Non-Destructive Evaluation (NDE)

Chapter 7

Radiographic Testing

Mohamad Fathi GHANAMEH

Radiographic Testing (RT)

- An NDT method that utilizes x-rays or gamma radiation to detect discontinuities in materials, and to present their images on recording medium.
- X-rays and gamma rays are types of electromagnetic radiation of shorter wavelengths than visible light:

$\lambda_{visible}$ = 600 Angstroms, $\lambda_{x\text{-}rays}$ = 1 A, $\lambda_{gamma\ rays}$ = 0.0001 A

  - shorter wavelengths permit penetration through materials
  - high energy levels break chemical bonds

    *Leads to destruction of living tissue

- X-rays and gamma rays differ only in source of origin

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 surface, subsurface and internal 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.

Basic Principles

Atoms and Their Components

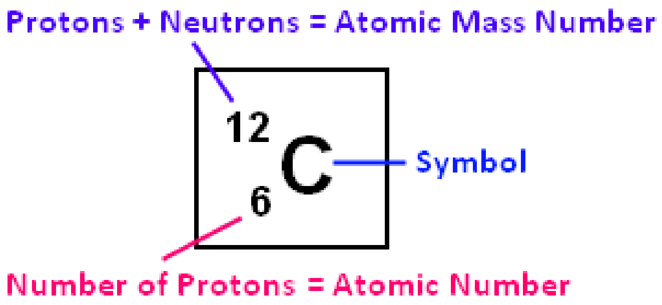
- Subatomic particles organize to form all atoms.
  - The three basic subatomic particles are the proton, neutron, and electron.
  - Protons and electrons are charged particles.
  - Neutrons are neutral or uncharged.
  - Protons have a positive (+) charge, and electrons have a negative (-) charge.
  - Overall, atoms have *no charge* because the number of protons is equal to the number of electrons.

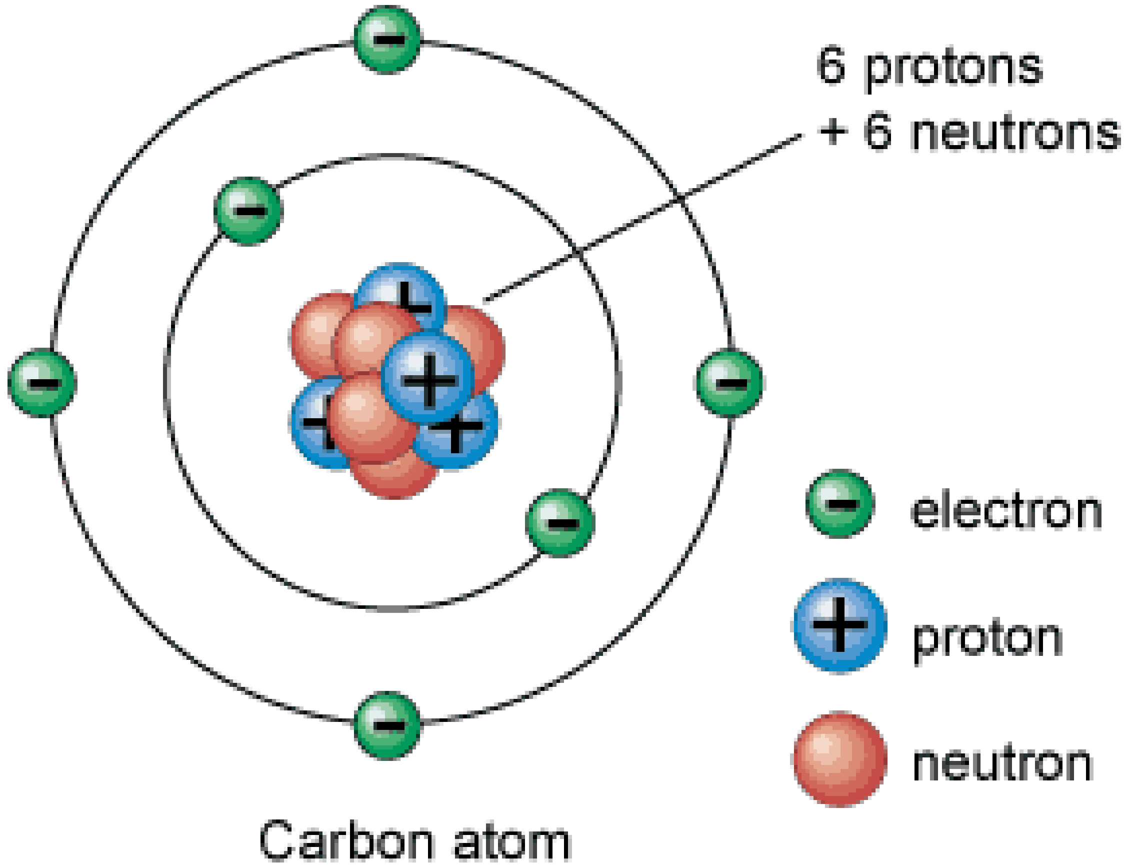
Basic Principles

Atoms and Their Components

- Structure of an Atom
  - Protons and neutrons are clustered together in the nucleus.
  - Electrons are dispersed throughout the area around the nucleus.
  - The space occupied by the electrons is called the electron cloud since the electrons are constantly moving and are difficult to pinpoint
  - Most of an atom consists of empty space.

Basic Principles





Basic Principles

Atomic Number and Mass Number

- All atoms of the same element always have the same number of protons.
- Atomic Number
  - The number of protons in an atom of any element can be determined from the periodic table.
  - The number that appears above each element within its block is its atomic number.
  - The atomic number indicates the number of protons present.

Basic Principles

Atomic Number and Mass Number

- The number of protons gives an atom its unique properties.
- A carbon atom, atomic number 6, contains six protons.
- All atoms of carbon have six protons.
- Because atoms are neutral (no charge), the number of electrons in an atom is equal to the number of protons.
- Carbon must contain six electrons.

Basic Principles

Atomic Number and Mass Number

- Mass Number
  - The number of neutrons in an atom can be found from an atom's mass number, which is the # of protons plus the # of neutrons.
  - Once the atomic number and the mass number are known, you can determine the number of subatomic particles present.
  - We can represent an atom in symbolic notation:

$$^{12}_{6}C$$

Basic Principles

Isotopes and Atomic Mass

- Atoms of the same element *can* have different numbers of neutrons.
- Not all atoms of the same element have the same mass number.
- Atoms of the same element with different mass numbers are called isotopes.
- Isotopes can be indicated in two ways:
  - Symbolic notation
  - Stating the mass number after the element name: carbon-12

Basic Principles

Isotopes and Atomic Mass

Symbolic Notation for Isotopes

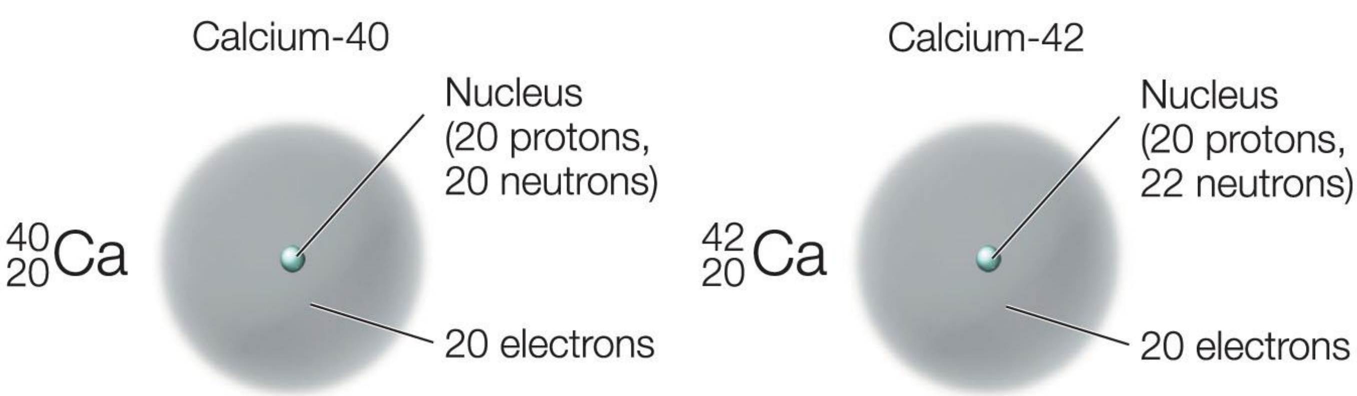
$${}^{A}_{Z}X$$

A = Mass Number

Z = Atomic Number

X = Atomic symbol

Isotopes of Calcium and the Number of Particles in Each



Basic Principles

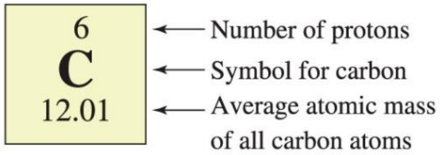
Isotopes and Atomic Mass

- The number below each element on the periodic table shows ***the average atomic mass*** for that element.
- The atomic mass depends on the proportion of each isotope.
- The **atomic mass** is the average atomic mass weighted for all the isotopes of that element found naturally.

Basic Principles

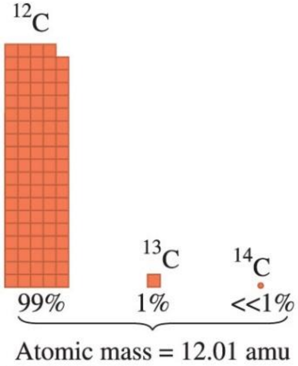
Isotopes and Atomic Mass

(a)



Isotope	^{12}C	^{13}C	^{14}C
Atomic number	6	6	6
Protons	6	6	6
Neutrons	6	7	8
Abundance	Most	1/100	1/1,000,000,000,000

(b)



Basic Principles

Radioactivity and Radioisotopes

- Energy given off spontaneously from the nucleus of an atom is called nuclear radiation.
- Elements that emit radiation are said to be *radioactive*.
- Radiation is a form of energy that we get from natural and human-made sources.
- In 1896, Henri Becquerel got an exposure on a photographic plate by exposing the plate to a rock that contained uranium.

Basic Principles

Radioactivity and Radioisotopes

- Most naturally occurring isotopes have a stable nucleus and are not radioactive.
- Isotopes that are not stable become stable by spontaneously emitting radiation from their nuclei.
- This is radioactive decay.
- Isotopes that emit radiation are also called radioisotopes.
- All the isotopes of elements with atomic number 83 and higher are radioactive.
- Some smaller elements also have radioisotopes.

Basic Principles

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Basic Principles

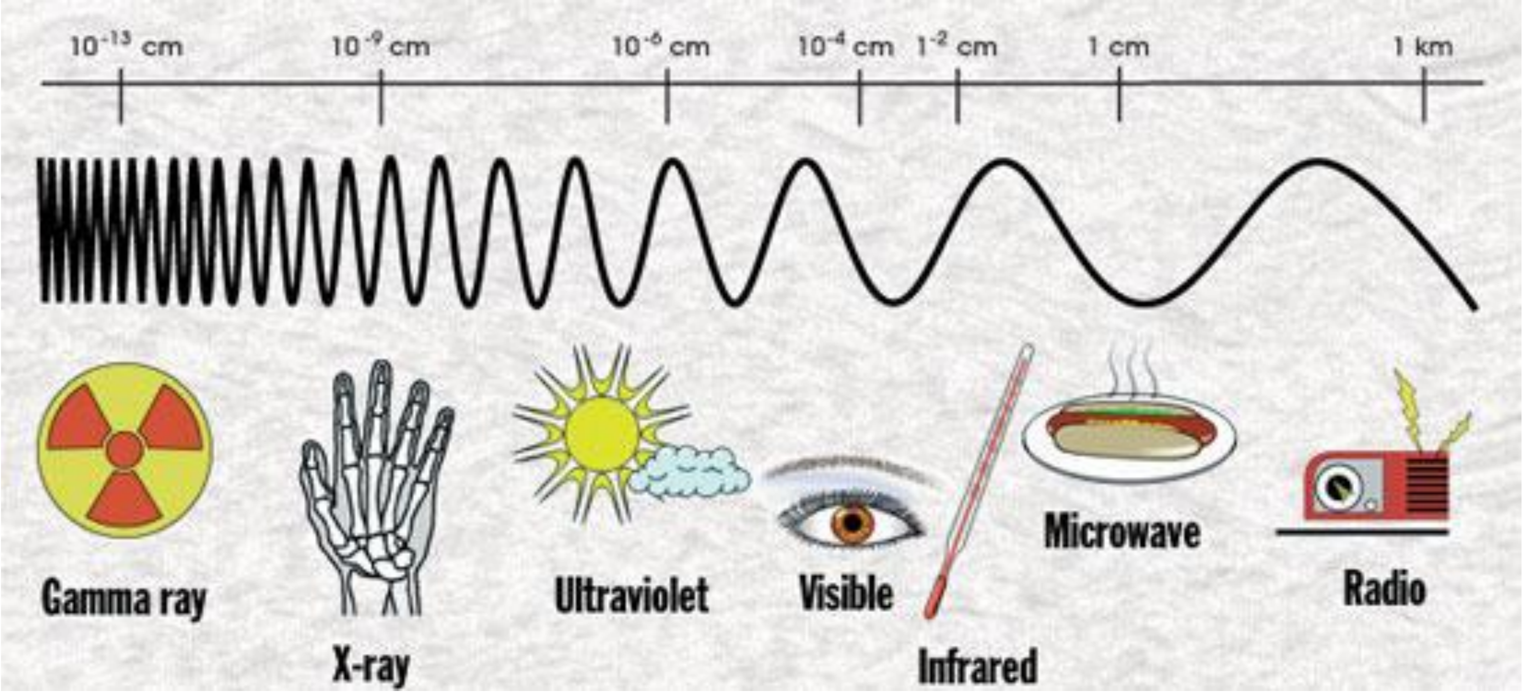
Radiation Properties

- Undetectable by human senses
  - Cannot be seen, felt, heard, or smelled
- Possesses no charge or mass
  - Referred to as photons (packets of energy)
- Generally travels in straight lines (can bend at material interfaces)
- Characterized by frequency, wavelength, and velocity
- Part of electromagnetic spectrum but not influenced by electrical or magnetic fields

Basic Principles

Electromagnetic Spectrum

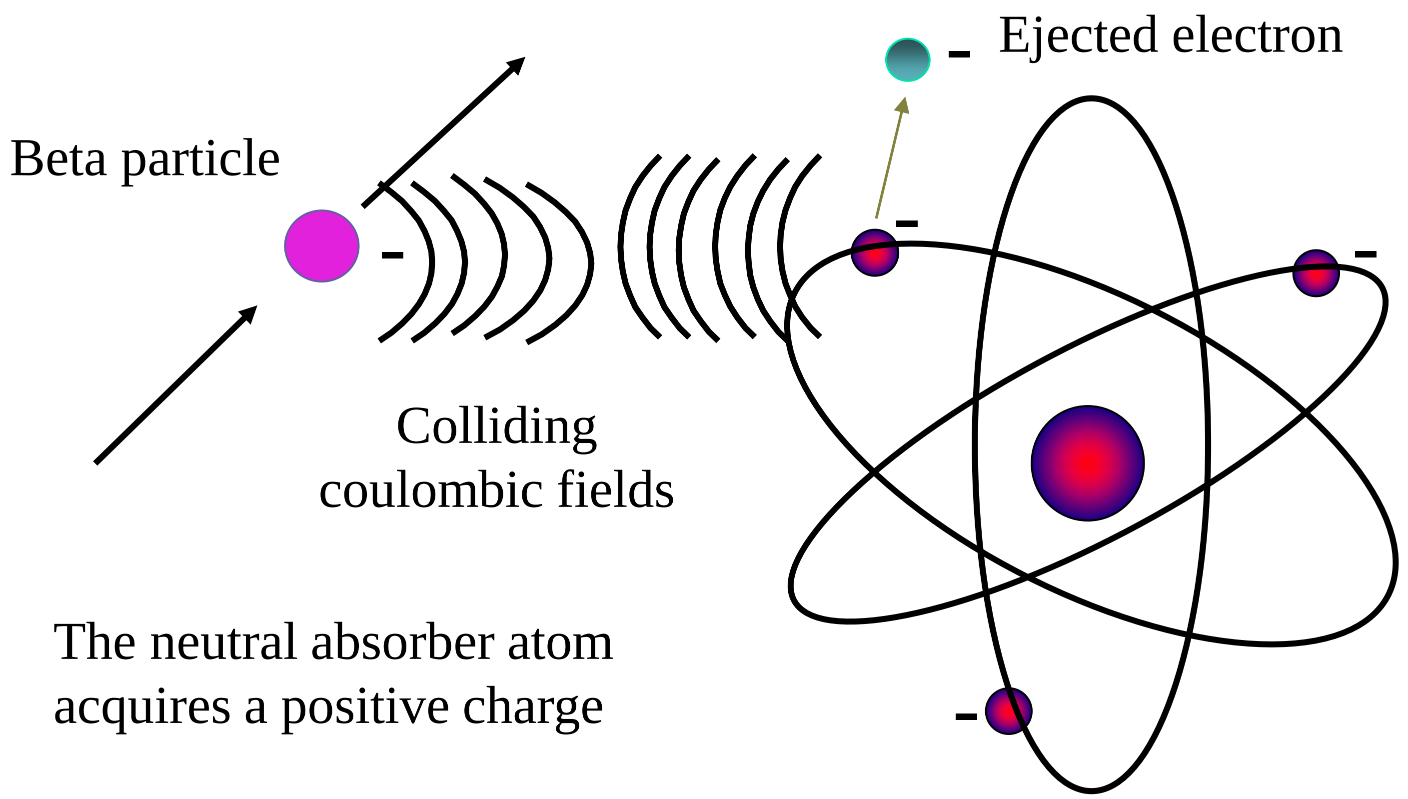
The radiation used in Radiography testing is a higher energy (shorter wavelength) version of the electromagnetic waves that we see every day. Visible light is in the same family as x-rays and gamma rays.



Basic Principles

Ionizing

Formation of a charged and reactive atom



Basic Principles

Ionizing

▪**<u>Non-Ionizing Radiation</u>**: Radiation that does not have sufficient energy to dislodge orbital electrons.

Examples of non-ionizing radiation: microwaves, ultraviolet light, lasers, radio waves, infrared light, and radar.

▪**<u>Ionizing Radiation</u>**: Radiation that has sufficient energy to dislodge orbital electrons.

Examples of ionizing radiation: alpha particles, beta particles, neutrons, gamma rays, and x-rays.

Basic Principles

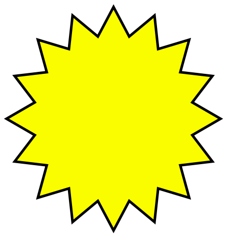
Ionizing radiation

- Occurs from the addition or removal of electrons from neutral atoms
- Four main types of ionizing radiation
  - alpha, beta, gamma and neutrons

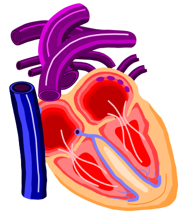
Basic Principles

Radioactive Sources

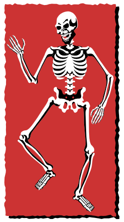
Solar Radiation



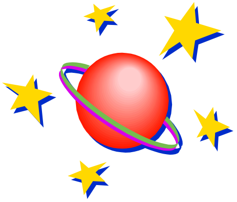
Nuclear Medicine



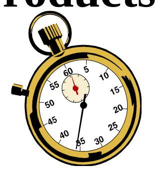
X-Rays



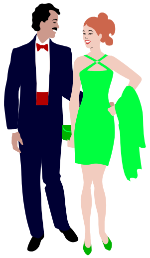
Cosmic Rays



Consumer Products

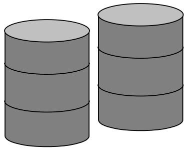


Each Other



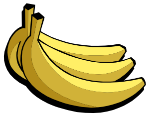
Radon $^{4}_{2}\alpha^{++}$

Radioactive Waste

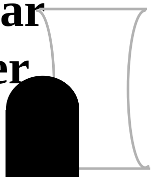


Terrestrial Radiation

Food & Drink



Nuclear Power



Basic Principles

Determining Half-Lives

Defined as the time required for the activity of a particular radioisotope to decrease to half of its original value

- Varies for different radioisotopes
- Ranges from microseconds to billions of years (uranium)

Half-life of Cobalt-60 = 5.3 years

Half-life Iridium-192 = 74 days

Carbon-14 dating

- used to approximate the age of fossils
- Decays with a half-life of 5730 years

$$\text{isotope remaining} = \left(\frac{1}{2}\right)^{n} \times \text{starting amount}$$

where n = the number of half-lives determined

Basic Principles

Radioactivity Units

Becquerel

- Amount of radioactive sample s.t. there is 1 atomic decay per second
- Henri Becquerel: discovered radioactivity through experiments with uranium and other radioactive matter

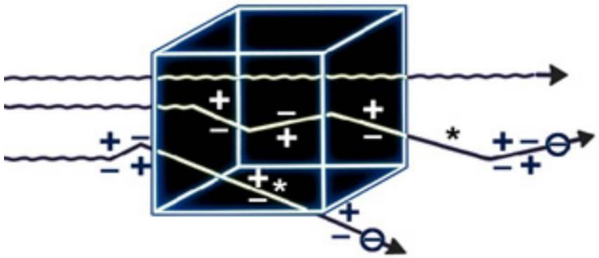
Curie (Ci)

- $3.7*10^{10}$ decays per second
- Approx. activity of 1g radium

Basic Principles

Radiation exposure

The roentgen is a unit for measuring *exposure*. It is defined only for effect on air. The roentgen is essentially a measure of how many ion pairs are formed in a given volume of air when it is exposed to radiation. Therefore it is **not** a measure of energy absorbed, or *dose*. It applies only to gamma and x-rays. It does not relate the amount of exposure to biological effects of radiation in the human body.



SI unit: coulomb/kilogram

Traditional unit: Roentgen (R) = 2.58×10^{-4} coulomb/kg

= $1 esu/cm^3$

Basic Principles

Radiation exposure

The roentgen describes the amount of x-rays or gamma rays to which a target (e.g., fly, mouse, rat, dog, human, cow, elephant, etc.) is exposed. The roentgen relates to the ability of x-rays and gamma rays to remove electrons from atoms in one cm^3 of air. 1 R (Roentgen) = 1000 mR (milliRoentgen)

Basic Principles

Absorbed dose (D)

Energy imparted to matter from any type of radiation

$$D = E/m$$

D: absorbed dose

E: energy absorbed by material of mass 'm'

Units of absorbed dose

The SI unit: gray (Gy)   1 Gy = 1 joule/kilogram

Old unit : rad   1 Gy=100 rad

Basic Principles

The rad is a unit for measuring *absorbed dose* in any material. Absorbed dose results from energy being deposited by the radiation. It is defined for any material. It applies to all types of radiation. It does **not** take into account the potential effect that different types of radiation have on the body.

Therefore, it can be used as a measure of energy absorbed by the body, but not as a measure of the relative biological effect (harm or risk) to the body.

Basic Principles

Different absorbed doses can arise in different organs or tissue of the body for the same exposure in R. Thus, if a person were exposed to 10 R of gamma rays, the eye, the thyroid, and the lung would have different absorbed doses. Special computer programs can calculate such doses.

Units of absorbed dose often used are the rad and gray (an SI unit).

Basic Principles

Equivalent dose (H_T)

Accounts for biological effect per unit dose

radiation weighting factor (W_R) * absorbed dose (D)

$$H_T = W_R \times D$$

Unit of equivalent dose

SI unit: sievert (Sv) H_T (Sv) = W_R x D (Gy)

Old unit: rem (roentgen equivalent man)

$$H_T \text{ (rem)} = (W_R) \times D \text{ (rad)}$$

1 Sv = 100 rems

Basic Principles

Radiation weighting factor (W_R)

Radiation type and energy range		W_R
Photons (X-rays and gamma-rays) all energies		1
Electrons, all energies		1
Neutrons		
	<10 keV	5
	10-100 keV	10
	>100 kev to 2 MeV	20
	2-20 MeV	10
	>20 MeV	5
Protons	>20MeV	5
Alpha-particles, fission fragments		20

Basic Principles

Effective dose (E)

Risk related parameter, taking relative *radiosensitivity* of each organ and tissue into account

$E(Sv) = \Sigma_T W_T \times H_T$

W_T : tissue weighting factor for organ T

H_T : equivalent dose received by organ or tissue T

Basic Principles

Tissue and organ weighting factors

Organ or tissue	Tissue weighting factor (W_T)
Gonads	0.2
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05
Total	1.0

Basic Principles

Conversion between units used in radiation protection

Physical quantity	SI unit	Non-SI unit	Relationship
Activity	becquerel	curie (Ci)	1 Bq=2.7x10^{-11} Ci 1 Ci=3.7x10^{10}Bq 1 mCi=37 MBq
Exposure	coulomb/kg	roentgen ®	1 R=2.58x10^{-4} C/kg 1C/kg=3876 R
Absorbed dose	gray (=J/kg)	rad	1 Gy=100 rad 1 rad=1 cGy
Equivalent dose	sievert	rem	1 Sv=100 rem 1 rem=10 mSv

Basic Principles

Dose limits recomended by ICRP (1991) - whole body

Occupational exposure

50 mSv maximum in any 1 year
100 mSv in 5 years

Working figure 20 mSv per year

Public exposure

5 mSv in any 5 consecutive years

Working figure 1 mSv per year

Basic Principles

Annual doses to tissues

	Occupational	Public
Lens of the eye	150 mSv	15 mSv
Skin ($1 cm^2$)	500 mSv	
Hands and feet or individual organ	500 mSv	50 mSv

Basic Principles

Summary of Biological Effects of Radiation

- Radiation may…
  - Deposit Energy in Body
  - Cause DNA Damage
  - Create Ionizations in Body
    - Leading to Free Radicals
- Which may lead to biological damage

Basic Principles

Radiation protection

Basic principles of radiation protection

- Justification of practice
- Optimization of protection
- Individual dose limits

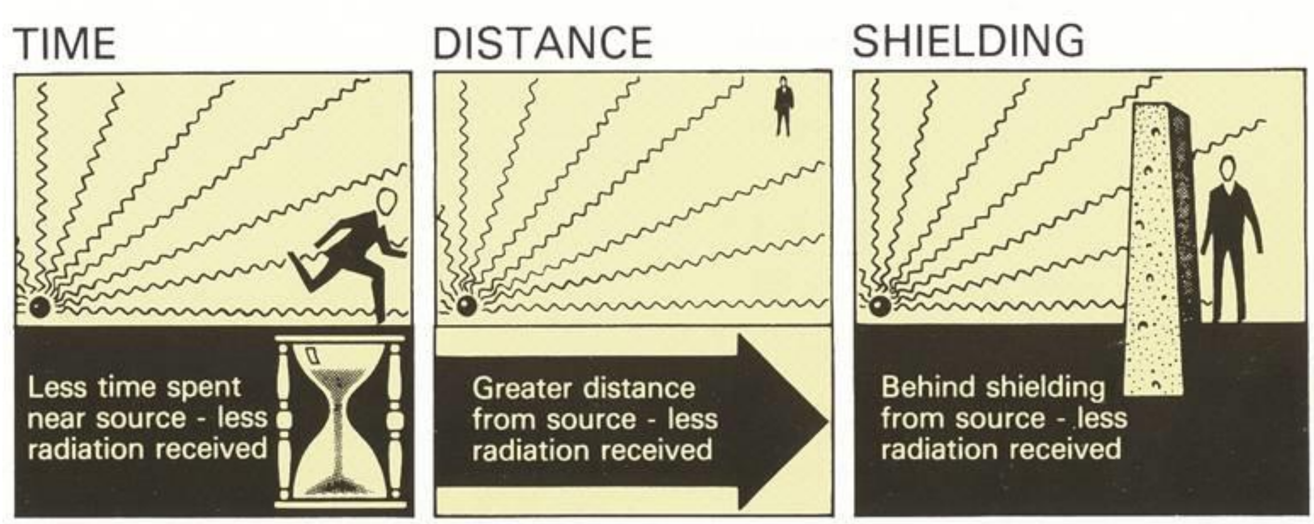
ALARA **As low as reasonably achievable**

Basic Principles

Radiation protection

Basic methods of protection against exposure to ionizing radiation

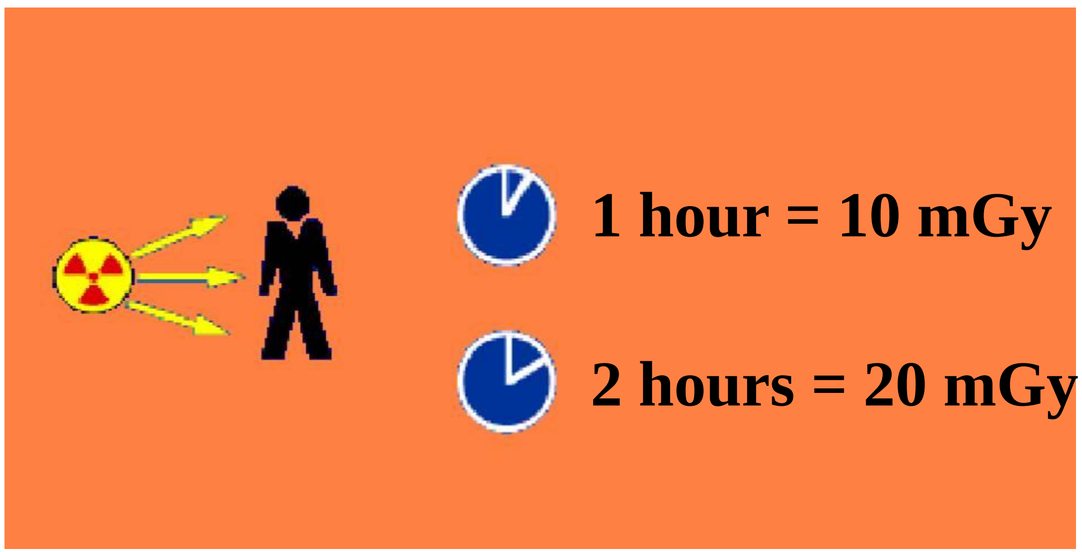
- Three basic factors
  - Time
  - Distance
  - Shielding



Basic Principles

Radiation protection - Time

Exposure rate =10mGy/h * Time = Total dose



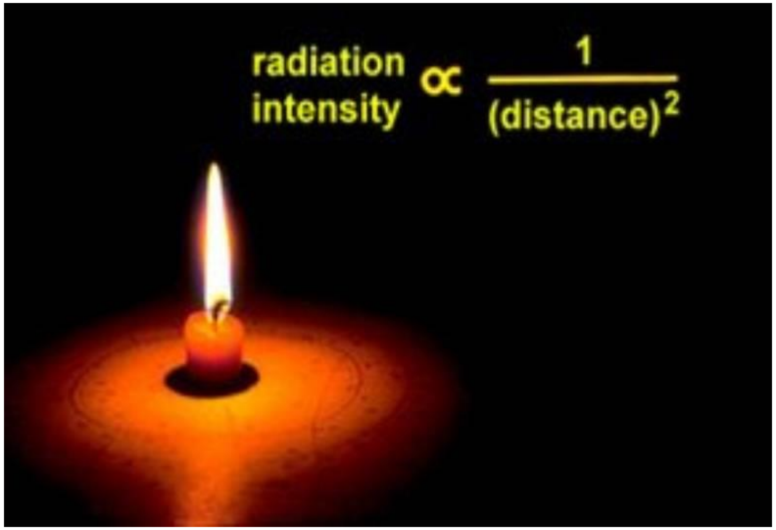
Basic Principles

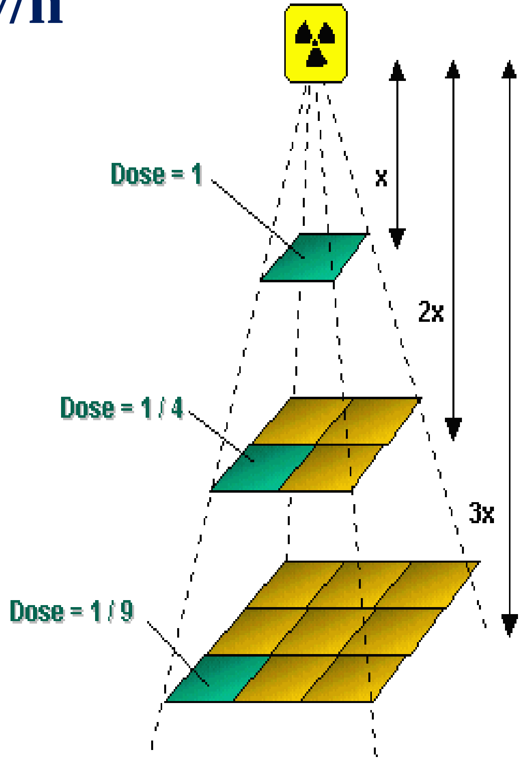
Radiation protection - Distance

Inverse square law

d=50cm

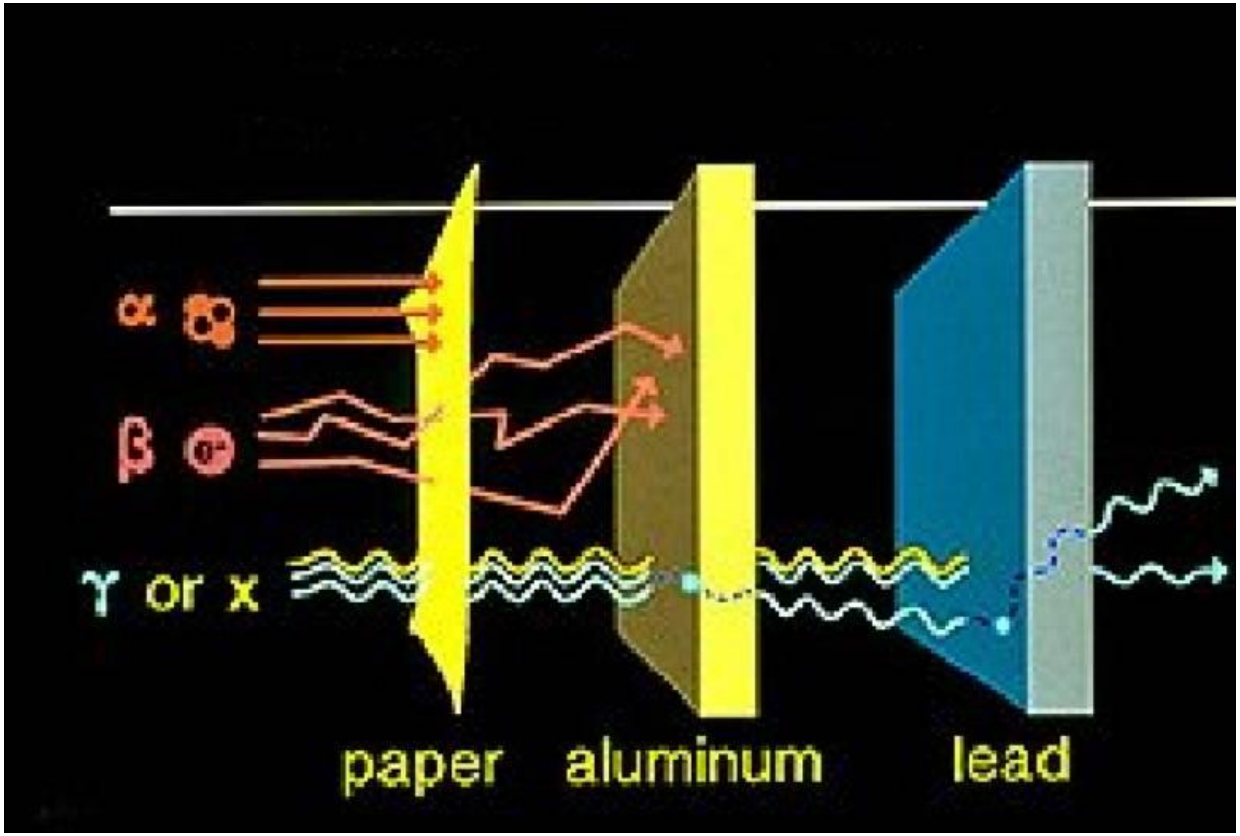
150 mSv/h } **0.06 mSv/h**





Basic Principles

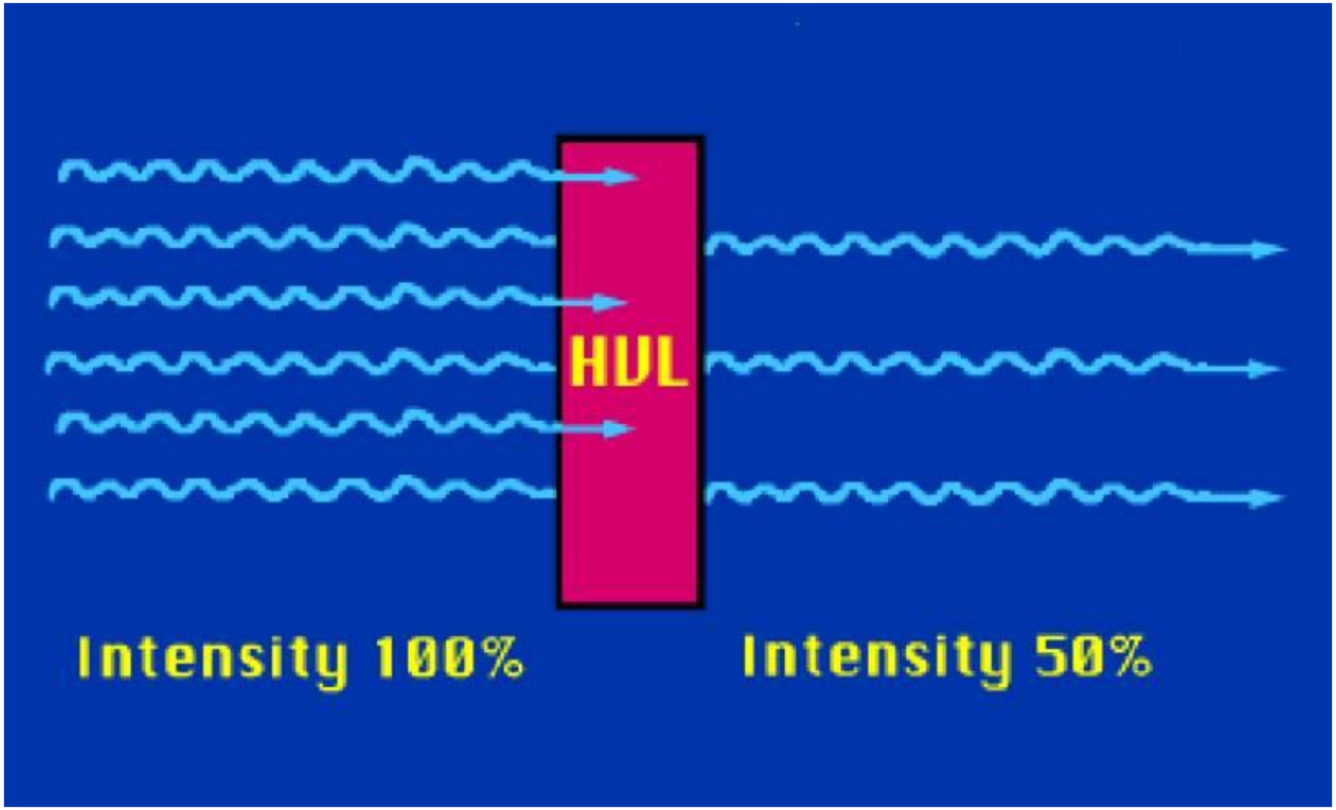
Radiation protection - Shielding



Basic Principles

Radiation protection - Shielding

Half-Value Layer



Basic Principles

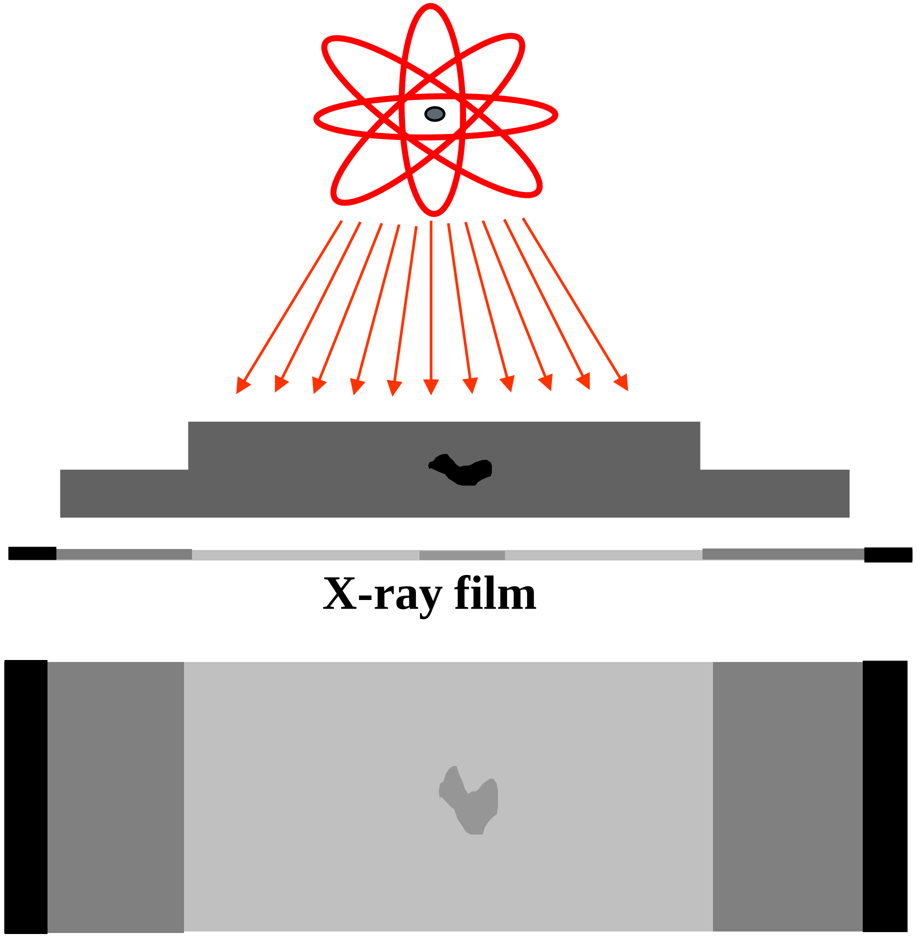
Radiation protection - Shielding

Half-Value Layer

- Defined as the thickness of a material needed to reduce the radiation intensity to ½ of its original value
  - To provide shielding
  - Depends on radioisotope used for gamma radiation (or voltage if radiation source is an x-ray)
  - Depends on voltage if radiation source if an x-ray

	Half-Value Layer, mm (inch)				
Source	Concrete	Steel	Lead	Tungsten	Uranium
Iridium-192	44.5 (1.75)	12.7 (0.5)	4.8 (0.19)	3.3 (0.13)	2.8 (0.11)
Cobalt-60	60.5 (2.38)	21.6 (0.85)	12.5 (0.49)	7.9 (0.31)	6.9 (0.27)

General Principles of Radiography



Top view of developed film

The part is placed between the radiation source and a piece of film. The part will stop some of the radiation. Thicker and more dense area will stop more of the radiation.

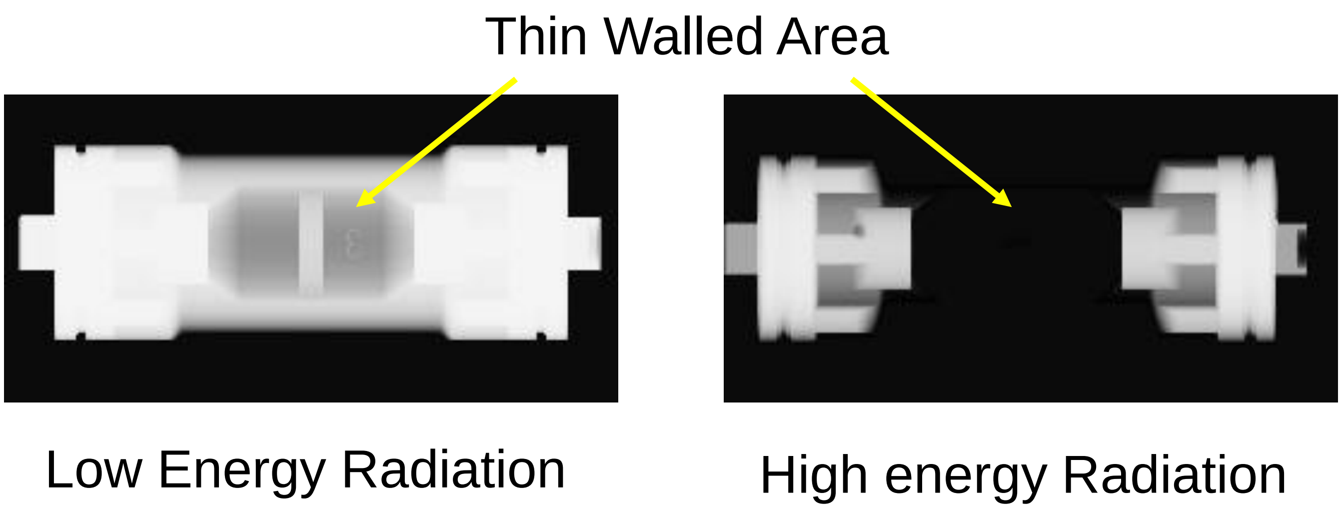
The film darkness (density) will vary with the amount of radiation reaching the film through the test object.

= less exposure

= more exposure

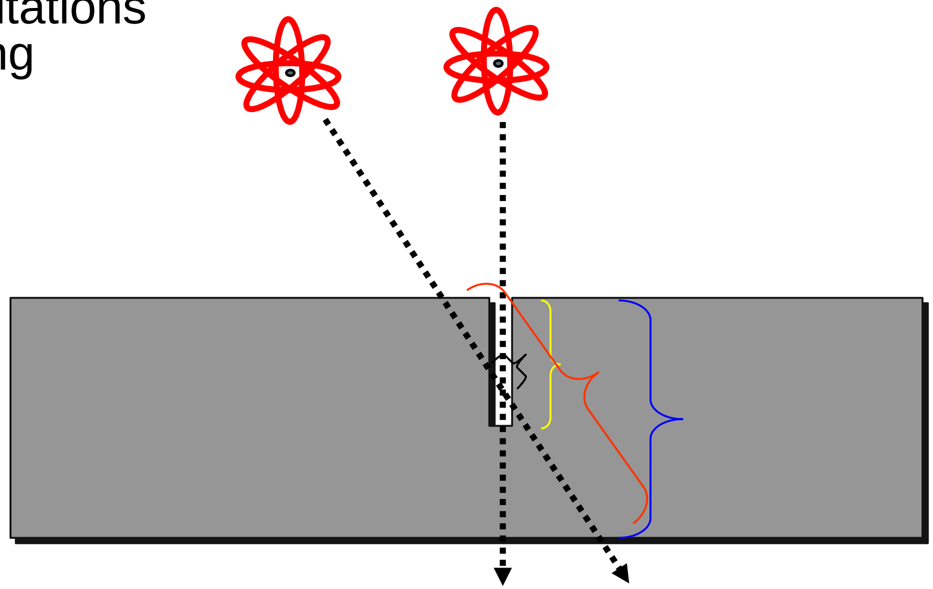
General Principles of Radiography

- The energy of the radiation affects its penetrating power. Higher energy radiation can penetrate thicker and more dense materials.
- The radiation energy and/or exposure time must be controlled to properly image the region of interest.



Flaw Orientation

Radiography has sensitivity limitations when detecting cracks.

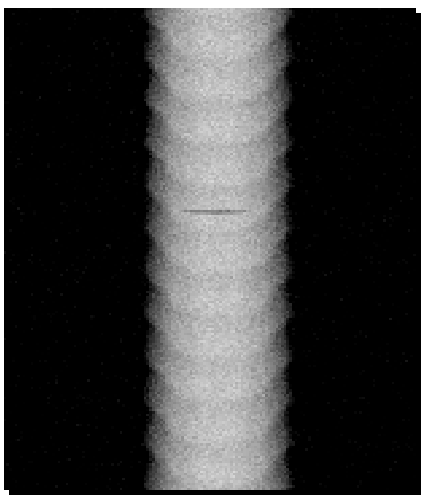


X-rays "see" a crack as a thickness variation and the larger the variation, the easier the crack is to detect.

When the path of the x-rays is not parallel to a crack, the thickness variation is less and the crack may not be visible.

Flaw Orientation

Since the angle between the radiation beam and a crack or other linear defect is so critical, the orientation of defect must be well known if radiography is going to be used to perform the inspection.



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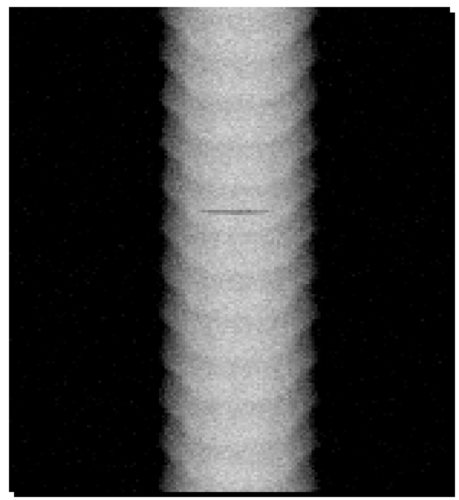

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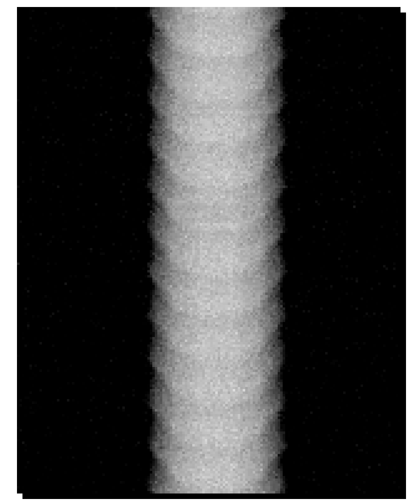


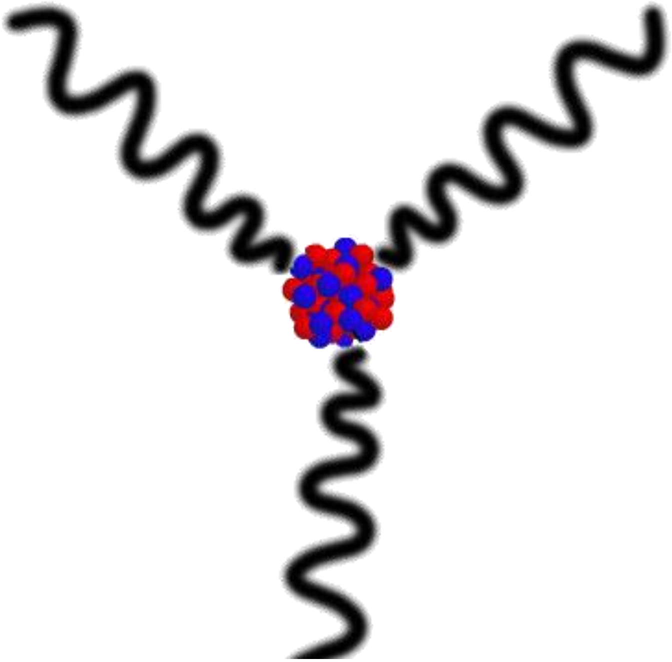
20^o

Radiation Sources

Two of the most commonly used sources of radiation in industrial radiography are x-ray generators and gamma ray sources. Industrial radiography is often subdivided into "X-ray Radiography" or "Gamma Radiography", depending on the source of radiation used.

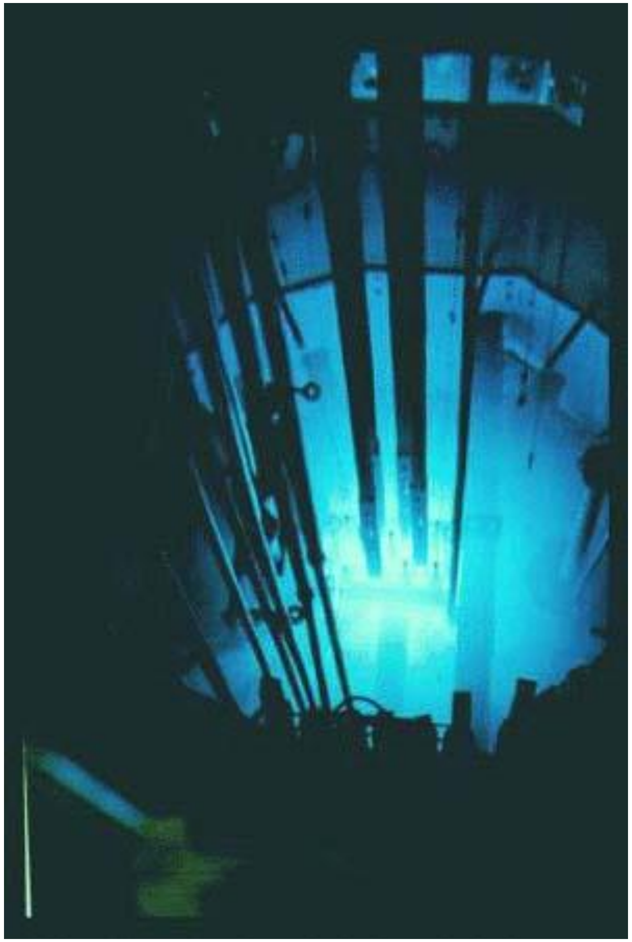
Gamma Radiography

- Gamma rays are produced by a radioisotope.
- A radioisotope has an unstable nuclei that does not have enough binding energy to hold the nucleus together.
- The spontaneous breakdown of an atomic nucleus resulting in the release of energy and matter is known as radioactive decay.



Gamma Radiography

- Most of the radioactive material used in industrial radiography is artificially produced.
- This is done by subjecting stable material to a source of neutrons in a special nuclear reactor.
- This process is called activation.

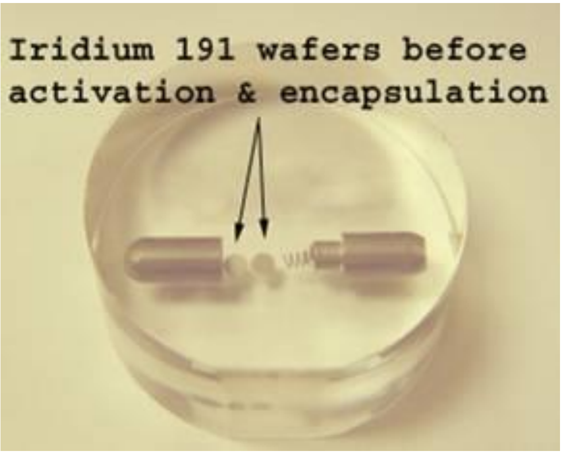


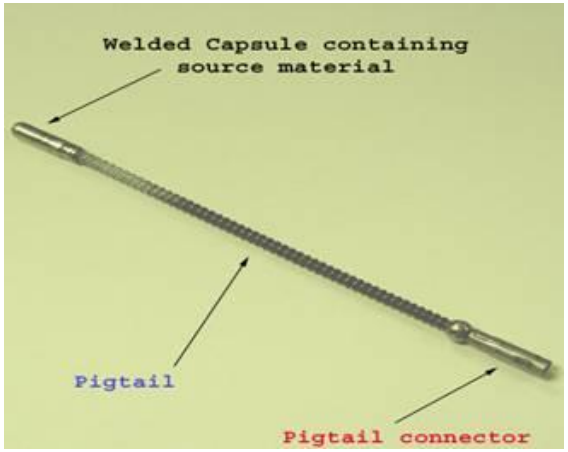
Gamma Radiography

Unlike X-rays, which are produced by a machine, gamma rays cannot be turned off. Radioisotopes used for gamma radiography are encapsulated to prevent leakage of the material.

The radioactive "capsule" is attached to a cable to form what is often called a "pigtail."

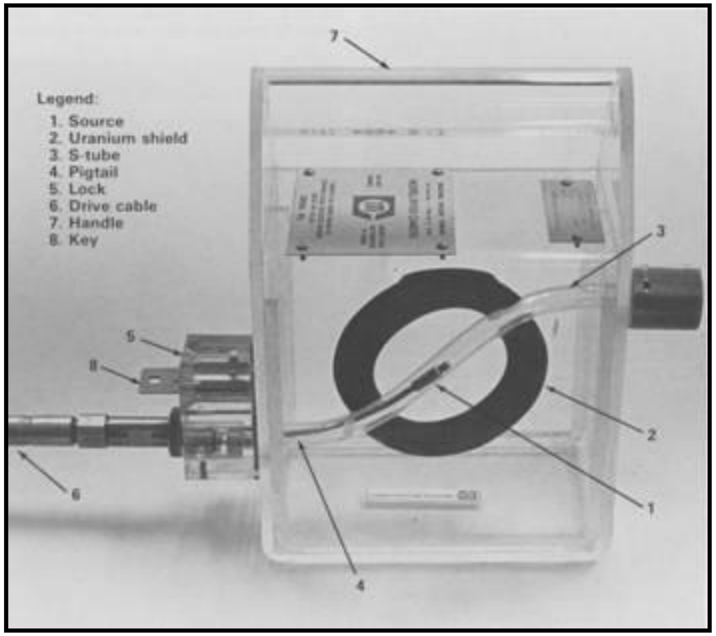
The pigtail has a special connector at the other end that attaches to a drive cable.





Gamma Radiography

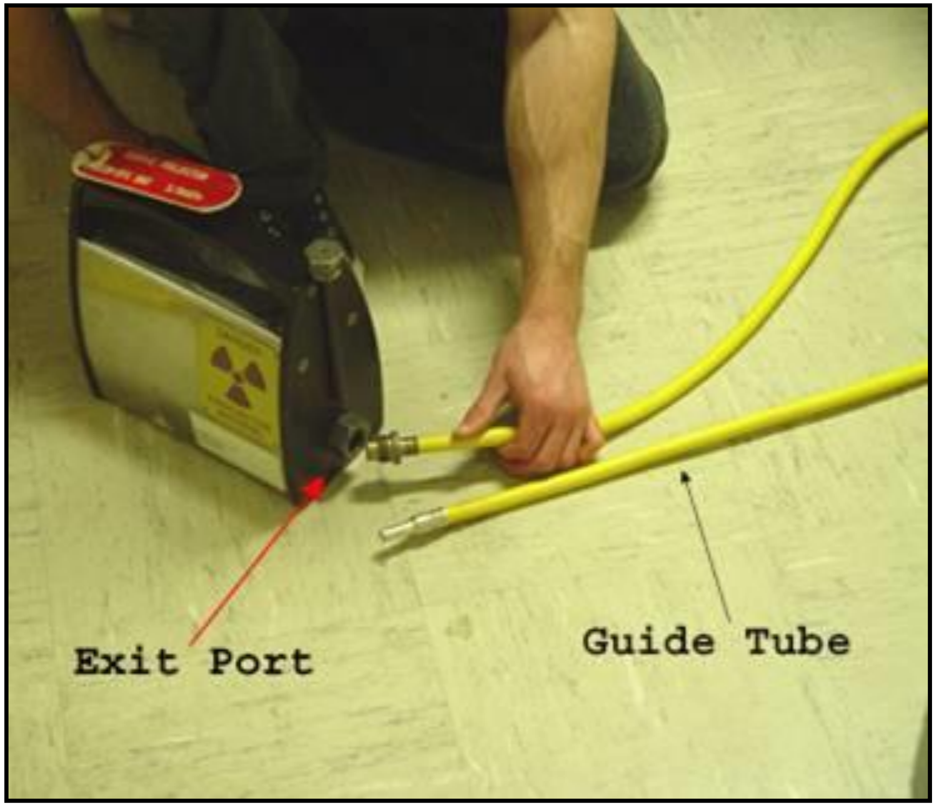
A device called a “camera” is used to store, transport and expose the pigtail containing the radioactive material. The camera contains shielding material which reduces the radiographer’s exposure to radiation during use.



Gamma Radiography

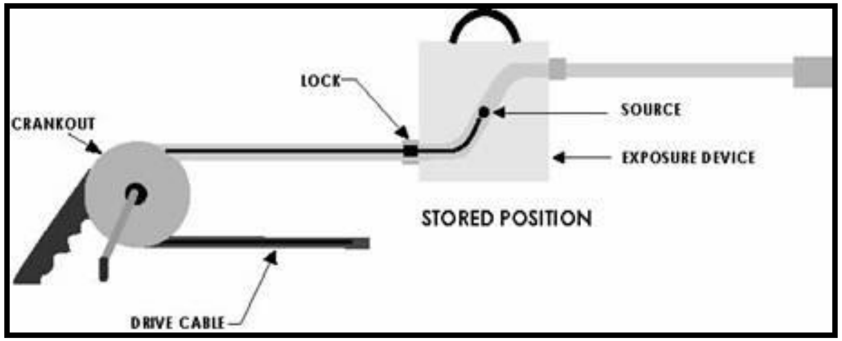
A hose-like device called a guide tube is connected to a threaded hole called an "exit port" in the camera.

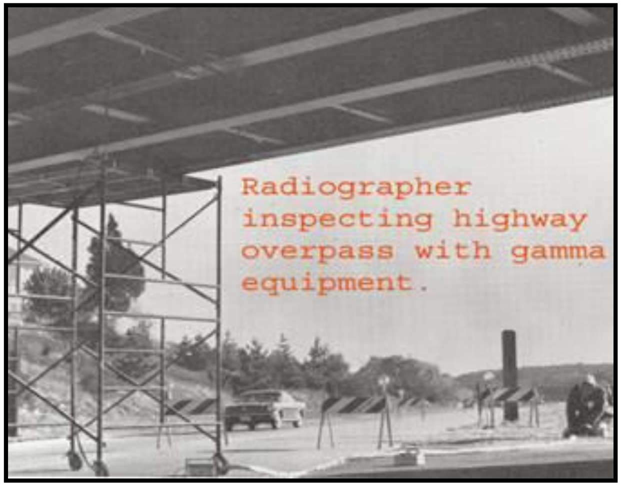
The radioactive material will leave and return to the camera through this opening when performing an exposure!



Gamma Radiography

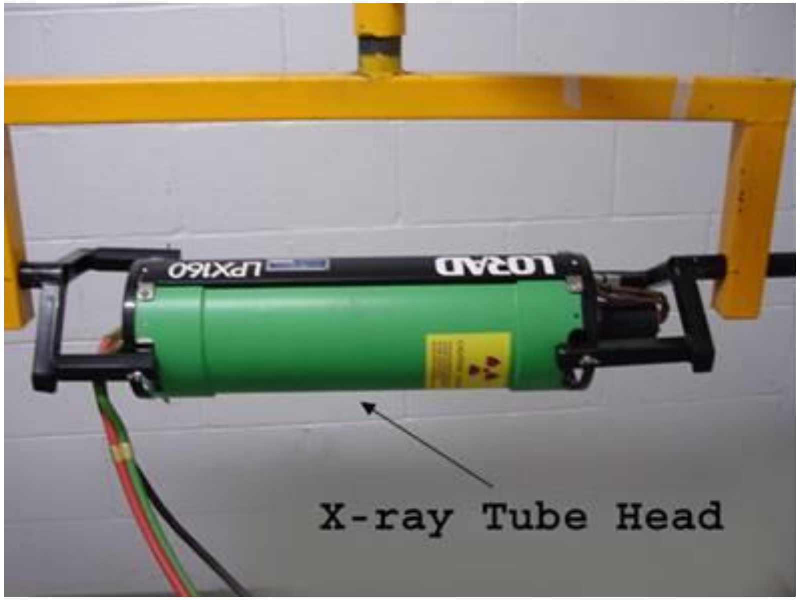
A “drive cable” is connected to the other end of the camera. This cable, controlled by the radiographer, is used to force the radioactive material out into the guide tube where the gamma rays will pass through the specimen and expose the recording device.





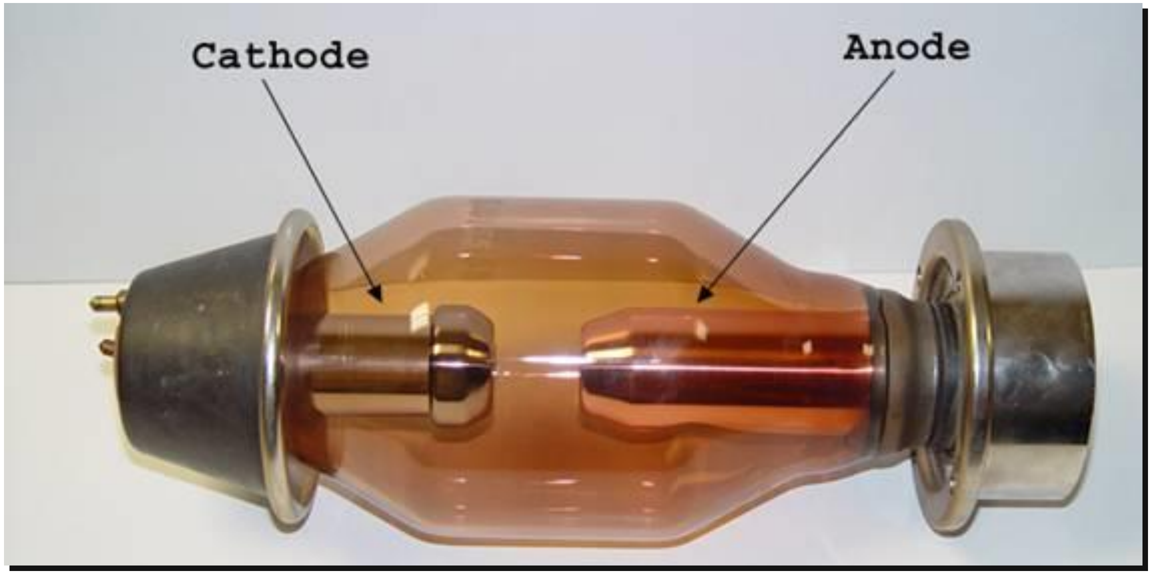
X-ray Radiography

Unlike gamma rays, x-rays are produced by an X-ray generator system. These systems typically include an X-ray tube head, a high voltage generator, and a control console.



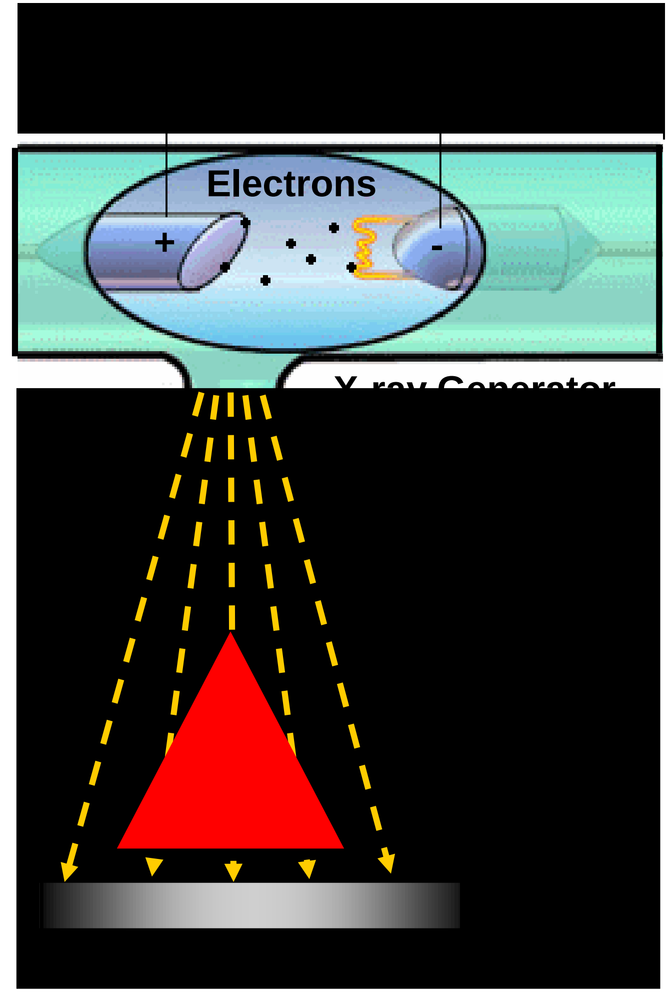
X-ray Radiography

- X-rays are produced by establishing a very high voltage between two electrodes, called the anode and cathode.
- To prevent arcing, the anode and cathode are located inside a vacuum tube, which is protected by a metal housing.



X-ray Radiography

- The cathode contains a small filament much the same as in a light bulb.
- Current is passed through the filament which heats it. The heat causes electrons to be stripped off.
- The high voltage causes these “free” electrons to be pulled toward a target material (usually made of tungsten) located in the anode.
- The electrons impact against the target. This impact causes an energy exchange which causes x-rays to be created.



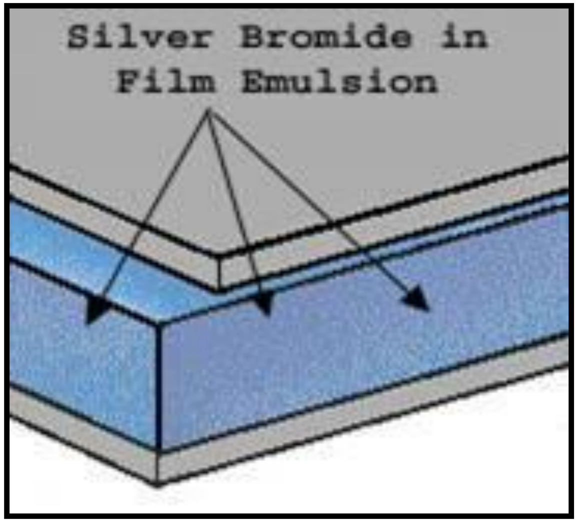
Imaging Modalities

Several different imaging methods are available to display the final image in industrial radiography:

- Film Radiography
- Real Time Radiography
- Computed Tomography (CT)
- Digital Radiography (DR)
- Computed Radiography (CR)

Film Radiography

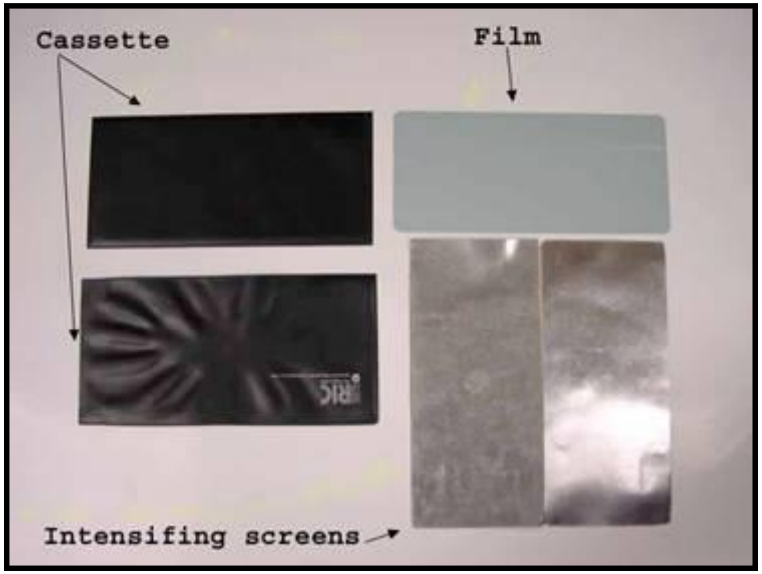
Photo Coutesy of AGFA-Gevaert Group

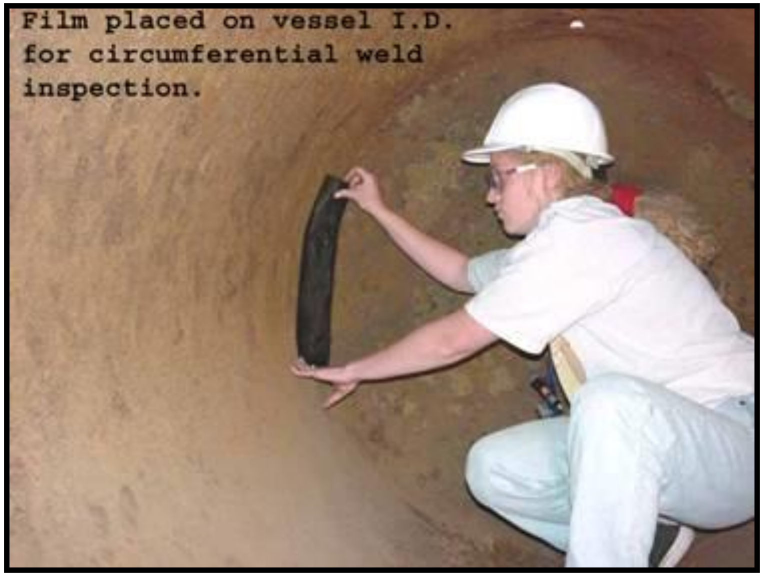


- One of the most widely used and oldest imaging mediums in industrial radiography is radiographic film.
- Film contains microscopic material called silver bromide.
- Once exposed to radiation and developed in a darkroom, silver bromide turns to black metallic silver which forms the image.

Film Radiography

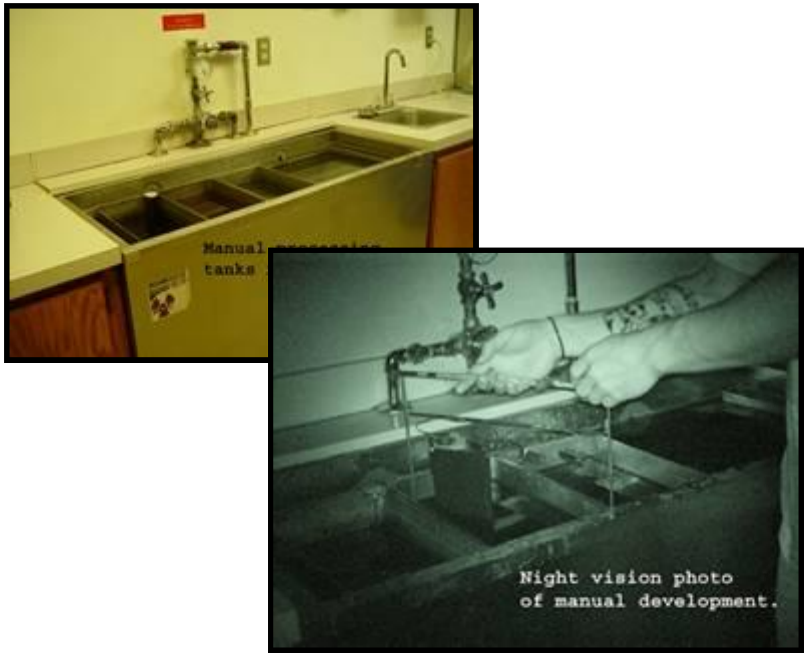
- **Film must be protected from visible light. Light, just like x-rays and gamma rays, can expose film. Film is loaded in a "light proof" cassette in a darkroom.**
- **This cassette is then placed on the specimen opposite the source of radiation. Film is often placed between screens to intensify radiation.**

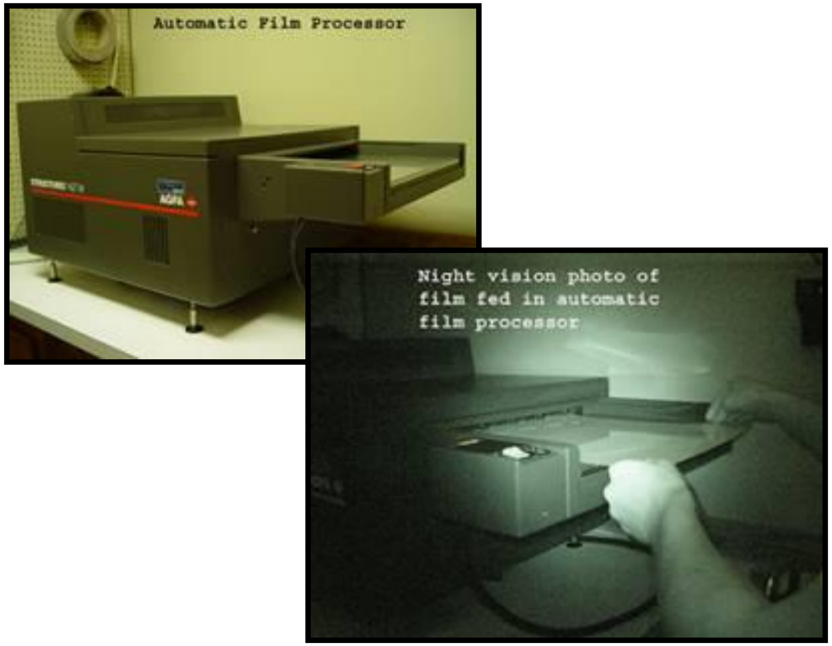




Film Radiography

- In order for the image to be viewed, the film must be “developed” in a darkroom. The process is very similar to photographic film development.
- Film processing can either be performed manually in open tanks or in an automatic processor.





Digital Radiography

- One of the newest forms of radiographic imaging is "Digital Radiography".
- Requiring no film, digital radiographic images are captured using either special phosphor screens or flat panels containing micro-electronic sensors.
- No darkrooms are needed to process film, and captured images can be digitally enhanced for increased detail.
- Images are also easily archived (stored) when in digital form.

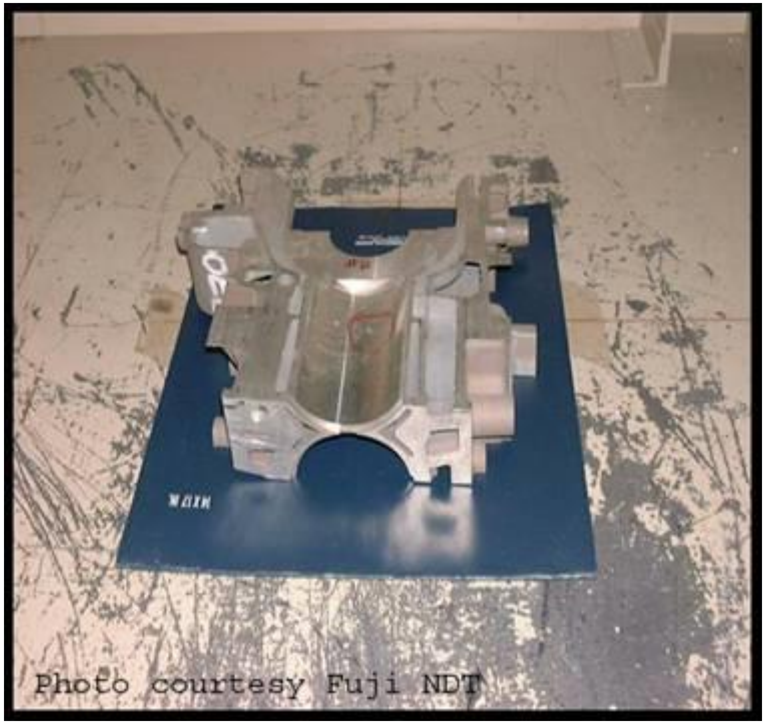
Digital Radiography

There are a number of forms of digital radiographic imaging including:

- Computed Radiography (CR)
- Real-time Radiography (RTR)
- Direct Radiographic Imaging (DR)
- Computed Tomography

Computed Radiography

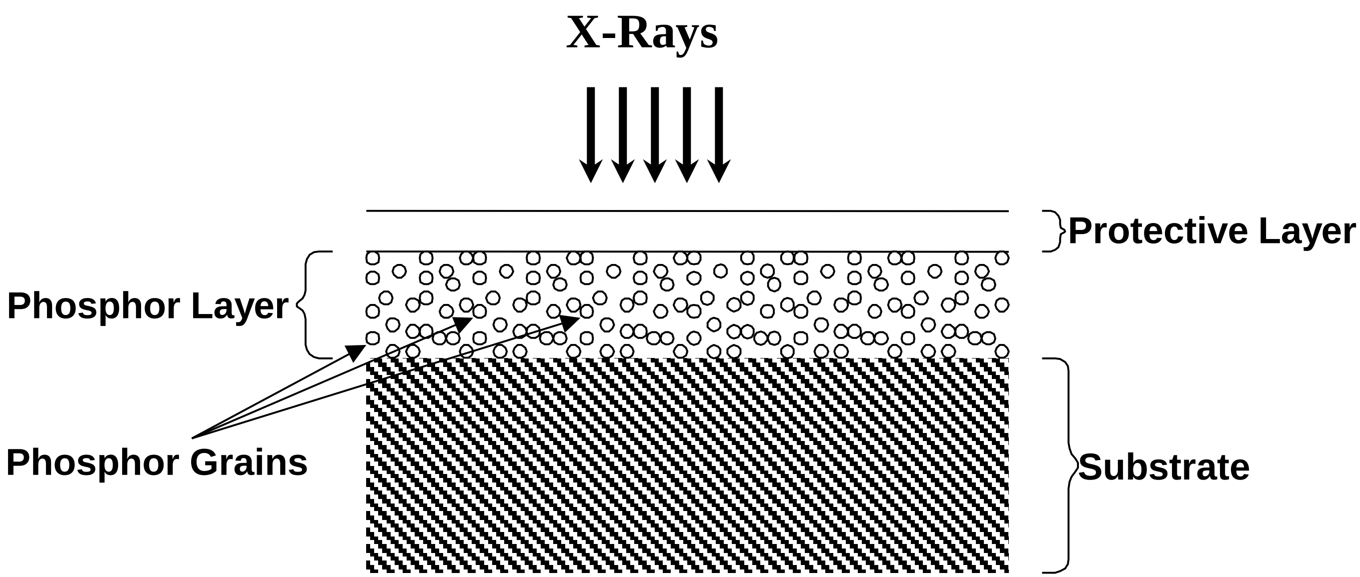
Computed Radiography (CR) is a digital imaging process that uses a special imaging plate which employs storage phosphors.



Computed Radiography

X-rays penetrating the specimen stimulate the phosphors. The stimulated phosphors remain in an excited state.

CR Phosphor Screen Structure



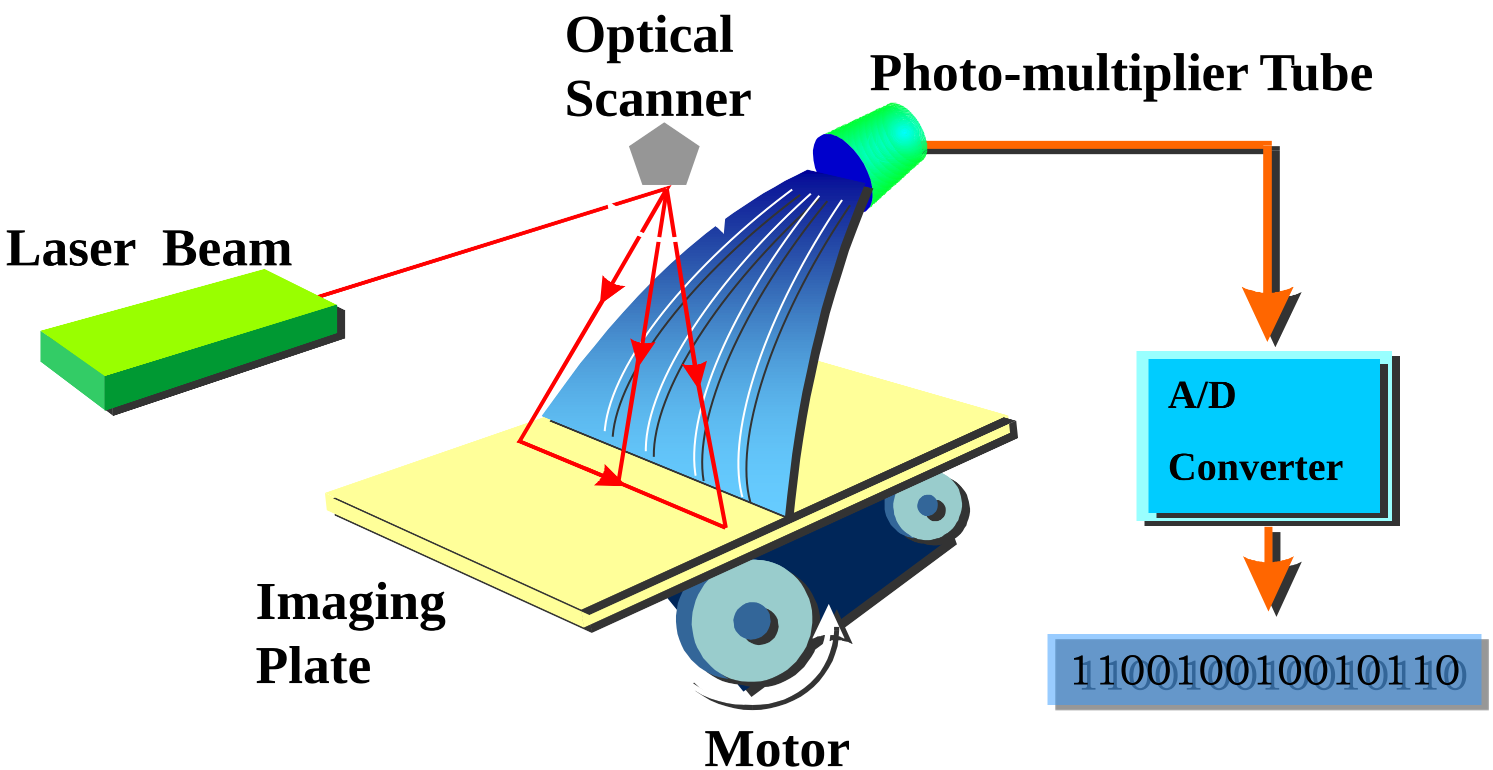
Computed Radiography

After exposure:

The imaging plate is read electronically and erased for re-use in a special scanner system.

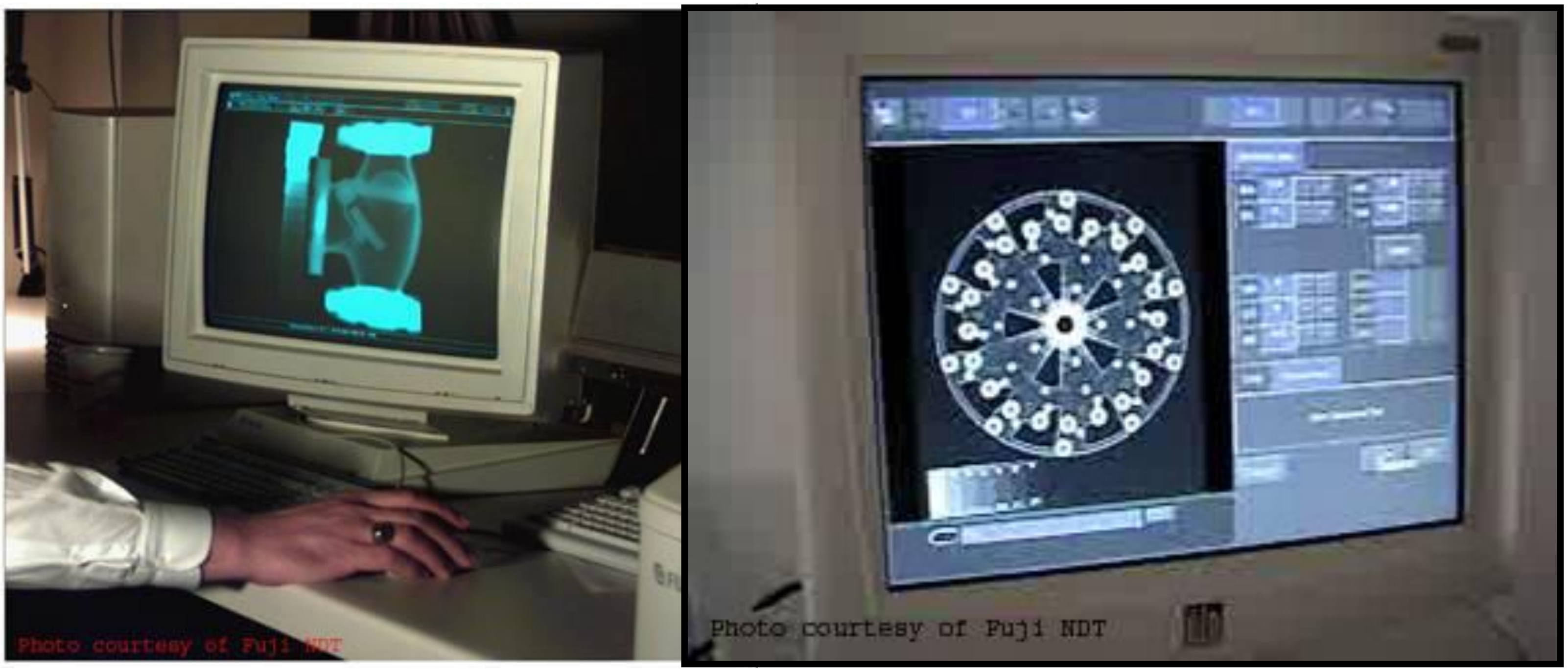
Computed Radiography

As a laser scans the imaging plate, light is emitted where X-rays stimulated the phosphor during exposure. The light is then converted to a digital value.



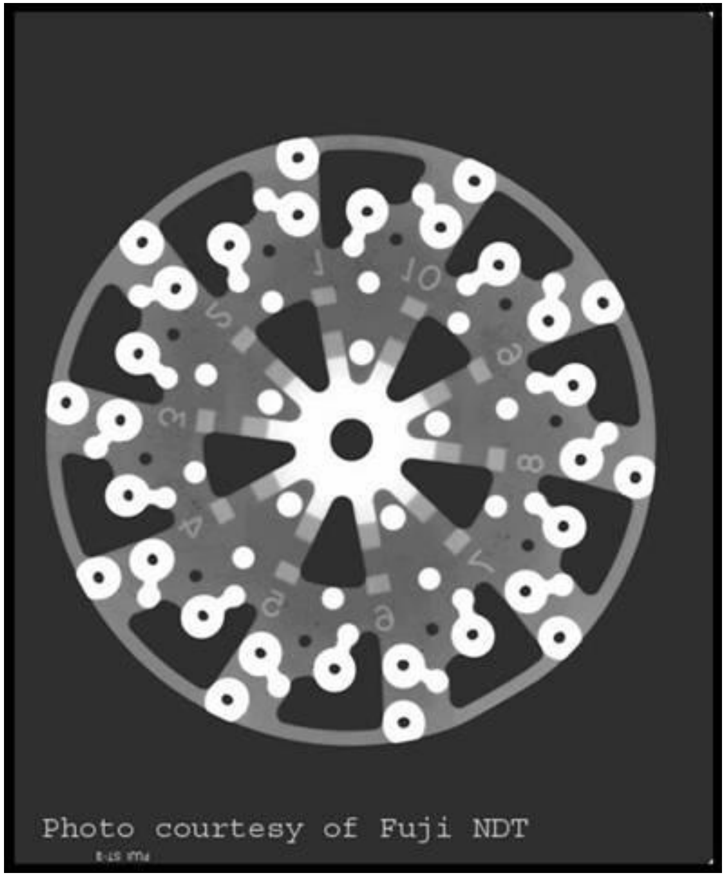
Computed Radiography

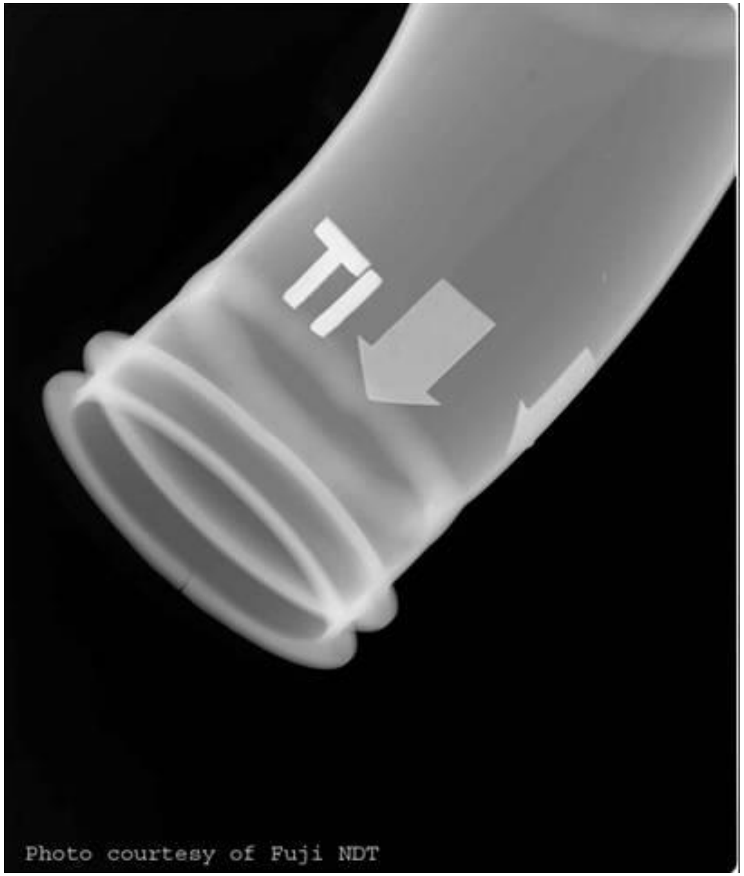
Digital images are typically sent to a computer workstation where specialized software allows manipulation and enhancement.



Computed Radiography

Examples of computed radiographs:





Real-Time Radiography

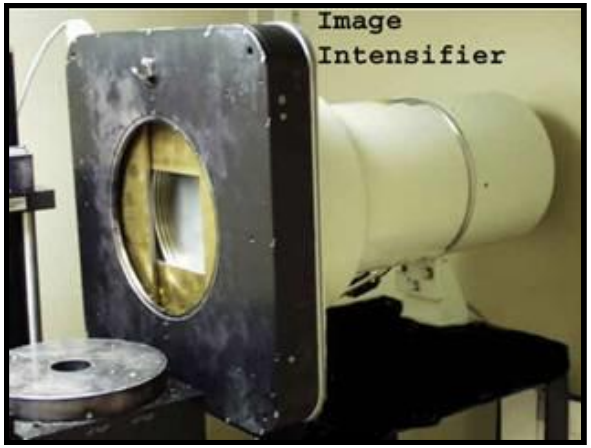
- Real-Time Radiography (RTR) is a term used to describe a form of radiography that allows electronic images to be captured and viewed in real time.
- Because image acquisition is almost instantaneous, X-ray images can be viewed as the part is moved and rotated.
- Manipulating the part can be advantageous for several reasons:
  - It may be possible to image the entire component with one exposure.
  - Viewing the internal structure of the part from different angular prospectives can provide additional data for analysis.
  - Time of inspection can often be reduced.

Real-Time Radiography

- The equipment needed for an RTR includes:
  - X-ray tube
  - Image intensifier or other real-time detector
  - Camera
  - Computer with frame grabber board and software
  - Monitor
  - Sample positioning system (optional)

Real-Time Radiography

- The image intensifier is a device that converts the radiation that passes through the specimen into light.
- It uses materials that fluoresce when struck by radiation.
- The more radiation that reaches the input screen, the more light that is given off.
- The image is very faint on the input screen so it is intensified onto a small screen inside the intensifier where the image is viewed with a camera.

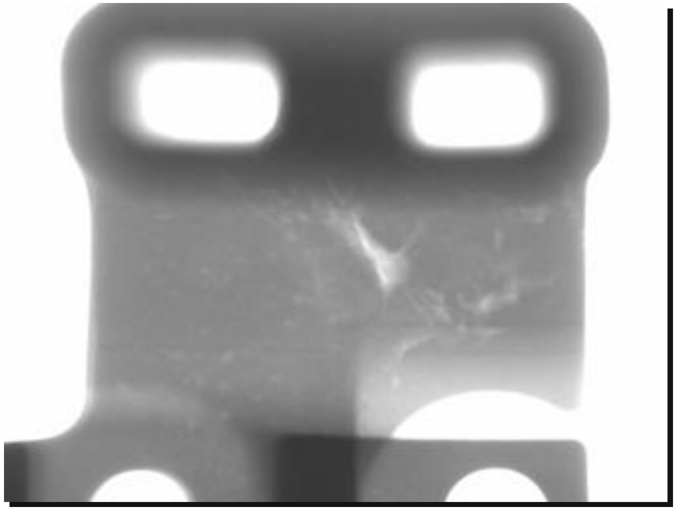


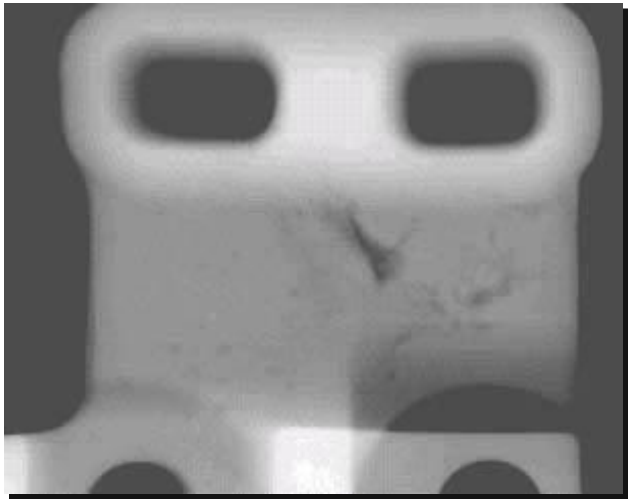
Real-Time Radiography

- A special camera which captures the light output of the screen is located near the image intensifying screen.
- The camera is very sensitive to a variety of different light intensities.
- A monitor is then connected to the camera to provide a viewable image.
- If a sample positioning system is employed, the part can be moved around and rotated to image different internal features of the part.

Real-Time Radiography

Comparing Film and Real-Time Radiography





<u>Real-time</u> images are lighter in areas where more X-ray photons reach and excite the fluorescent screen.

<u>Film images</u> are darker in areas where more X-ray photons reach and ionize the silver molecules in the film.

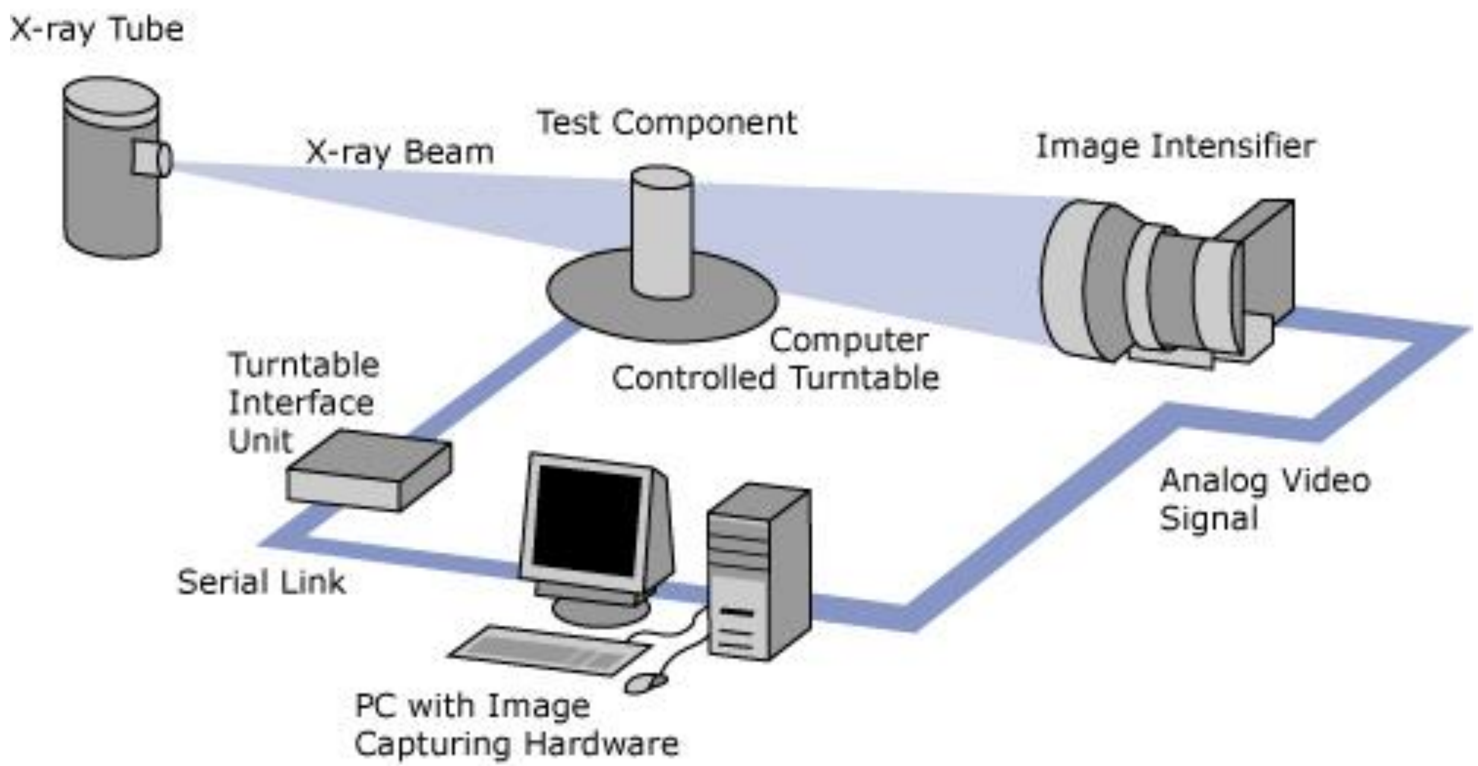
Direct Radiography

- Direct radiography (DR) is a form of real-time radiography that uses a special flat panel detector.
- The panel works by converting penetrating radiation passing through the test specimen into minute electrical charges.
- The panel contains many micro-electronic capacitors. The capacitors form an electrical charge pattern image of the specimen.
- Each capacitor's charge is converted into a pixel which forms the digital image.

Image courtesy AFGA NDT

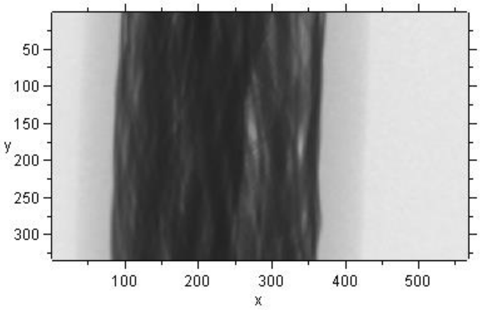
Computed Tomography

Computed Tomography (CT) uses a real-time inspection system employing a sample positioning system and special software.

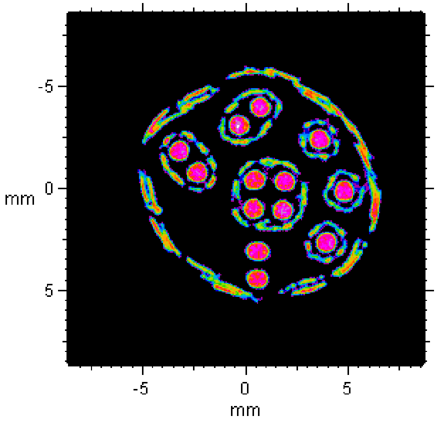


Computed Tomography

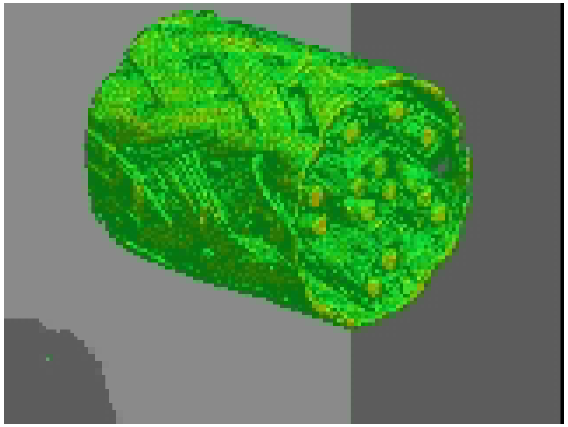
- Many separate images are saved (grabbed) and complied into 2-dimensional sections as the sample is rotated.
- 2-D images are them combined into 3-dimensional images.



Real-Time Captures



Compiled 2-D Images



Compiled 3-D Structure

Image Quality

- Image quality is critical for accurate assessment of a test specimen’s integrity.
- Various tools called Image Quality Indicators (IQIs) are used for this purpose.
- There are many different designs of IQIs. Some contain artificial holes of varying size drilled in metal plaques while others are manufactured from wires of differing diameters mounted next to one another.

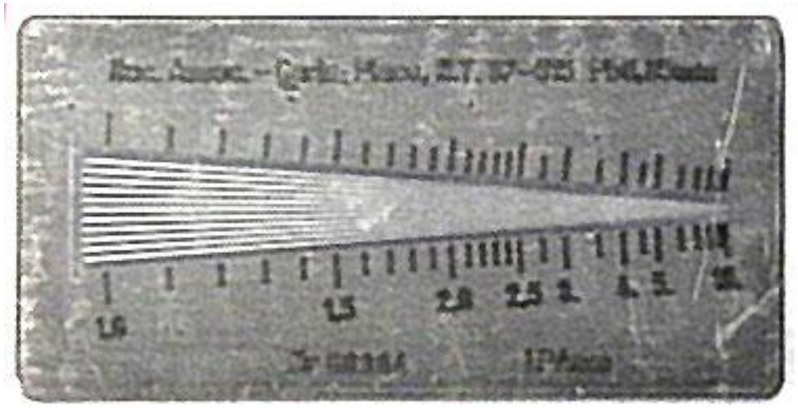
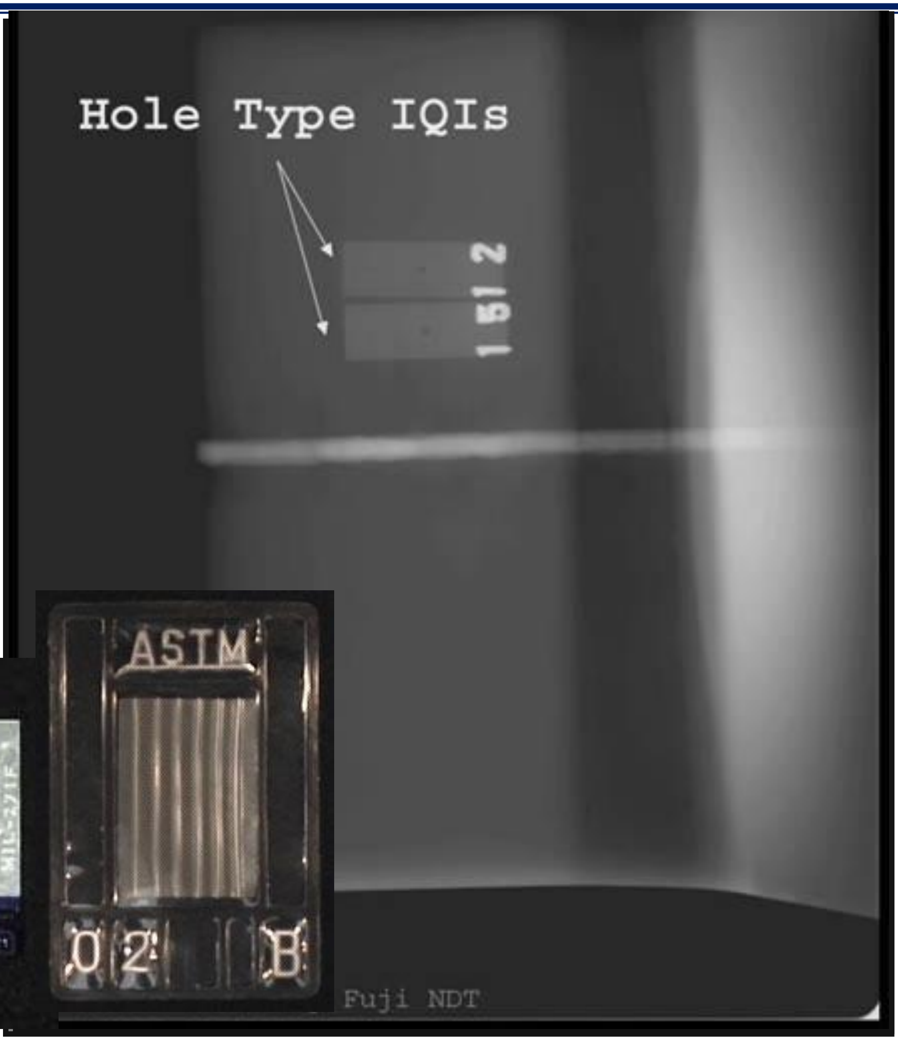
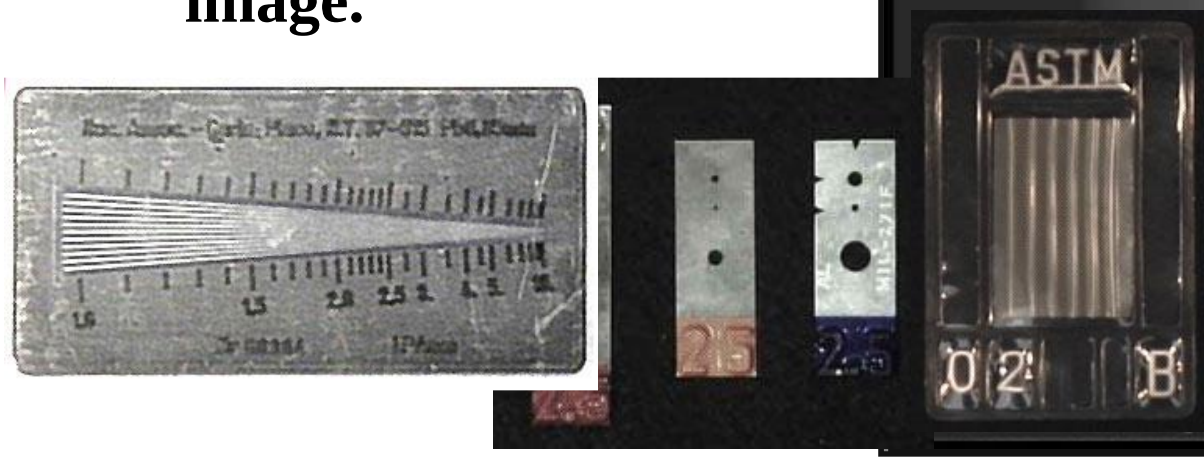



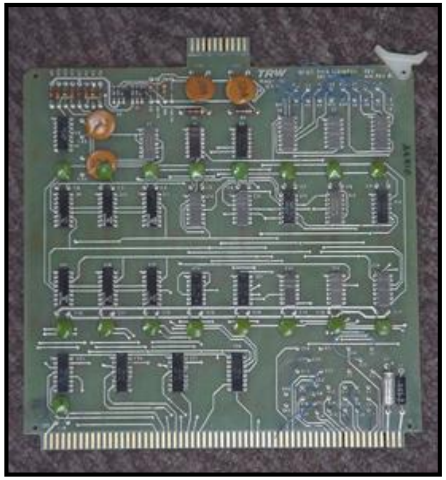
Image Quality

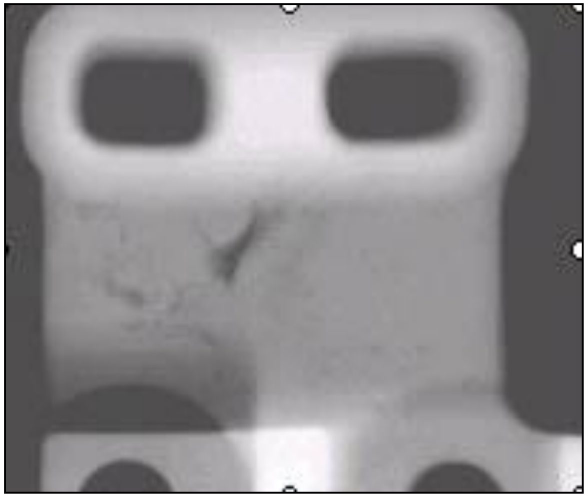
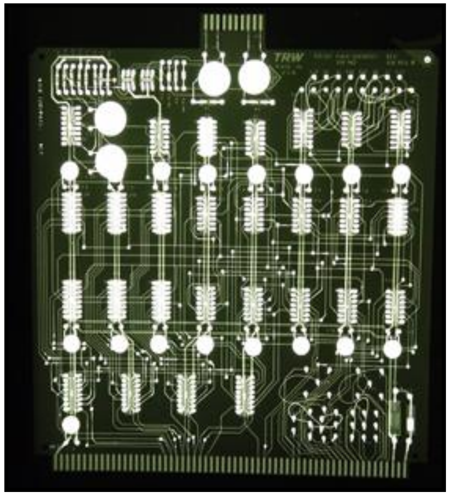
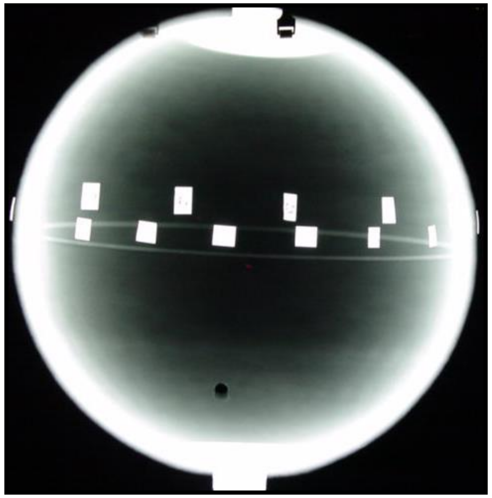
- **IQIs are typically placed on or next to a test specimen.**
- **Quality typically being determined based on the smallest hole or wire diameter that is reproduced on the image.**



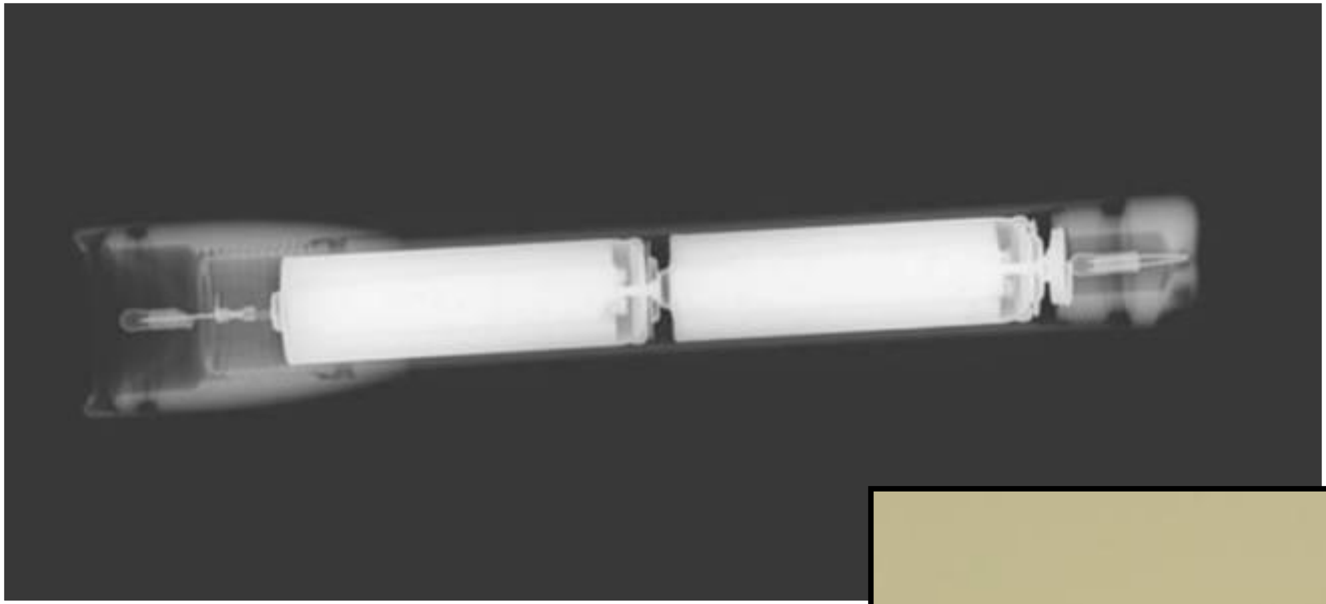


Radiographic Images

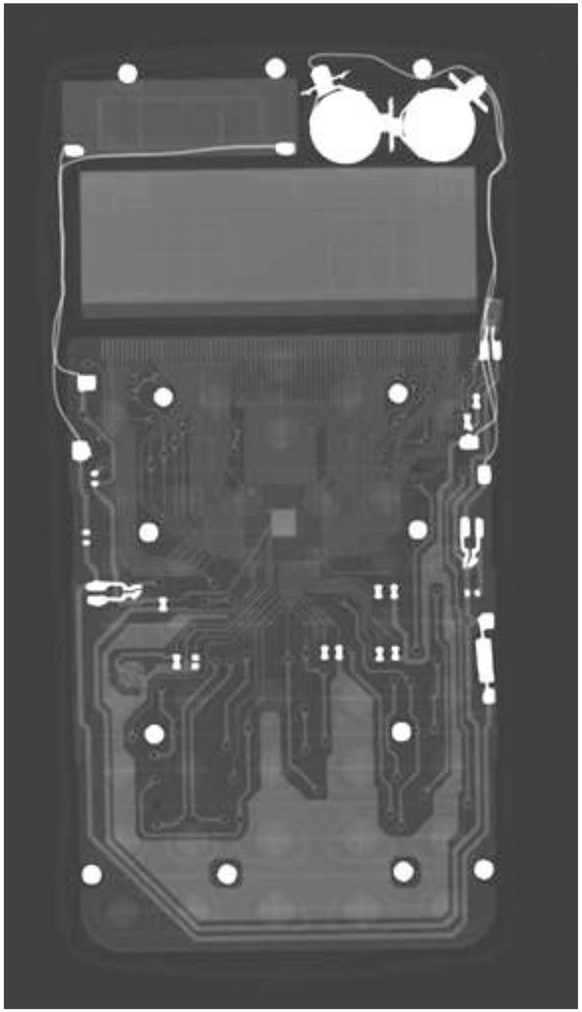



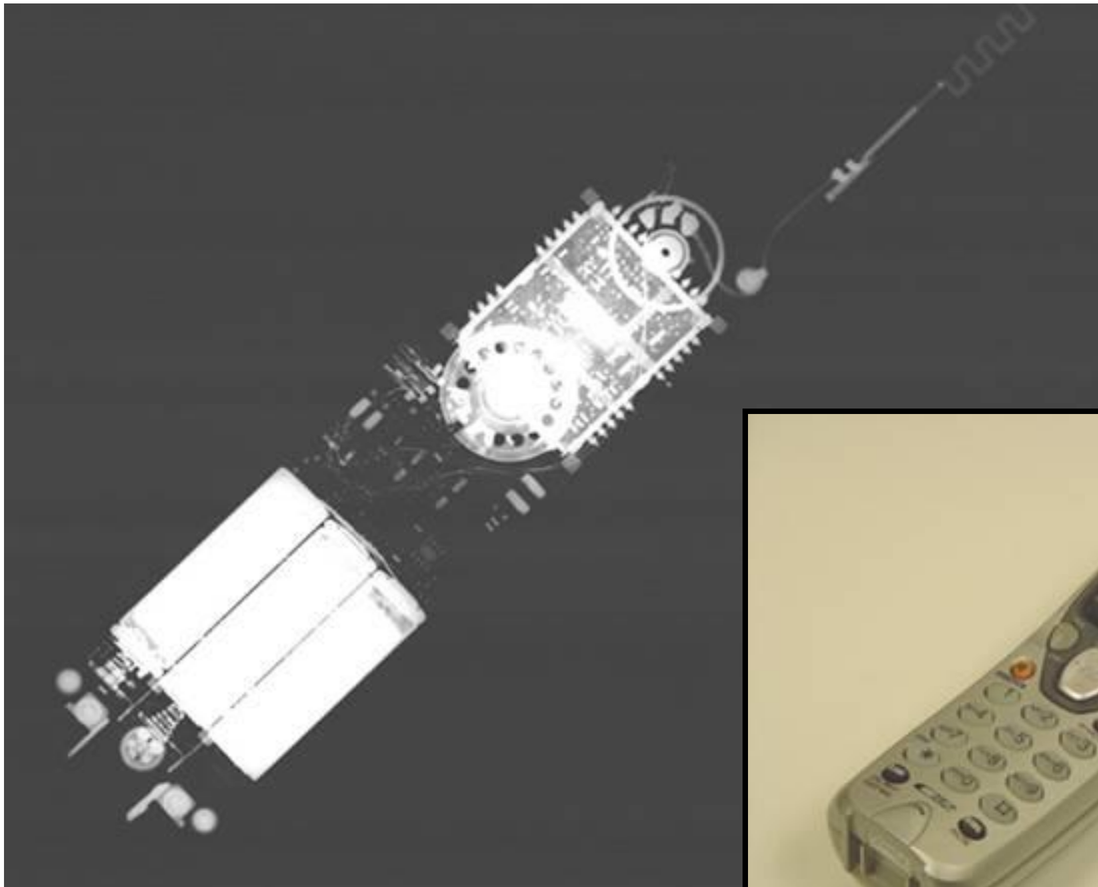
Radiographic Images



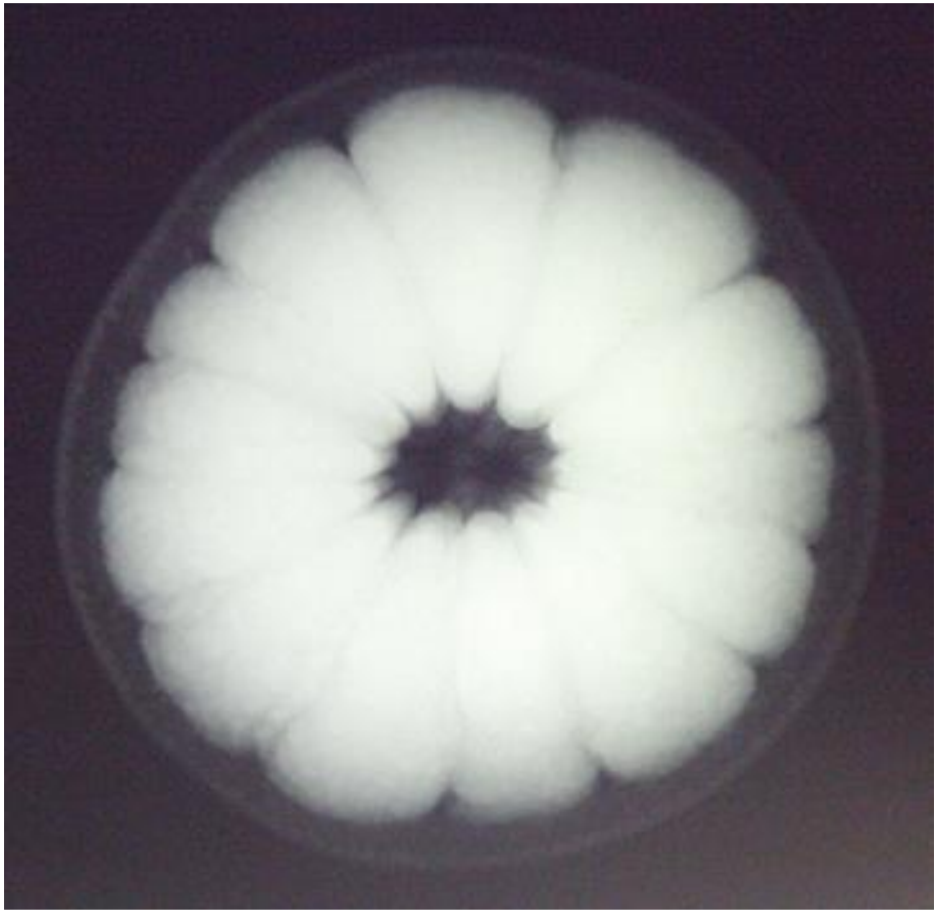
Radiographic Images

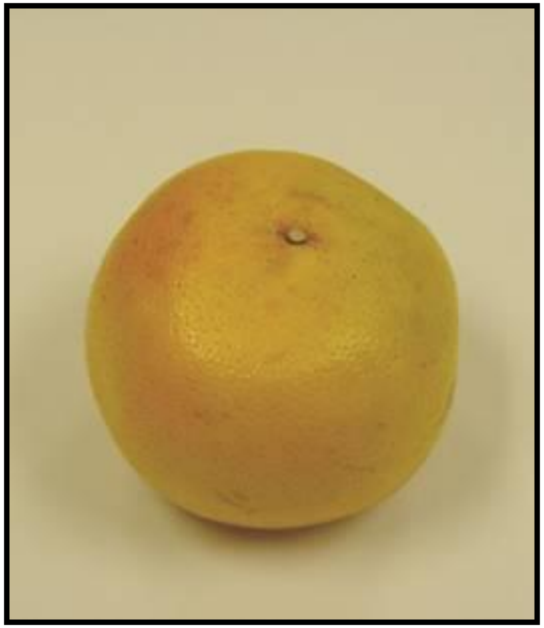


Radiographic Images



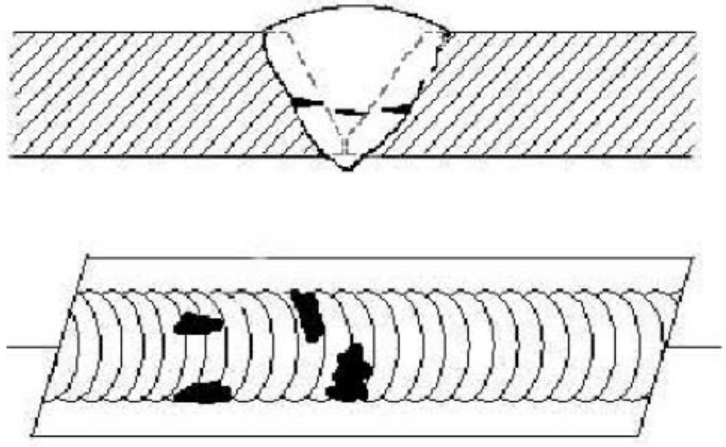
Radiographic Images

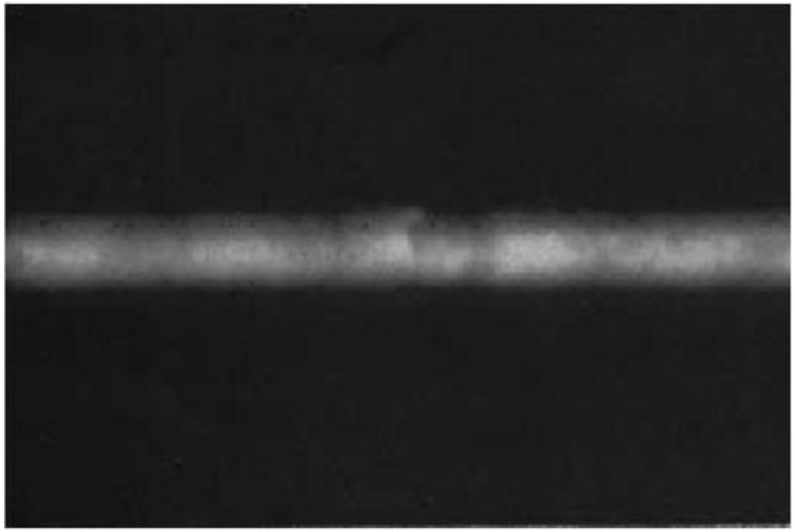




Examples of radiographs

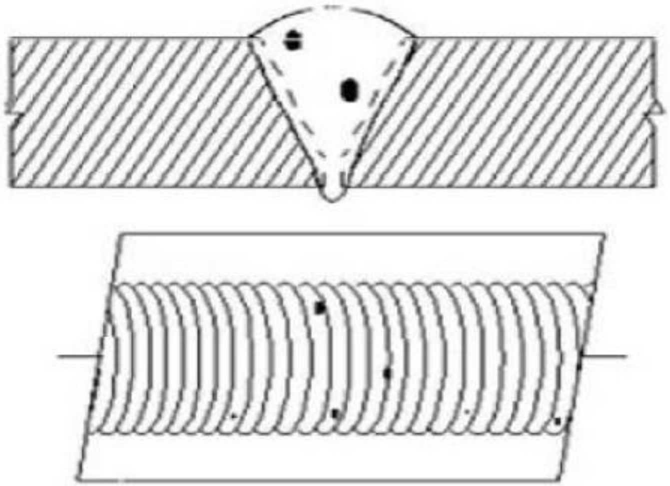
Cold lap

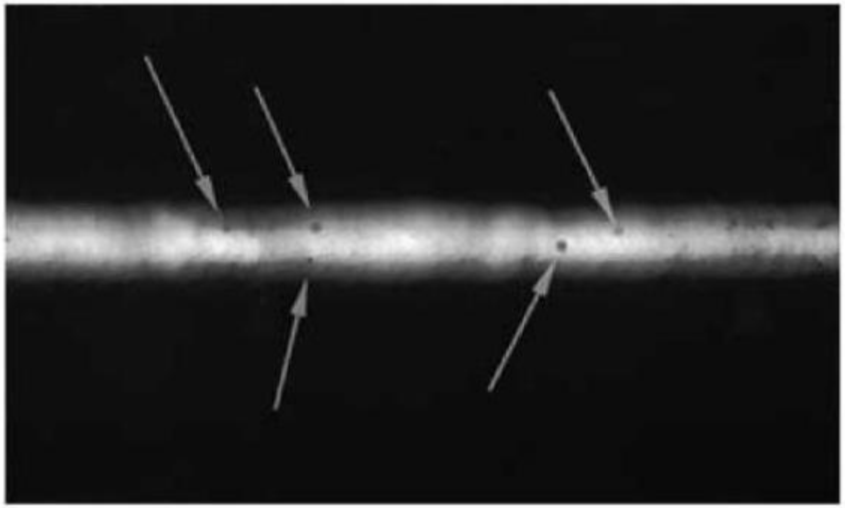




Examples of radiographs

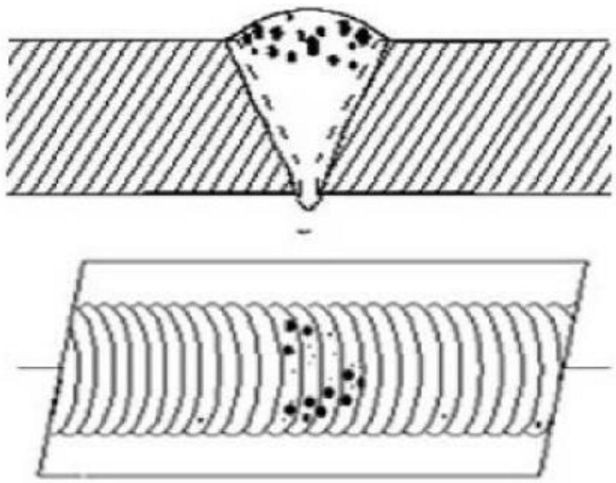
Porosity

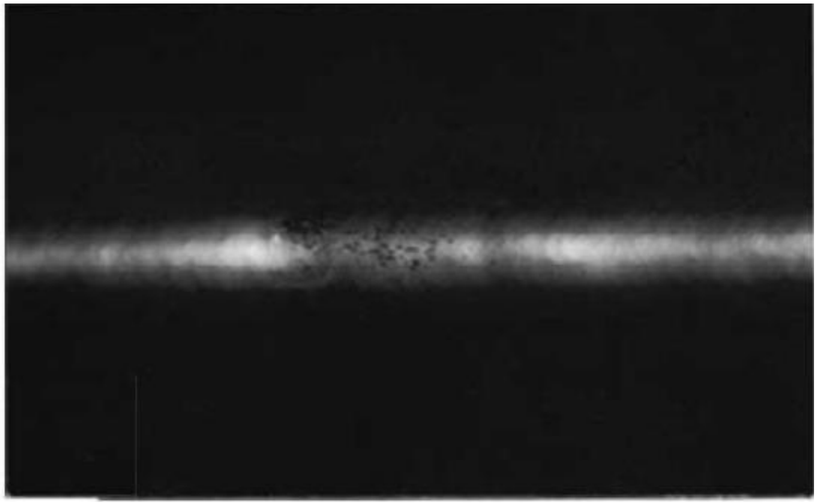




Examples of radiographs

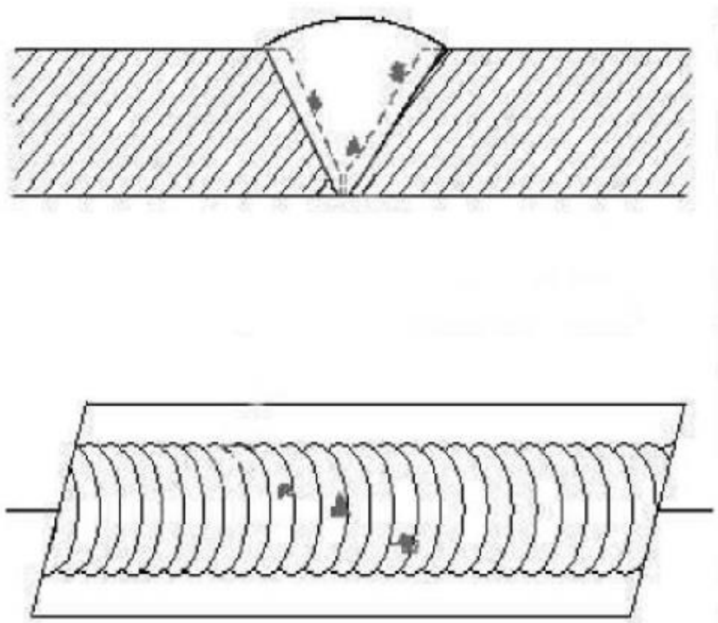
Cluster porosity

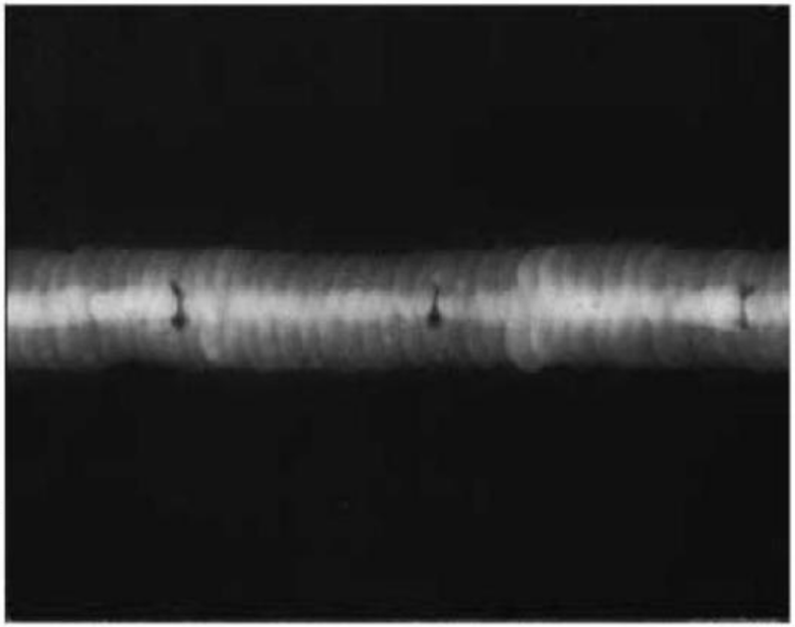




Examples of radiographs

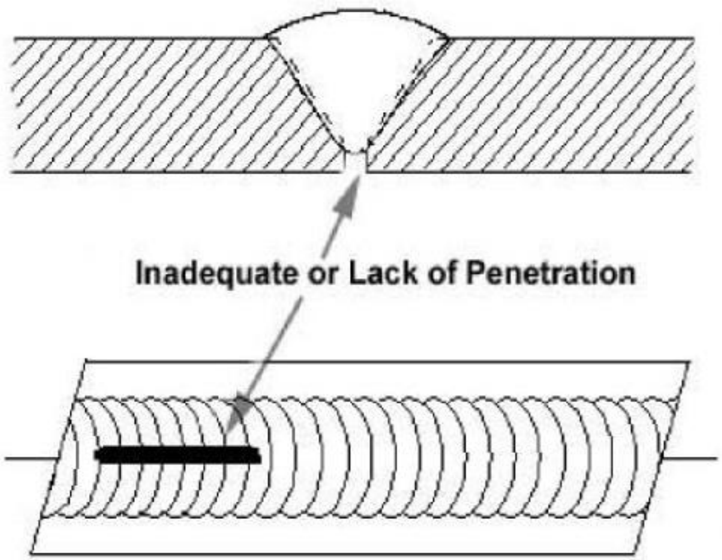
Slag inclusions

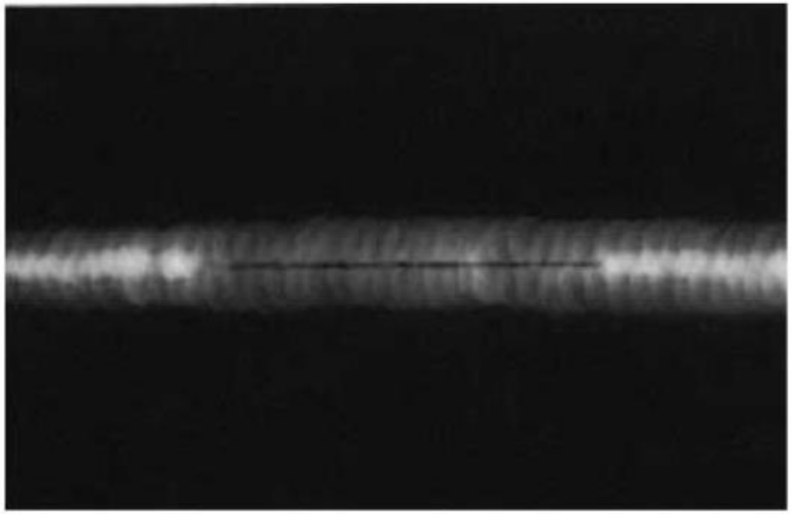




Examples of radiographs

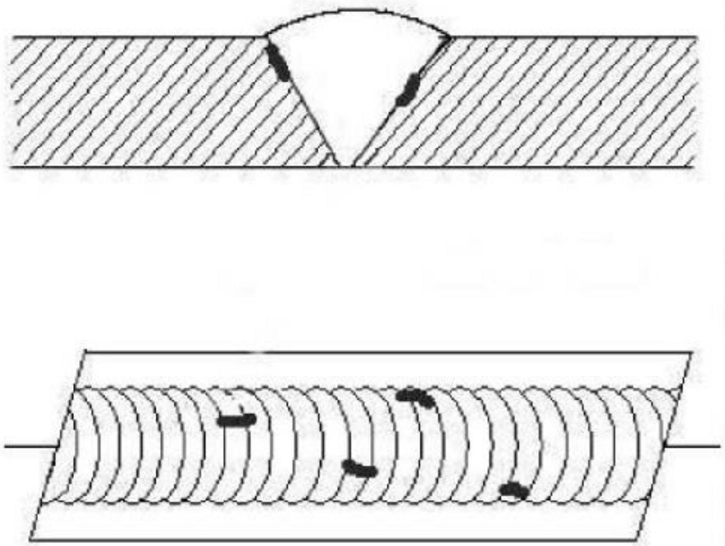
Incomplete penetration (IP) or lack of penetration (LOP)

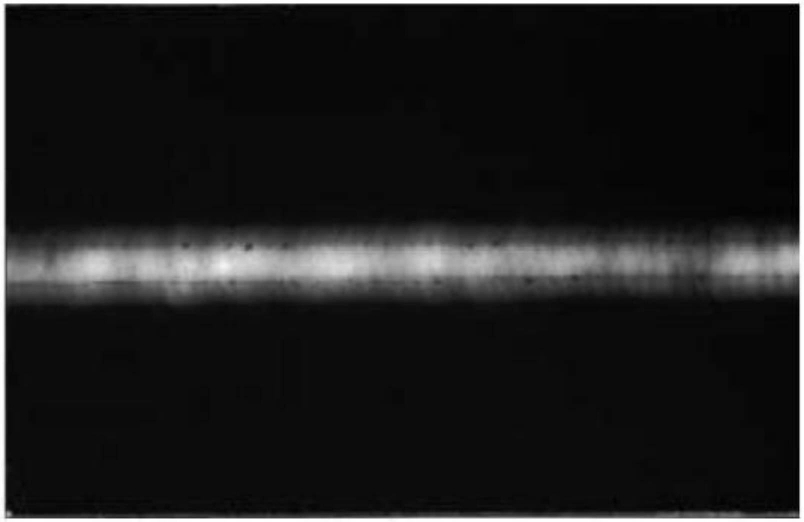




Examples of radiographs

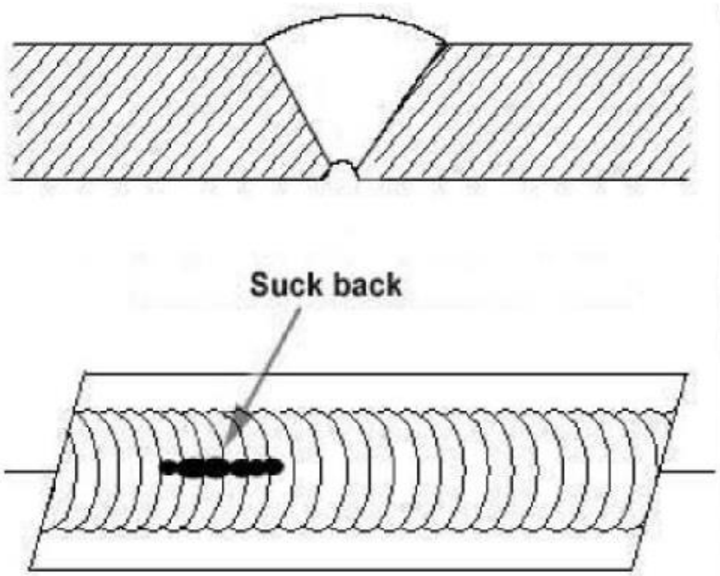
Incomplete fusion

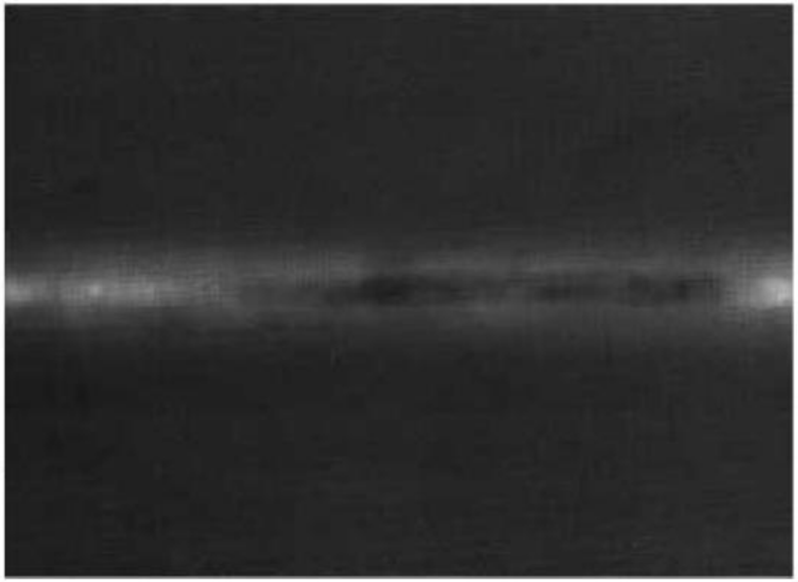




Examples of radiographs

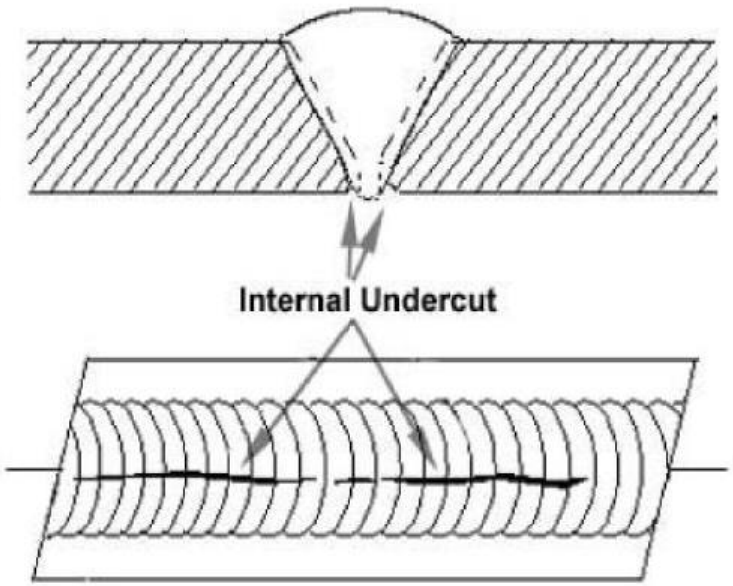
Internal concavity or suck back

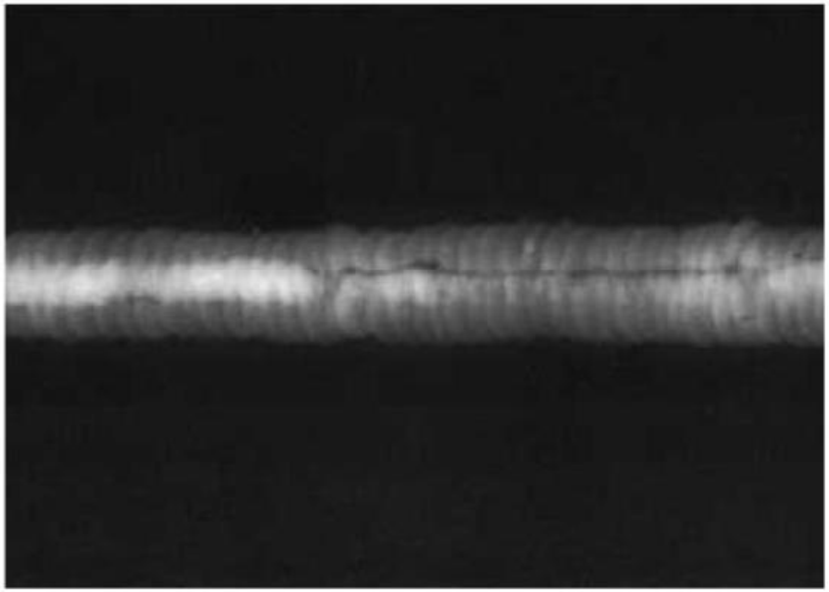




Examples of radiographs

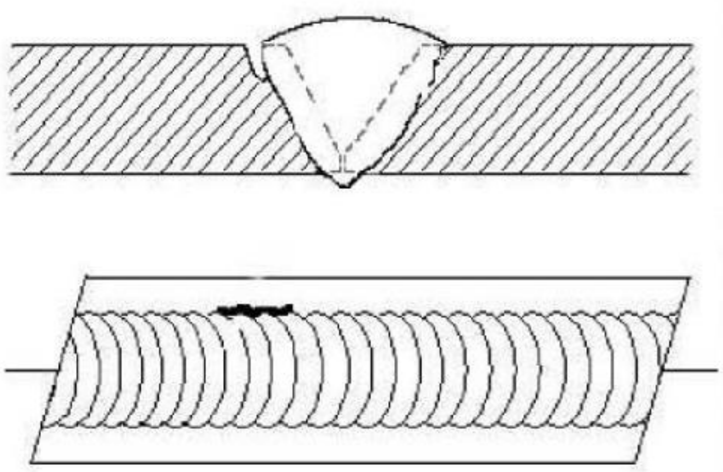
Internal or root undercut

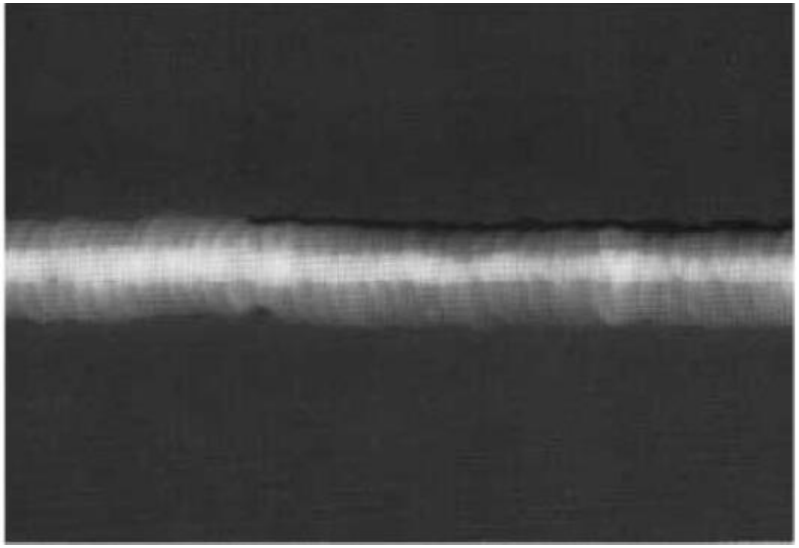




Examples of radiographs

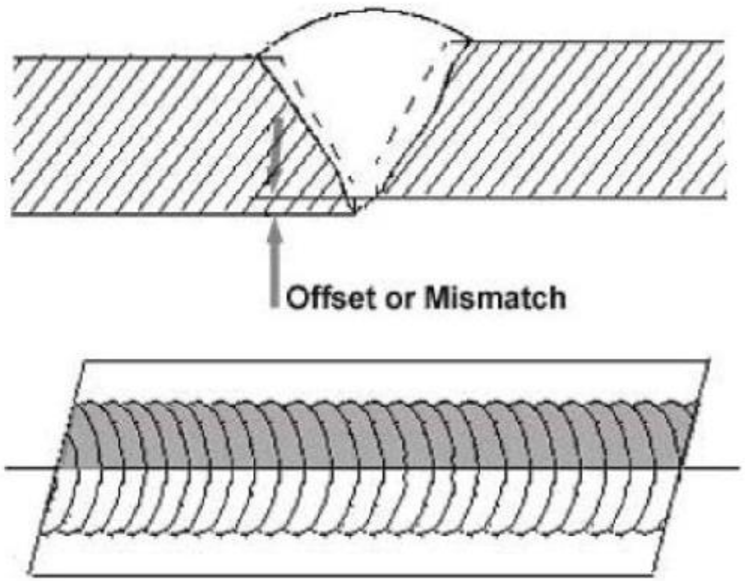
External or crown undercut

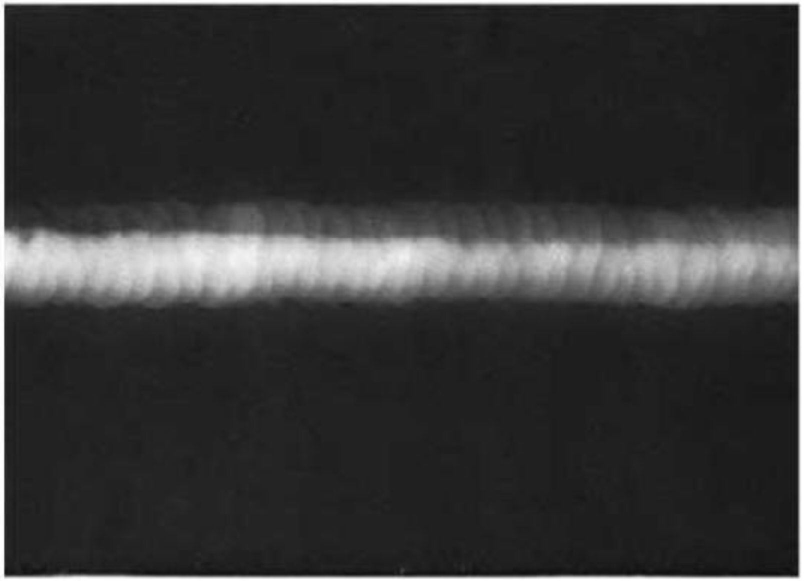




Examples of radiographs

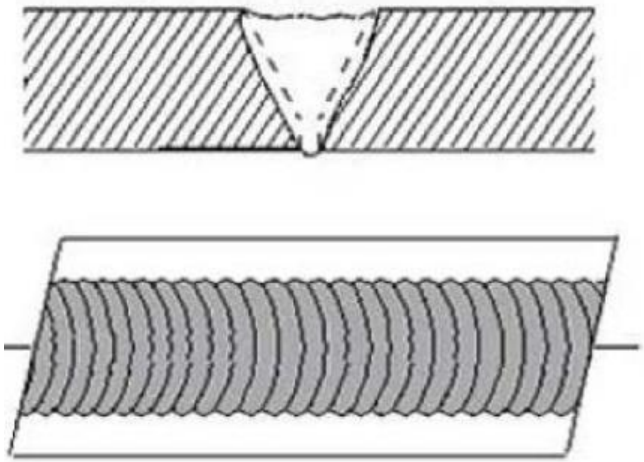
Offset or mismatch

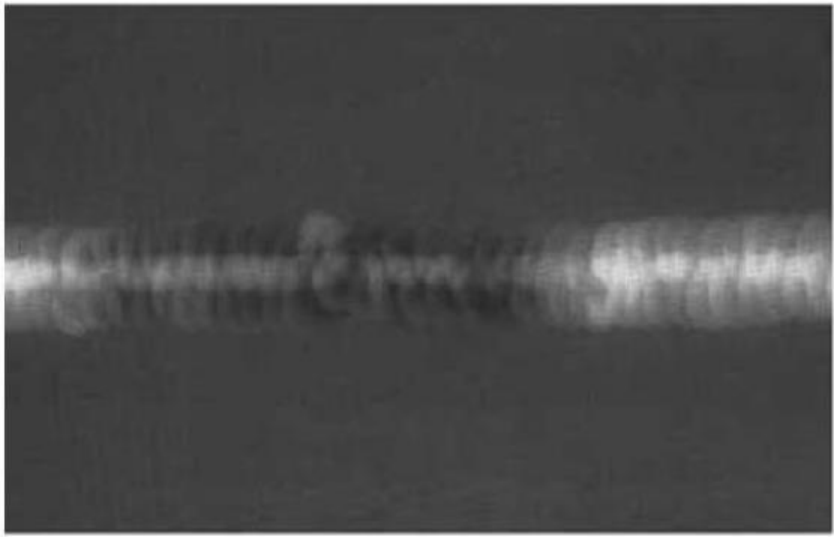




Examples of radiographs

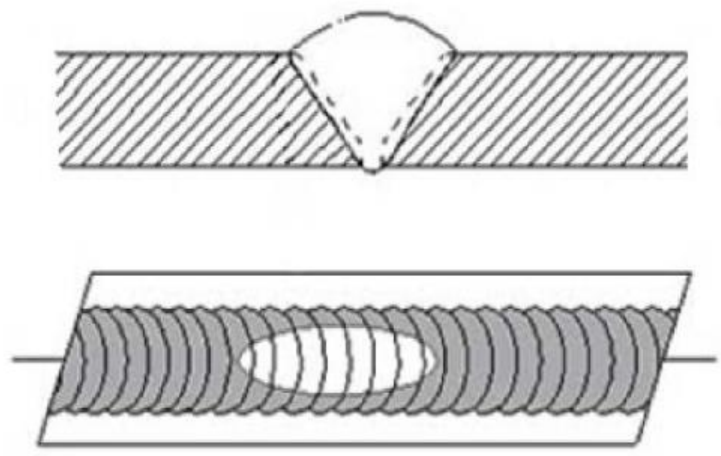
Inadequate weld reinforcement

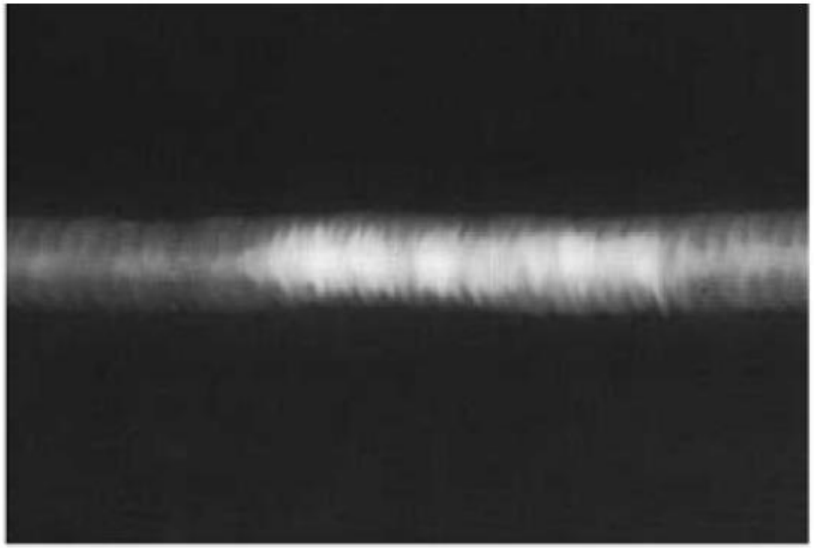




Examples of radiographs

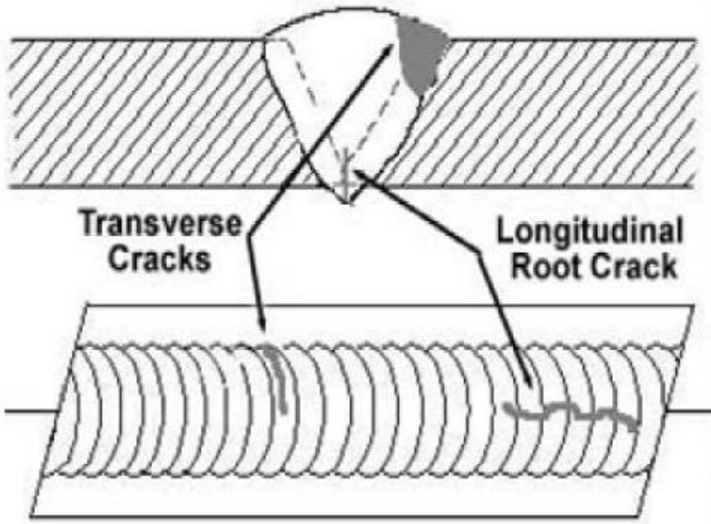
Excess weld reinforcement

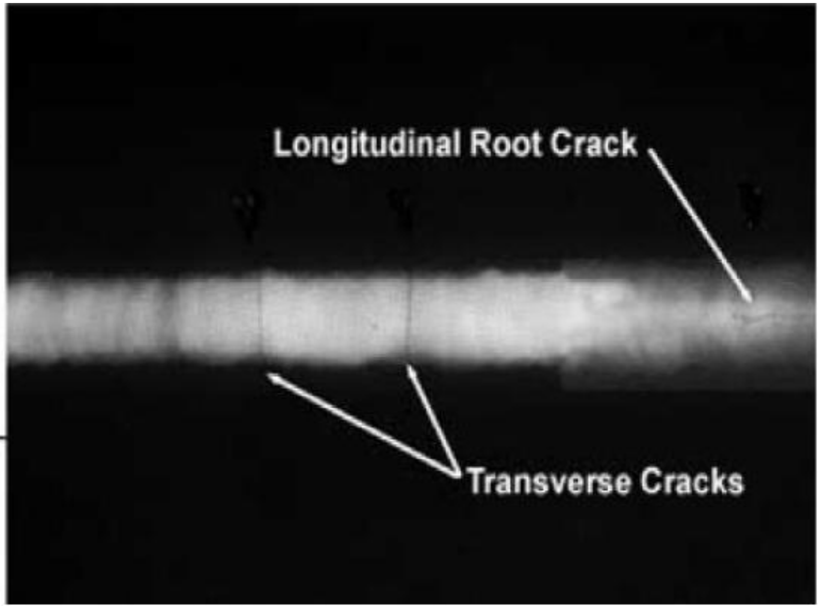




Examples of radiographs

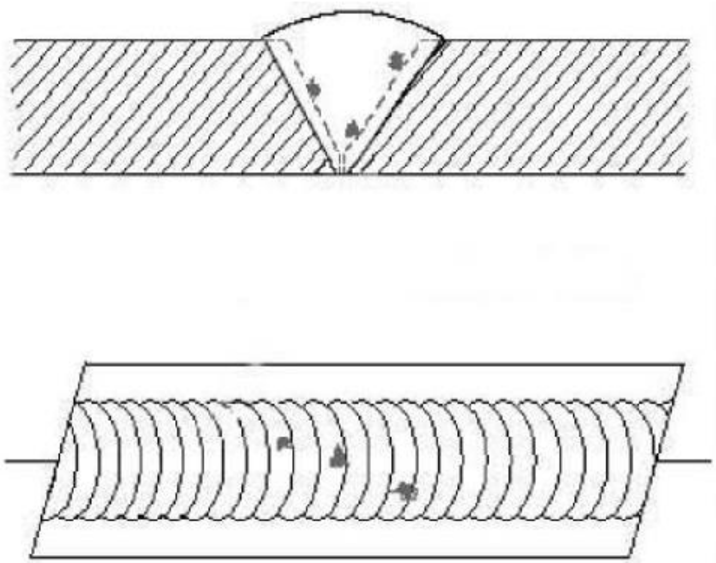
Cracking

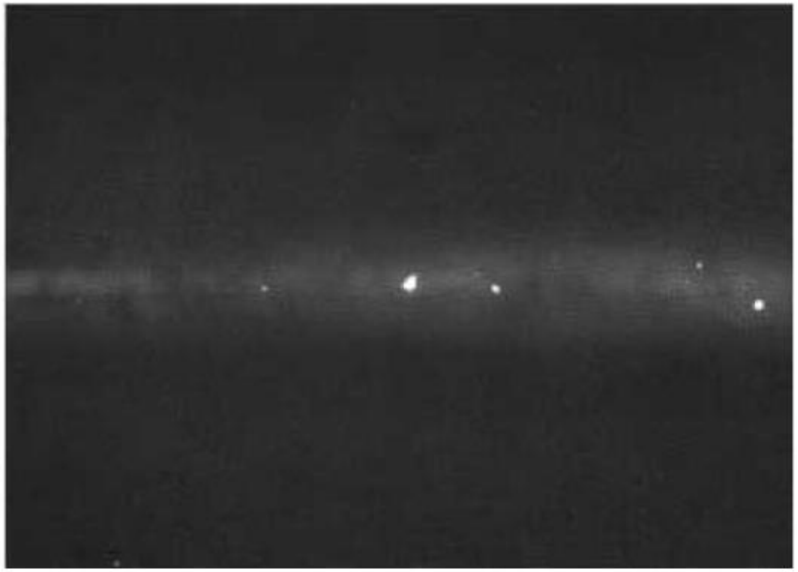




Examples of radiographs

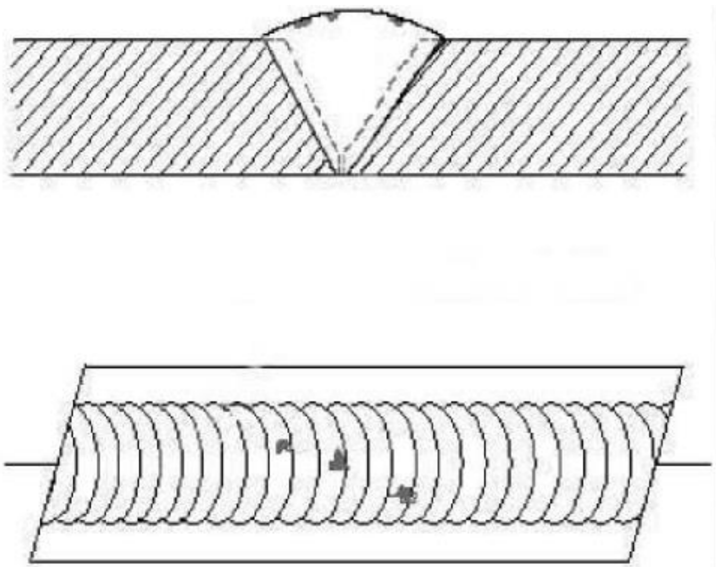
Tungsten inclusions.

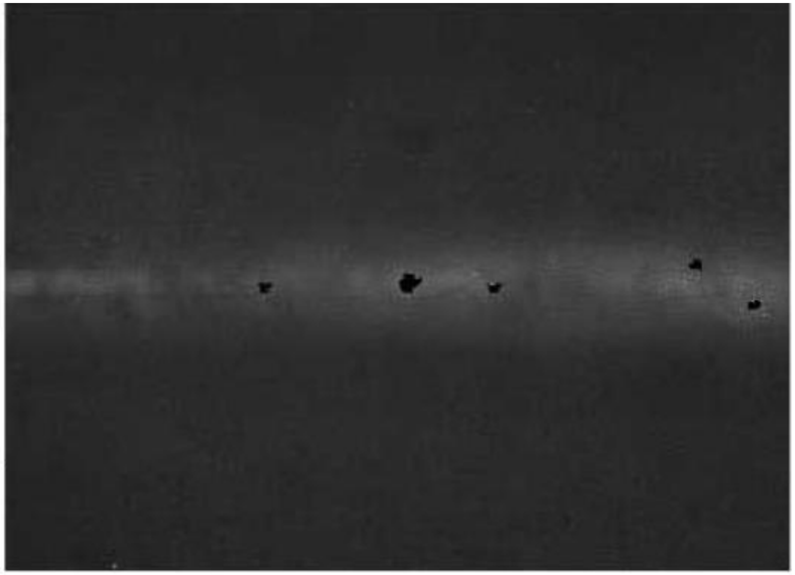




Examples of radiographs

Oxide inclusions





Glossary of Terms

- **Activation:** the process of creating radioactive material from stable material usually by bombarding a stable material with a large number of free neutrons. This process typically takes place in a special nuclear reactor.
- **Anode:** a positively charged electrode.
- **Automatic Film Processor:** a machine designed to develop film with very little human intervention. Automatic processors are very fast compared to manual development.
- **Capacitor:** an electrical device that stores an electrical charge which can be released on demand.
- **Cathode:** a negatively charged electrode.
- **Exposure:** the process of radiation penetrating and object.

Glossary of Terms

- **Darkroom:** a darkened room for the purpose of film development. Film is very sensitive to exposure by visible light and may be ruined.
- **Gamma Rays**: electromagnetic radiation emitted from the nucleus of a some radioactive materials.
- **Phosphor:** a chemical substance that emits light when excited by radiation.
- **Pixel:** Short for ***Pic****ture* ***El****ement*, a pixel is a single point in a graphic image. Graphics monitors display pictures by dividing the display screen into thousands (or millions) of pixels, arranged in rows and columns. The pixels are so close together that they appear connected.
- **Photo-multiplier tube:** an amplifier used to convert light into electrical signals.

Glossary of Terms

- **Radioactive:** to give off radiation spontaneously.
- **Radiograph:** an image of the internal structure of and object produced using a source of radiation and a recording device.
- **Silver Bromide:** silver and bromine compound used in film emulsion to form the image seen on a radiograph.