film when its grain would begin reacting to the exposure considerably slower than other films and have extra fine grain, which gives better quality

Quality of the film

Its depends on two factors

Film Density

Film graininess

Screens used in Radiography

Screens

Radiographic film emulsion, when exposed to radiation, absorbs only a small amount of radiation. In order to fully utilize the radiation and enhance the photographic effect, screens are used in combination with films. Screens are of two types: metal foil screens and fluorescent salt screens.

Metal foil screens are usually lead foil screens, consisting of lead foil mounted on cardboard or plastic. These are used in pairs by sandwiching the film between them. One of the screens facing the source side is called the front screen and the other, the back screen—which is placed behind the film.

The main advantages of using lead screens are:

- Enhancement of photographic action on the film by emission of photoelectrons and secondary radiations generated in the lead
- Soft scattered radiation is absorbed more than the primary radiation
- Photographic effect of the primary radiation is intensified at higher energies
- The harmful effect of scattered radiation is reduced, thereby producing greater contrast and clarity in the radiographic image
- Higher intensification reduces exposure time

Besides lead intensifying screens, other metal screens such as copper, tantalum and tungsten screens are also used in high KV X-ray and Co_{60} gamma ray radiography.

Table 2.6 gives screen materials and thickness of front and back screens for various radiations.

Fluorescent intensifying screen or salt screens Fluorescent intensifying screens or salt screens consist of a powdered fluorescent material, such as calcium tungstate or barium lead sulfate, of which a thin

uniform layer is spread with a suitable binder on a cardboard or a plastic support. The fluorescent material emits visible or ultraviolet light when exposed to X-rays or gamma rays. The intensity of emitted light depends on the intensity of incident radiation. The main advantage of using fluorescent salt screens is to drastically reduce the exposure time since the intensification factor is very high compared to lead intensifying screens. However, the intensification factor diminishes both at lower as well as very high energies. The use of these screens is limited in the field of industrial radiography because they produce poor definition and grainy images.

Fluorescent screens are not used in gamma radiography, as intensification is poor with long exposures, usually common in gamma ray radiography.

Foreign particles—dirt, dust, etc.—should be prevented from accumulating between the screen and the film, as they tend to cast their shadow on the film. Further, the screen should not be exposed to the primary beam and should be stored away from chemicals and other sources of contamination.

Quality of a good radiography

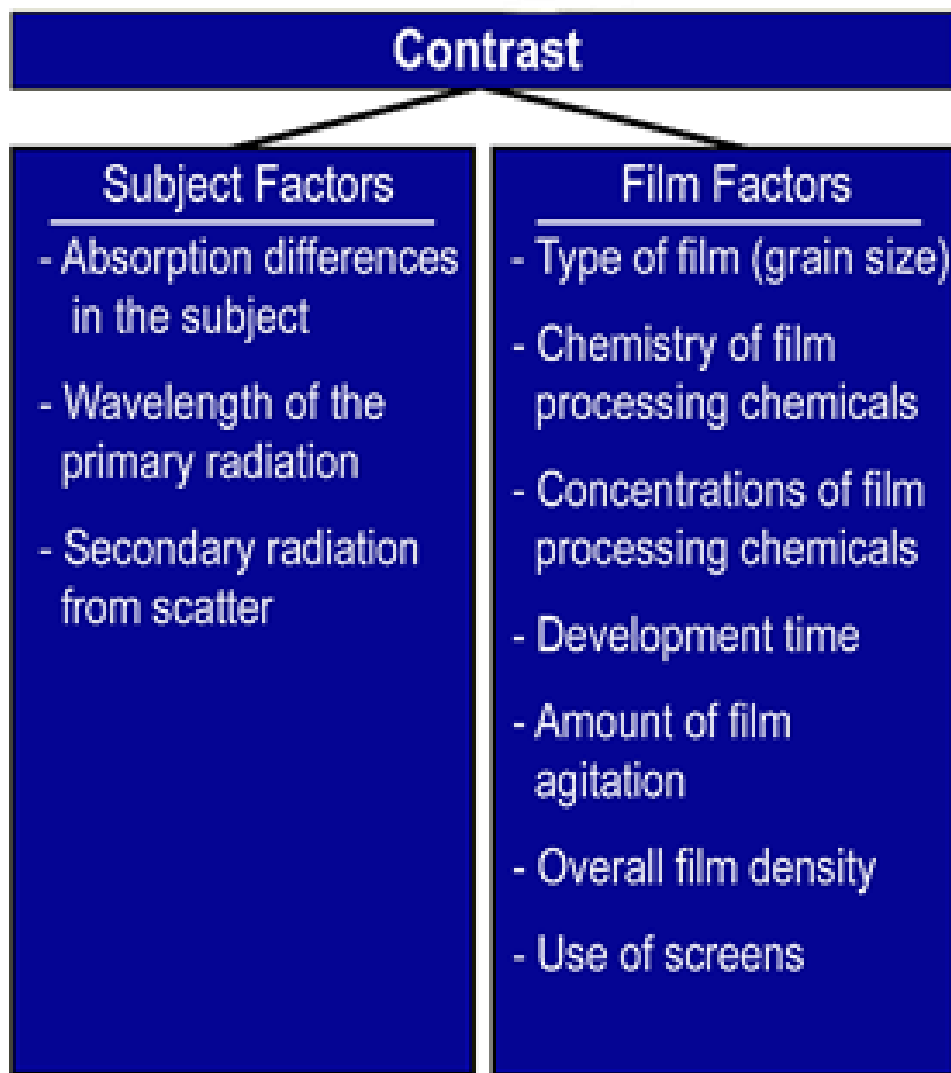
- The quality of a radiograph is generally assessed using four criteria they are.
- Density
- Contrast
- Definition
- Sensitivity

Radiographic Density

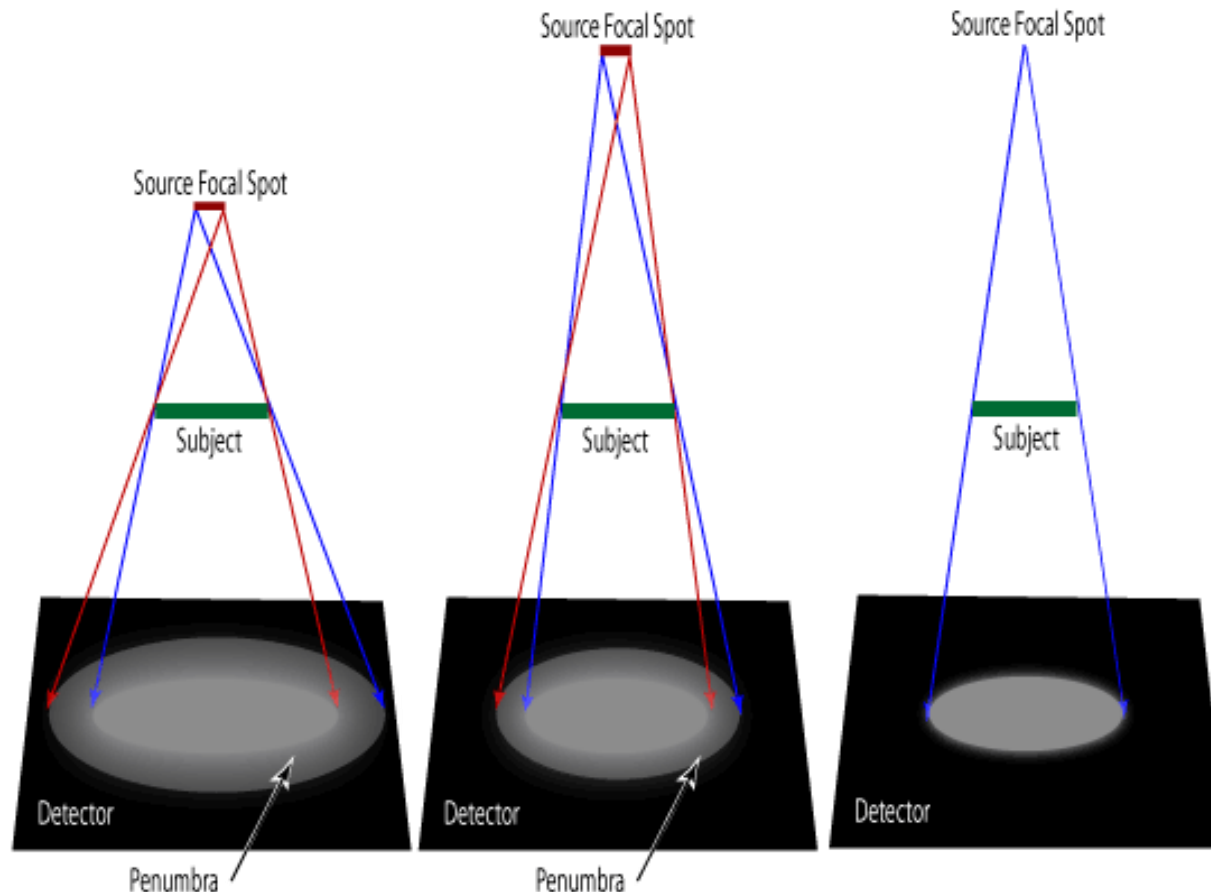
Radiographic density (photographic, or film density) is a measure of the degree of film darkening. Technically it should be called "transmitted density" when associated with transparent-base film since it is a measure of the light transmitted through the film. Radiographic density is the logarithm of two measurements: the intensity of light incident on the film (I_0) and the intensity of light transmitted through the film (I_t). This ratio is the inverse of transmittance.

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

Radiographic **contrast** describes the differences in photographic density in a radiograph. The contrast between different parts of the image is what forms the image and the greater the contrast, the more visible features become. Radiographic contrast has two main contributors: subject contrast and detector (film) contrast.



Geometric factors of the equipment and the radiographic setup, and **film and screen factors** both have an effect on **definition**. Geometric factors include the size of the area of origin of the radiation, the source-to-detector (film) distance, the specimen-to-detector (film) distance, movement of the source, specimen or detector during exposure, the angle between the source and some feature and the abruptness of change in specimen thickness or density.



Definition	
Geometric Factors	Film and Screen Factors
- Size of source (focal-spot size)	- Type of film (grain size)
- Source to film distance	- Mottling due to use of a fluorescent screen
- Specimen to detector (film) distance	- Wavelength of the primary radiation
- Movement of the specimen during the exposure	- Development time and other film processing factors
- Angle between source and features of interest	
- Abruptness of changes in specimen thickness	

Sensitivity

Radiographic sensitivity is a measure of the quality an image in terms of the smallest detail or discontinuity that may be detected. The higher the sensitivity, the higher the quality of radiograph

Film Processing

When the film is processed, it is exposed to several different chemical solutions for controlled periods of time. Processing film basically involves the following five steps.

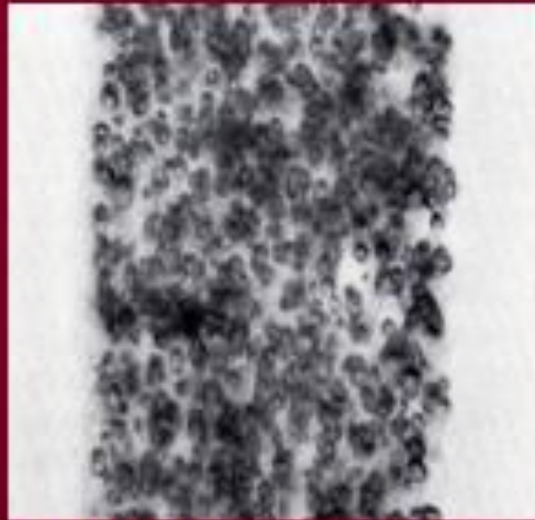
1. Development - The developing agent gives up electrons to convert the silver halide grains to metallic silver. Grains that have been exposed to the radiation develop more rapidly, but given enough time the developer will convert all the silver ions into silver metal. Proper temperature control is needed to convert exposed grains to pure silver while keeping unexposed grains as silver halide crystals.

2. Stopping the development - The stop bath simply stops the development process by diluting and washing the developer away with water.

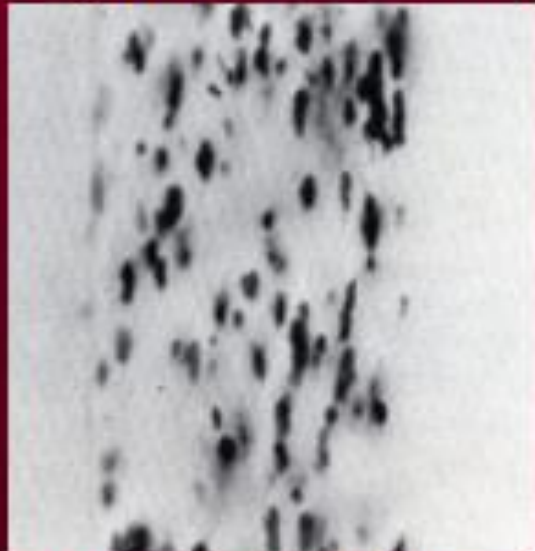
3. Fixing - Unexposed silver halide crystals are removed by the fixing bath. The fixer dissolves only silver halide crystals, leaving the silver metal behind.

4. Washing - The film is washed with water to remove all the processing chemicals.

5. Drying - The film is dried for viewing.



Unprocessed Film

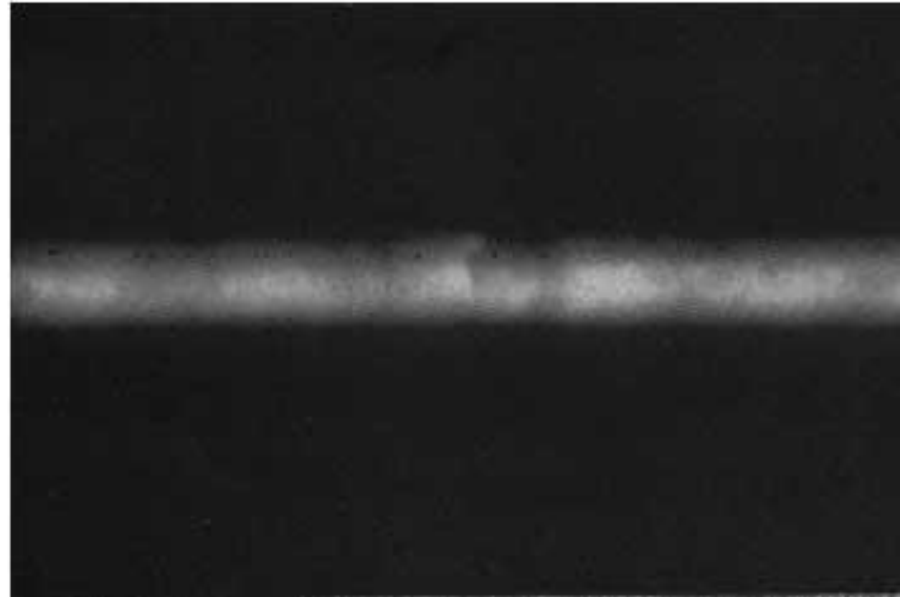
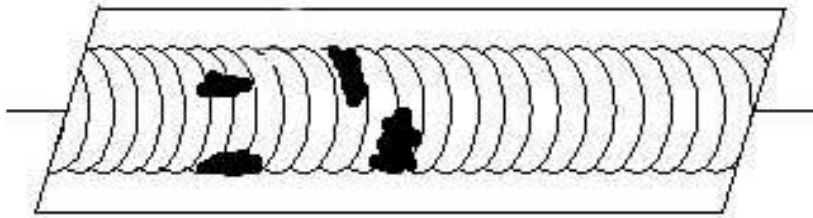
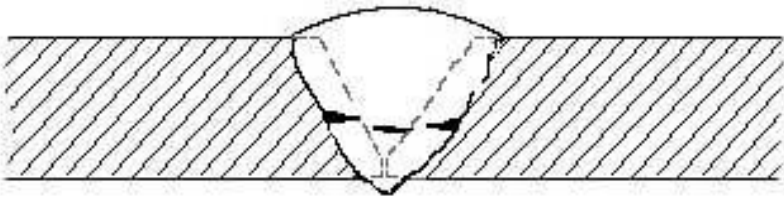


Processed Film

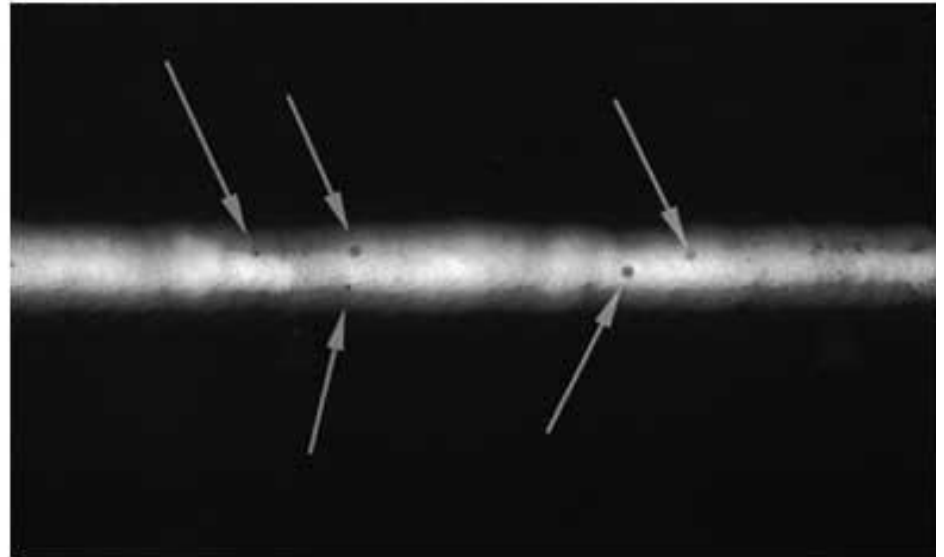
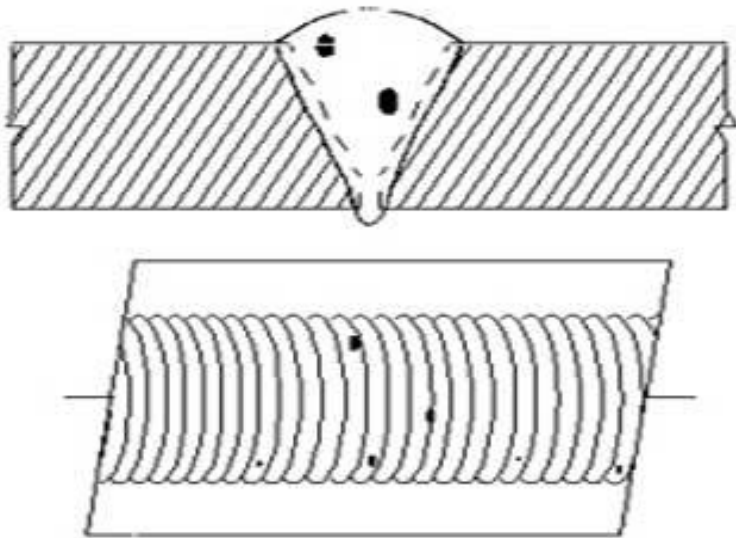
Photos Courtesy of Kodak

Interpretation and Evaluation

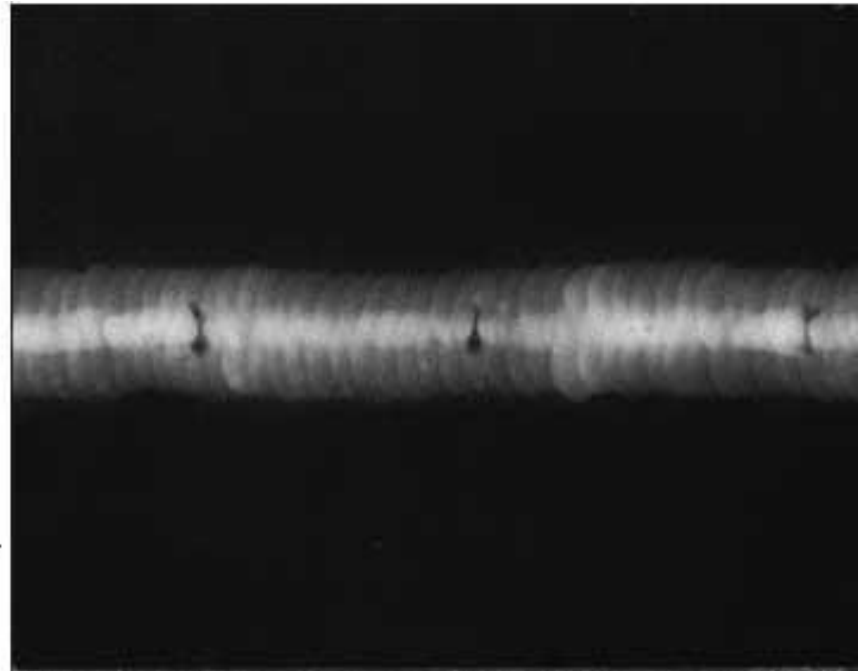
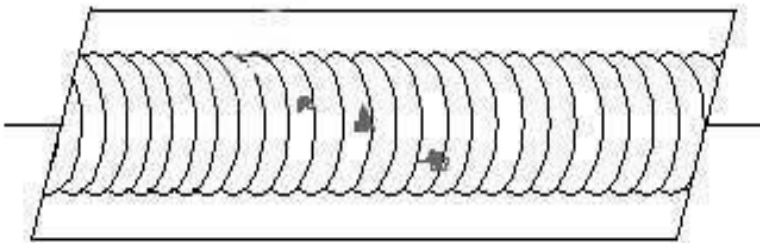
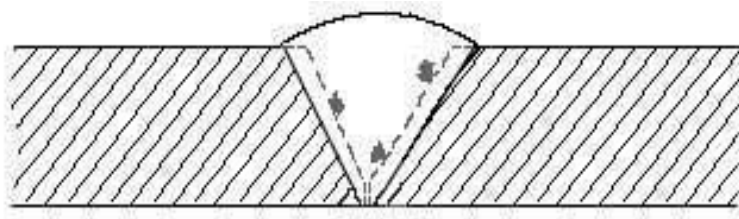
Cold lap is a condition where the weld filler metal does not properly fuse with the base metal. The arc does not melt the base metal sufficiently and causes the slightly molten puddle to flow into the base material without bonding.



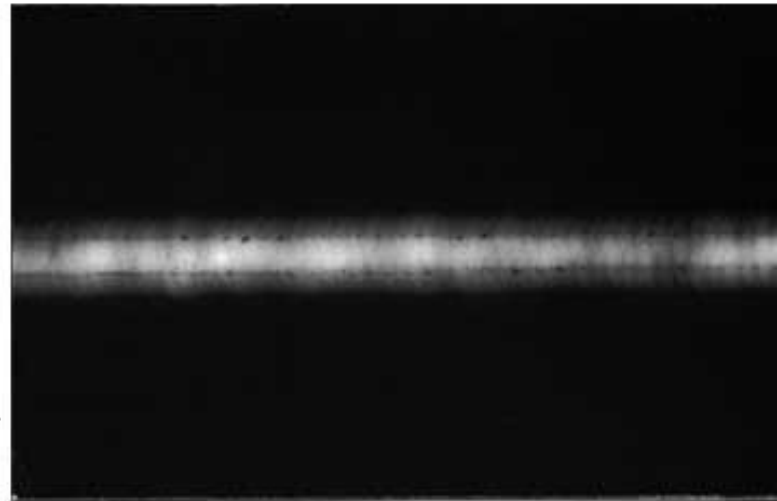
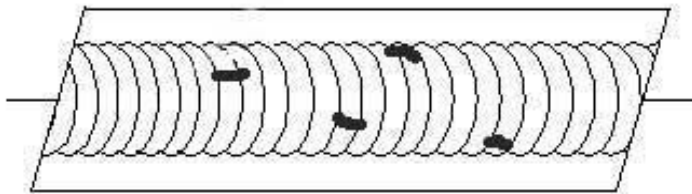
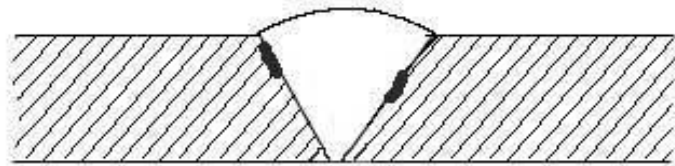
- **Porosity** is the result of gas entrapment in the solidifying metal. Porosity can take many shapes on a radiograph but often appears as dark round or irregular spots or specks appearing singularly, in clusters, or in rows. Sometimes, porosity is elongated and may appear to have a tail. This is the result of gas attempting to escape while the metal is still in a liquid state and is called wormhole porosity. All porosity is a void in the material and it will have a higher radiographic density than the surrounding area



Slag inclusions are nonmetallic solid material entrapped in weld metal or between weld and base metal. In a radiograph, dark, jagged asymmetrical shapes within the weld or along the weld joint areas are indicative of slag inclusions.



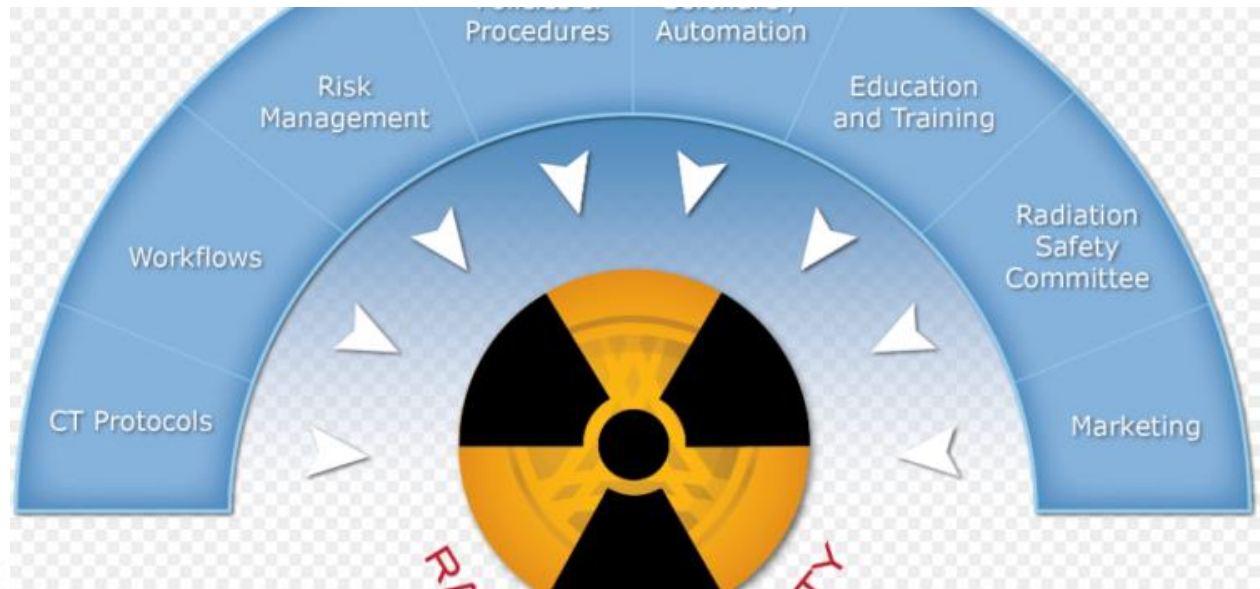
Incomplete fusion is a condition where the weld filler metal does not properly fuse with the base metal. Appearance on radiograph: usually appears as a dark line or lines oriented in the direction of the weld seam along the weld preparation or joining area.



Safety requirement in Radiography

Two main aspects of safety

1. Monitoring radiation dosage
2. Protection of personal



Radiation dose monitoring

- Thermo-Luminescent Dosimeters
- Real-time monitoring devices
 - Pocket dosimeters
- Area surveillances using survey meters



Real time monitoring



Survey meter





Radiation Safety





Use of radiation sources in industrial radiography is heavily regulated by state and federal organizations due to potential public and personal risks.



Radiation Safety (cont.)

There are many sources of radiation. In general, a person receives roughly 100 mrem/year from natural sources and roughly 100 mrem/year from manmade sources.

Natural Sources		Annual Dose (mrem/year)
	Cosmic rays (radiation from the sun and outer space)	28
	Building materials	4
	The human body	25
	The earth	26

Manmade Sources		Annual Dose (mrem/year)
	Medical (primarily from diagnostic X-rays)	90
	Fallout from atomic bombs	5
	Nuclear power production	.3
	Consumer products (mostly from color TV sets)	1

Radiation Safety (cont.)



Technicians who work with radiation must wear monitoring devices that keep track of their total absorption, and alert them when they are in a high radiation area.



Survey Meter



Pocket Dosimeter



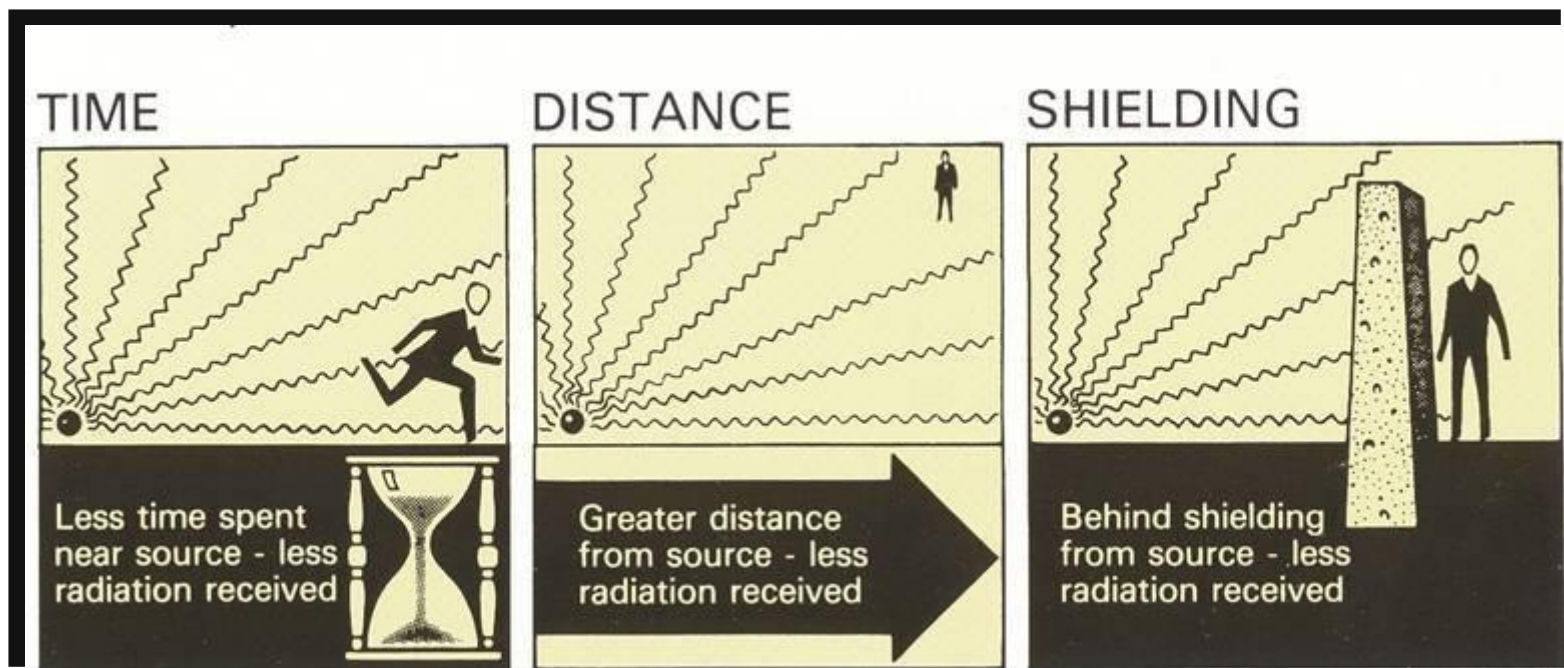
Radiation Alarm



Radiation Badge

Radiation Safety (cont.)

There are three means of protection to help reduce exposure to radiation:



Advantages of Radiography

- Technique is not limited by material type or density.
- Can inspect assembled components.
- Minimum surface preparation required.
- Sensitive to changes in thickness, corrosion, voids, cracks, and material density changes.
- Detects both surface and subsurface defects.
- Provides a permanent record of the inspection.

Disadvantages of Radiography

- Many safety precautions for the use of high intensity radiation.
- Many hours of technician training prior to use.
- Access to both sides of sample required.
- Orientation of equipment and flaw can be critical.
- Determining flaw depth is impossible without additional angled exposures.
- Expensive initial equipment cost.

Applications

- Can be used in most types of solid materials both ferrous and non-ferrous as well as non-metallic and composites.
- This is used for castings , weldments and forgings
- Used for semi conductor devices for detection of cracks, broken wires.