UNIT V RADIOGRAPHIC TESTING

RADIOGRAPHIC TESTING

Fundamental principles

The method of radiographic testing involves the use of a source of radiation from which the radiations hit the test specimen, pass through it and are detected by a suitable radiation detector placed on the side opposite to that of the source. This is schematically shown in the Figure 3.11. While passing through the test specimen the radiations are absorbed in accordance with the thickness, physical density and the internal defects of the specimen and the detector system therefore receives the differential radiations from different parts of a defective specimen which are recorded onto the detector.

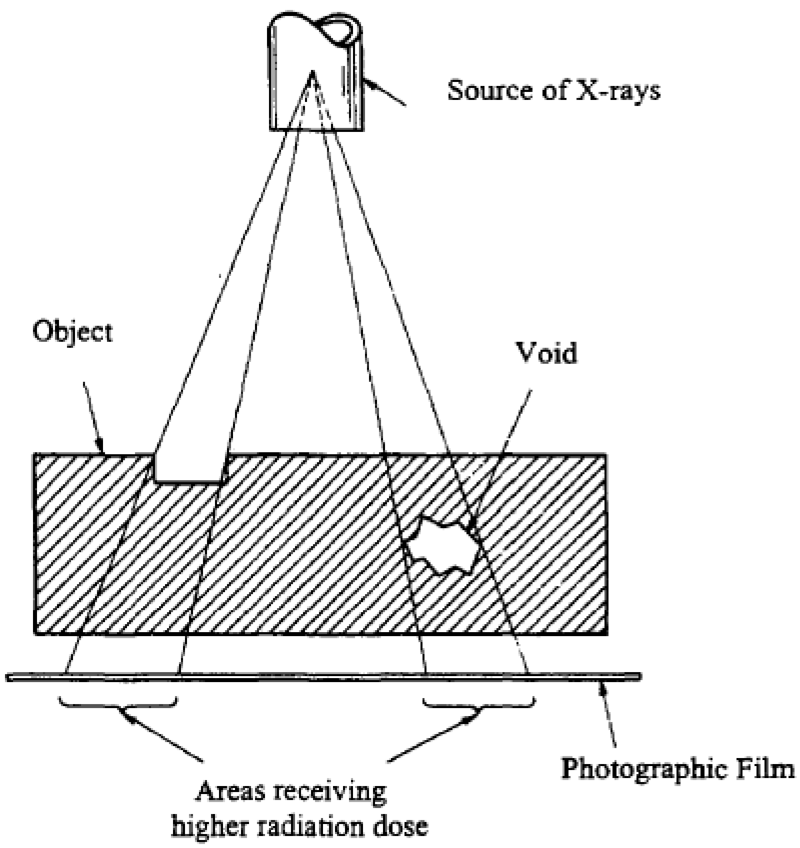


Figure: Arrangement of source, specimen and film in a typical radiographic set up

Properties of radiations

X-rays and gamma rays are electromagnetic radiations which have the following common properties.

(i) They are invisible.

(ii) They cannot be felt by human senses.

(iii) They cause materials to fluoresce. Fluorescent materials are zinc sulfide, calcium tungstate, diamond, barium platinocyanide, napthalene, anthracene, stilbene, thalium activated sodium iodide etc.

(iv) They travel at the speed of light i.e. 3×10^{10}cm/sec.

(v) They are harmful to living cells.

(vi) They can cause ionization. They can detach electrons from the atoms of a gas, producing positive and negative ions.

(vii) They travel in a straight line. Being electromagnetic waves, X-rays can also be reflected, refracted and diffracted.

(viii) They obey the inverse square law according to which intensity of X-rays at a point is inversely proportional to the square of the distance between the source and the point. Mathematically I a $1/r^2$ where I is the intensity at a point distant r from the source of radiation.

(ix) They can penetrate even the materials through which light cannot. Penetration depends upon the energy of the rays, the density and thickness of the material. A monoenergetic beam of X-rays obeys the well known absorption law, I = Io exp (-ux) where Io = the incident intensity of X-rays and 1= the intensity of X-rays transmitted through a thickness x of material having attenuation coefficient u.

(x) They affect photographic emulsions.

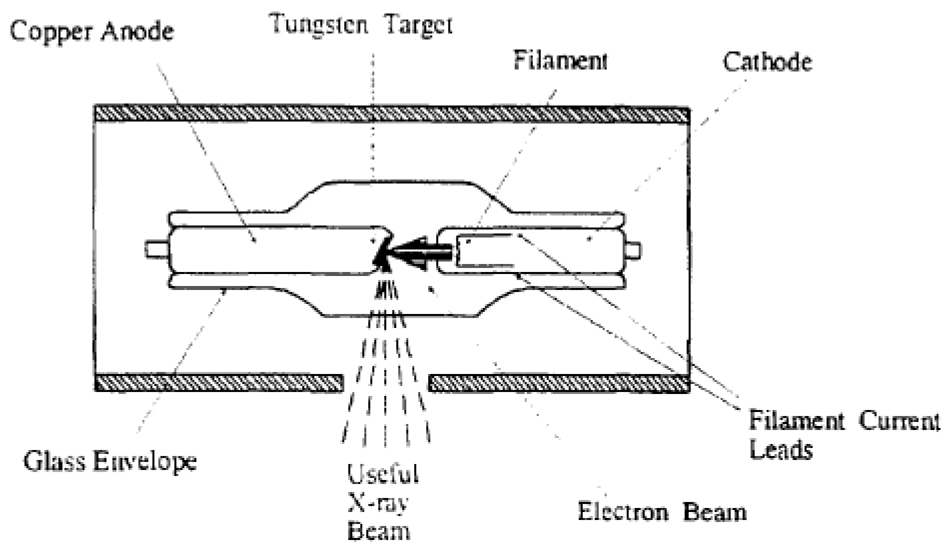
(xi) While passing through a material they are either absorbed or scattered.

Properties (vii), (viii), (ix), (x), (xi) are mostly used in industrial radiography.

Sources for radiographic testing

(i) X ray **machines**

X rays are generated whenever high energy electrons hit high atomic number materials. Such a phenomenon occurs in the case of X ray tubes, one of which is shown in above figure . The X ray tube consists of a glass envelope in which two electrodes called cathode and anode are fitted. The cathode serves as a source of electrons. The electrons are first accelerated by applying a high voltage across the cathode and the anode and then stopped suddenly by a solid target fitted in the anode. The sudden stoppage of the fast moving electrons results in the generation of X rays, These X rays are either emitted in the form of a cone or as a 360 degree beam depending upon the shape and design of the target. The output or intensity of X rays depend upon the kV and the tube current which control the number of electrons emitted and striking the target. The energy of X rays is mainly controlled by the voltage applied across the cathode and the anode which is of the order of kilovolts. The effect of a change in the tube current or the applied voltage on the production of X rays is shown in Figure.



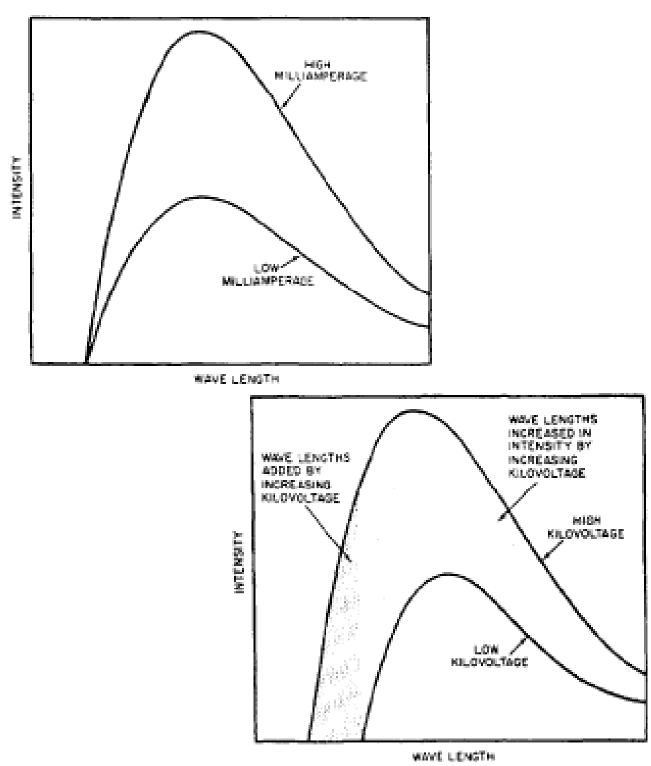


Figure : Effect of tube current (mA) and voltage (kV) on the intensity of X rays.

There is a variety of X ray machines available for commercial radiographic testing. Some of these emit X rays in a specified direction while others can give a panoramic beam. There are machines which have a very small focal spot size for high definition radiography. These are called micro focus machines. Some machines are specially designed to give very short but intense pulses of X rays. These are called flash X ray tubes and are usually used for radiography of objects at high velocity. Typically X ray machines of up to a maximum of about 450 kV are commercially available for radiographic testing.

(ii) Gamma ray sources:

These are some elements which are radioactive and emit gamma radiations. There are a number of radioisotopes which in principle can be used for radiographic testing. But of these only a few have been considered to be of practical value. The characteristics which make a particular radioisotope suitable for radiography include the energy of gamma rays, the half life, source size, specific activity and the availability of the source. In view of all these considerations the radioisotopes that are commonly used in radiography along with some of their characteristics are given in Table3.1.

(iii) Radiographic linear accelerators:

For the radiography of thick samples, X ray energy in the MeV range is required. This has now become possible with the availability of radiographic linear accelerators. In a linear accelerator the electrons from an electron gun are injected into a series of interconnected cavities which are energized at radio frequency (RF) by a klystron or magnetron. Each cavity is cylindrical and separated from the next by a diaphragm with a central hole through which the electrons can pass. Due to the imposed RF, alternate diaphragm hole edges will be at opposite potentials at all times and the field in each cavity will accelerate or decelerate the electrons at each half cycle. This will tend to bunch the electrons and those entering every cavity when the field is accelerating them will acquire an increasing energy at each pass. The diaphragm spacing is made such as to take into account the increasing mass of electrons as their velocity increases. They impinge on a target in the usual way to produce X rays. Linear accelerators are available to cover a range of energies from about 1 MeV to about 30 MeV covering a range of steel thicknesses of up to 300 mm. The radiations output is high (of the order of 5000 Rad per minute) and the focal spot sizes usually quite reasonable to yield good quality radiographs at relatively low exposure times.

(iv) Betatron

The principle of this machine is to accelerate the electrons in a circular path by using an alternating magnetic field. The electrons are accelerated in a toroidal vacuum chamber or doughnut which is placed between the poles of a powerful electromagnet. An alternating current is fed into the energising coils of the magnet and as the resultant magnetic flux passes through its zero value, a short burst of electrons is injected into the tube. As the flux grows the electrons are accelerated and bent into a circular path. The magnetic field both accelerates the electrons and guides them into a suitable orbit and hence, in order to maintain a constant orbit,

TABLE 3.1 : TYPICAL RADIOACTIVE SOURCES FOR INDUSTRIAL RADIOGRAPHY.

Characteristics / Source	Half life	Gamma ray energies (MeV)	RHM value per curie	Optimum thickness range (mm of steel)	Half value layer (mm of lead)
Thulium-170	128 Days	0.87, 0.52	0.0025	2.5 to 12	-
Cobalt-60	5.3 Years	1.17, 1.33	1.33	50 to 150	13
Iridium-192	74.4 Days	0.31, 0.47, 0.64	0.5	10 to 70	2.8
Caesium-137	30 Years	0.66	0.37	20 to 100	8.4

these two factors must be balanced so that the guiding field at the orbit grows at an appropriate rate. The acceleration continues as long as the magnetic flux is increasing, that is, until the peak of the wave is reached; at this point the electrons are moved out of orbit, either to the inner or outer circumference of the doughnut, by means of a DC pulse through a set of deflecting coils. The electrons then strike a suitable target. The electrons may make many thousands of orbits in the doughnut before striking the target, so that the path lengths are very great and the vacuum conditions required are in consequence very stringent. The radiation from betatrons is emitted in a series of short pulses. In order to increase the mean intensity some machines operate at higher than mains frequency. Most betatrons designed for industrial use are in the energy range of 6-30 MeV. Betatrons in general have a very small focal spot size typically about 0.2 mm, but the X ray output is low. Machines are built in the higher energy range in order to obtain a higher output, but this brings the disadvantages of a restricted X ray field size.

Films for radiographic testing

The detection system usually employed in radiographic testing is the photographic film usually called an X ray film. The film consists of a transparent, flexible base of clear cellulose derivative or like material. One or both sides of this base are coated with a light sensitive emulsion of silver bromide suspended in gelatin. The silver bromide is distributed throughout the emulsion as minute crystals and exposure to radiation such as X rays, gamma rays or visible light, changes its physical structure. This change is of such a nature that it cannot be detected by ordinary physical methods, and is called the latent image.

However, when the exposed film is treated with a chemical solution (called a developer) a reaction takes place causing the formation of tiny granules of black metallic silver. It is this base that constitutes the image. Above figure is an expanded pictorial view of the general make up of a film.

Radiographic film is manufactured by various film companies to meet a very wide diversified demand. Each type of film is designed to meet certain requirements and these are dictated by the circumstances of inspection such as (a) the part (b) the type of radiation used (c) energy of radiation (d) intensity of the radiation and (e) the level of inspection required. No single film is capable of meeting all the demands. Therefore a number of different types of films are manufactured, all with different characteristics, the choice of which is dictated by what would be the most effective combination of radiographic technique and film to obtain the desired result.

The film factors that must be considered in choosing a film are : speed, contrast, latitude and graininess. These four are closely related; that is, any one of them is roughly a function of the other three. Thus films with large grain size have higher speed than those with a relatively small grain size. Likewise, high contrast films are usually finer grained and slower than low contrast films. Graininess, it should be noted, influences definition or image details. For the same contrast, a small grained film will be capable of resolving more detail than one having relatively large grains. The films are generally used sandwiched between metallic screens, usually of lead. These screens give an intensification of the image and thus help to reduce the exposure times besides cutting down the scattered radiation.

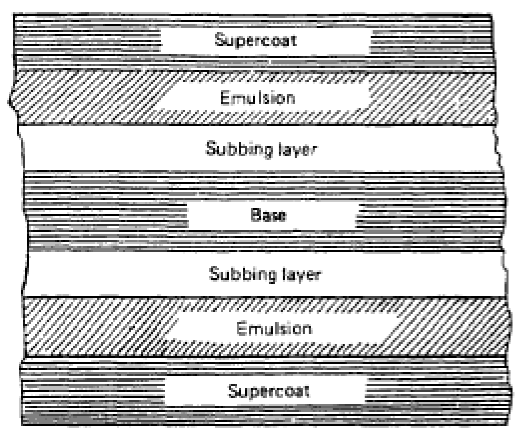


Figure : Construction of radiographic films

Intensifying Screens

Film is sandwiched between intensifying screens

Three types a) Lead Screens

b) Fluorescent Screens

c) Flurometallic screens

Lead Intensifying Screens

- o Front Screen shortens exposure time and improves quality by filtering backscatter
- o Back screens act as filter only
- o Screen thickness 0.02 mm to 0.15 mm

Fluorescent Screens

- o Intensification twice of Lead Screen
- o Cost effective

Flurometallic screens

- o Front screen act as filter and intensifier
- o Intensifying Action achieved by emitting light radiation and particulate radiation electrons

Film Processing

Types of Processing

1. Manual
2. Semi Automatic
3. Automatic

(a) Developer - converts latent image into manifest image (10-12 Min- Agitate)

(b) Stop Bath – Removes Excess Developer (10-15 Sec)

(c) Fixer -Clean the film of unexposed, undeveloped AgBr crystals, promotes archival quality (5 Min

(d) Wash – rid the film of residual chemicals

(e) Wetting the film to swell the emulsion

Note: For manual processing a floating thermometer, a timer and the time -temperature chart are essential.

Penetrameters /Image Quality Indication

Penetrameter is an artificial defect as well as the heart of the radiographic testing. The Penetrameter was introduced early 1950s as one penetrameter of a specific thickness approximately 2% of the designated pipe wall thickness and during mid 1960s the designated one penetrameter of a specific thickness was changed for a range of pipe wall thicknesses. It is a standard test piece is usually included in every radiograph as a check on the adequacy of the radiographic technique. The test piece is commonly referred to as penetrameter in America and an Image Quality Indicator (IQI) in Europe. It is tool to measure the contrast or change in density on an image for a known change in thickness in the specimen.

Penetrameter provides an effective check on the overall quality of the radiographic inspection. The image of the penetrameter transferring from source side of the test part to the film ensures that any defect equal and above that of the subject contrast of the penetrameter selected will be recorded on the film after crossing over the entire part thickness. Radiation beam is divergence in nature, maximum intensity at centre and minimum intensity at the edge of the central beam. The penetrameter should be usually placed on the source side of the test part and at the edge of the central beam. This is because, Penetrameter whose image cast on the film after crossing the entire part thickness, with the minimum intensity level at the edge of the central beam, ensures that any defect covering in the area of interest of the test part will be recorded on the radiograph.

The purpose of penetrameter are:

1. Check sensitivity (refers size of a defect);

2.Check technique (refers shape of a defect); and

3.Check material identification (penetrameter without notch for carbon steel materils and with notches for other than carbon steel materials)

Then there are two general type of penetrameters used in Industrial Radiogarphy:

1.Hole type (reduction of metal) and

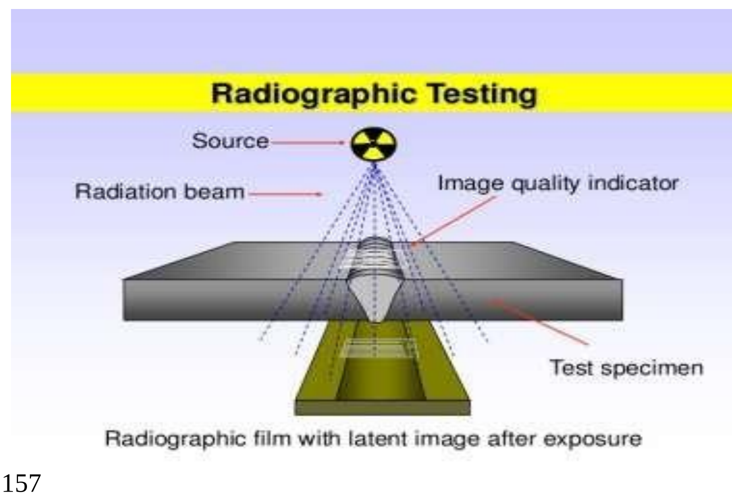
2.wire type (addition of metal).

Penetrameters are used,

- To achieve a radiographic image with highest quality
- It provide a means of visually informing the film interpreter of the contrast sensitivity and definition of the radiograph

Types of IQI Commonly Used

- Wire Type
- Step Hole Type
- Plaque Hole Type (Step – Hole Type)



1 Wire type IQI

2 Step/Hole type IQI

3 Plaque type IQI

(a) 1% Sensitivity –Aerospace Application

(b) 2 % Sensitivity –Industrial Application

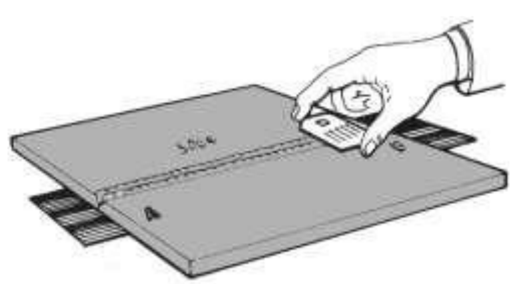
(c) Sensitivity–Ability to detect smallest flaw

(d) Suppose, Object – 8 mm, Thickness = 2 % (8) = 0.16 mm

So, the minimum size of the discontinuity that should be visible in the radiography film is of 0.16mm

Placement of Penetrameters /IQI

- To be placed at worst location/Extreme edge of radiographic film
- To be placed at Source Side, in case use Film Side ~ DWSI/DWDI (Indicate Letter F)
- For Weld, Wire Type IQI to be kept across the weld
- For Weld, Plate & Hole, Step Wedge, parallel to weld 3mm away from weld edge
- When there is no accessibility, Block/shim to be used & IQI to be placed on it.
- Density of radiograph varies from location of IQI by more than -15% to 30 % then another IQI is required
- For Circumferential weld in SWSI-Panaromic technique, 3 IQI’s at 120^{o} apart, 4 IQI at 90^{o} apart
- Backing rings or strips and root penetration are not to be considered as part of the weld or reinforcement thickness in selection of the IQI.
- The material of the IQI shall be of similar radiographic density to that of the material under examination, i.e. use steel for steel, aluminium for aluminium, etc.,



Radiographic Inspection

This is carried out where the welded components require a very critical inspection technique due to their application. Shielding from x-ray and gamma-ray radiation is a strict requirement; this can be of a portable means or the components can be brought to a specialised building to be x-rayed. In my old offshore construction yard, radiography was carried out during the dead hours between shifts, when a visible and audio alarm would howl continuously to warn against entrance to the assembly buildings.

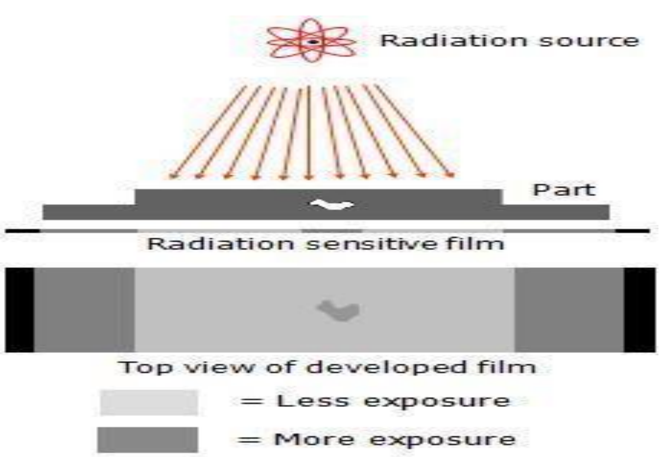
Anyway, the relative components are exposed to the radioactive source from which a radiograph is produced. This will show any irregularities in the welding when checked by an experienced radiograph interpret

Radiography is used in a very wide range of applications including medicine, engineering, forensics, security, etc. In NDT, radiography is one of the most important and widely used methods. Radiographic testing (RT) offers a number of advantages over other NDT methods, however, one of its major disadvantages is the health risk associated with the radiation.

In general, RT is method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. The intensity of the radiation that penetrates and passes through the material is either captured by a radiation sensitive film (*Film Radiography*) or by a planer array of radiation sensitive sensors (*Real-time Radiography*). Film radiography is the oldest approach, yet it is still the most widely used in NDT.

Basic Principles

In radiographic testing, the part to be inspected is placed between the radiation source and a piece of radiation sensitive film. The radiation source can either be an Xray machine or a radioactive source (Ir-192, Co-60, or in rare cases Cs-137). The part will stop some of the radiation where thicker and denser areas will stop more of the radiation. The radiation that passes through the part will expose the film and forms a shadow graph of the part. The film darkness (density) will vary with the amount of radiation reaching the film through the test object where darker areas indicate more exposure (higher radiation intensity) and lighter areas indicate less exposure (lower radiation intensity).This variation in the image darkness can be used to determine thickness or composition of material and would also reveal the presence of any flaws or discontinuities inside the material.



General procedure for radiographic testing

The test specimen is first of all properly cleaned and visually inspected and all the surface imperfections are noted. A properly selected film, usually sandwiched between intensifying screens and enclosed in a light proof cassette is prepared. The source of radiation, the test specimen and the film are arranged as shown in Figure 3.11. Image quality indicators and lead identification letters are also placed on the source side of the test specimen. From a previously prepared exposure chart for the material of the test specimen, the energy of radiations to be used and the exposure (intensity of radiations x time) to be given are determined. Then the exposure is made. After the source of radiation has been switched off or retrieved back into the shielding (in case of gamma ray source), the film cassette is removed and taken to the dark room. In the dark room, under safe light conditions, the film is removed from the cassette and the screens and processed. The processing of the film involves mainly four steps. Development reduces the exposed silver bromide crystals to black metallic silver thus making the latent image visible. Development is usually done for 5 minutes at 20°C. After development the film is fixed whereby all the unexposed and undeveloped crystals of film emulsion are removed and the exposed and image-forming emulsion is retained on the film. The fixing is done for approximately 2-6 minutes. The film is then washed preferably in running water for about 20-30 minutes and dried Finally the film is interpreted for defects and a report compiled. The report includes information about the test specimen, the technique used and the defects. It also sometime says something about acceptance or rejection of the reported defects. The report is properly signed by responsible persons.

Advantages

- Both surface and internal discontinuities can be detected.
- Significant variations in composition can be detected. It has a very few material limitations.
- Can be used for inspecting hidden areas (direct access to surface is not required)
- Very minimal or no part preparation is required.
- Permanent test record is obtained.
- Good portability especially for gamma-ray sources.

Disadvantages

- Hazardous to operators and other nearby personnel.
- High degree of skill and experience is required for exposure and interpretation.
- The equipment is relatively expensive (especially for x-ray sources).
- The process is generally slow.
- Highly directional (sensitive to flaw orientation).
- Depth of discontinuity is not indicated.
- It requires a two-sided access to the component.

Applications

- Industrial radiography is used in the inspection of new products and welds
- New pipelines (including bends and joints), storage containers and even insulated materials are routinely inspected using radiography.

- detection and measurement of internal flaws in existing plant.
- The early detection of internal flaws in pipelines and plant in the oil and gas sector,
- Detection of Corrosion Under Insulation (CUI), is another common application for radiography.
- NDT radiography is also used in security.

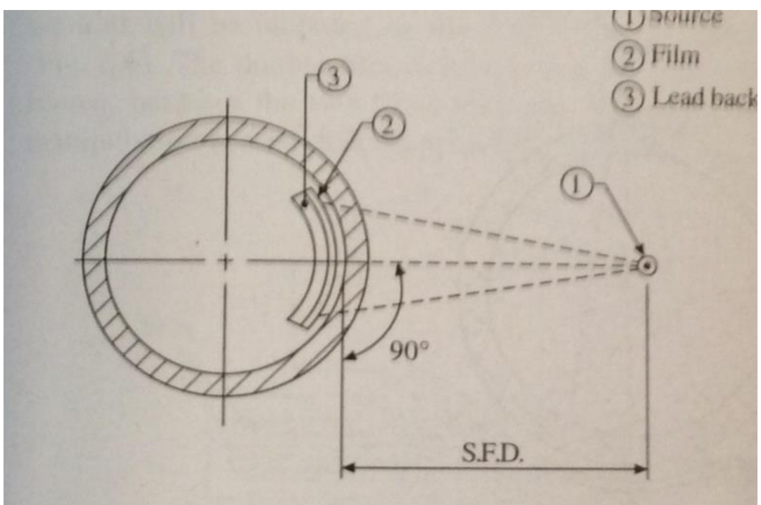
Radiographic Inspection techniques.

With the various techniques available, the choice of appropriate one is made on the basis of geometry, size, sensitivity requirements, in-situ space availability etc. The techniques used for various engineering components for radiographic inspection are:

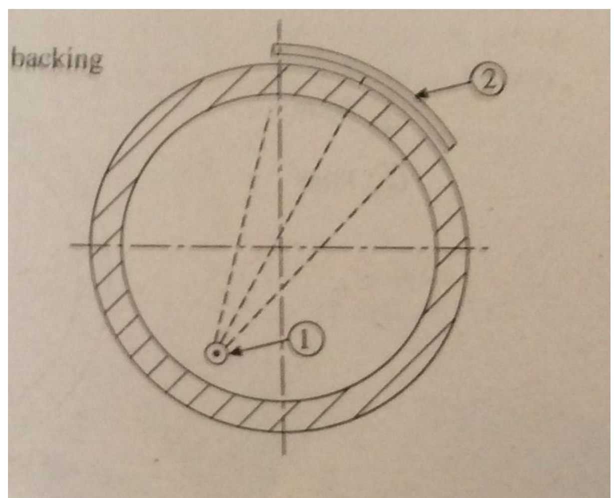
- Single wall single image technique
- Double wall penetration technique
- Double wall single image
- Double wall double image
- Double wall superimposing image

Single wall single image technique (SWSI)

Single wall single image technique (SWSI) is used when both the sides of the specimen are accessible. The source is kept outside and the film inside or vice versa and the weld is exposed part by part (a smaller length of weld).



(a) Source outside film inside

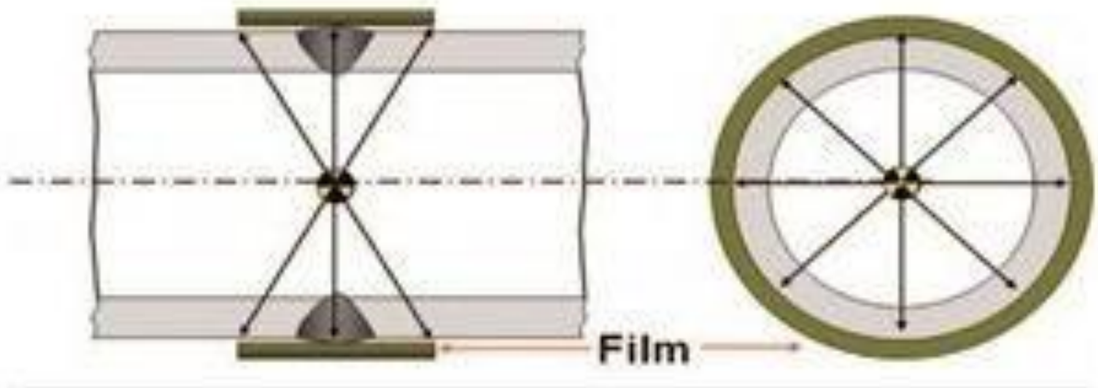


(b) Source inside film inside

This is used for plates, cylinders, shells and large diameter pipes.

Panoramic technique

- The 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.
- The total circumferential weld length is exposed at a time.
- Reduces the examination time considerably.
- It can be effectively employed only when the source to film distance is sufficient enough to ensure the proper sensitivity.

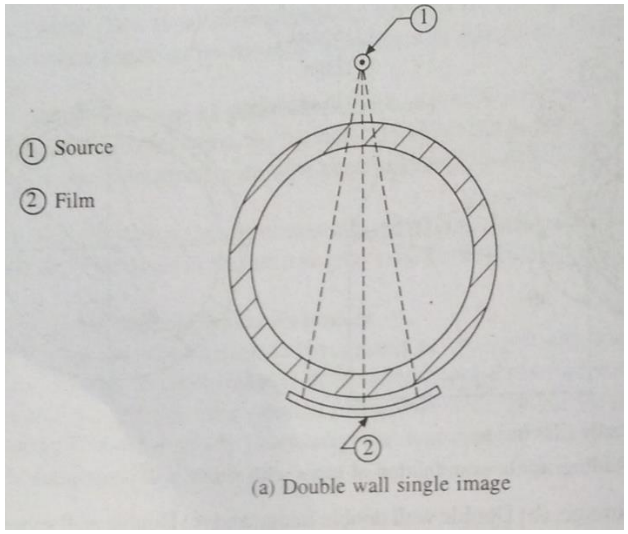


Double wall penetration technique

- Used where the inside surface of the pipe is not accessible.
- The source of radiation and the film are kept outside.
- The radiation penetrates both the walls of the pipe.
- This can be effectively adopted in 3 different methods.
- Double wall single image (DWSI)
- Double wall double image (DWDI)
- Double wall superimposing image

Double wall single image (DWSI)

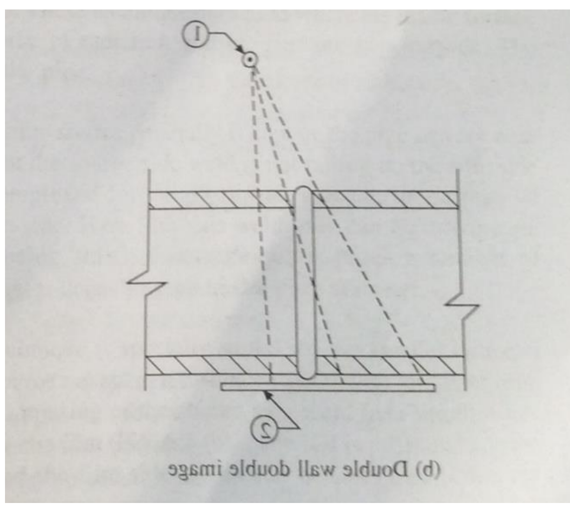
- The radiation source is kept on the pipe or very near to the OD and just near the weld.
- Used for pipes with diameter more than 90 mm OD.
- The image quality indicator (IQI) is placed on the film side.
- Here film side weld only can be interpreted.
- As the interpretable weld length is small, it requires a number of exposures to cover the entire weld length, depending upon the pipe diameter.



(a) Double wall single image

Double wall double image (DWDI)

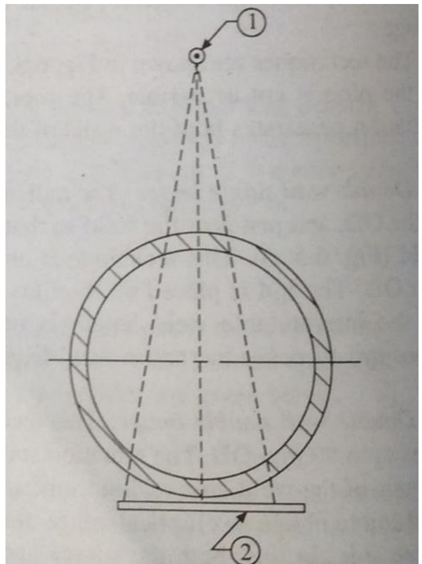
- Specially suited for small diameter pipes up to 90 mm OD.
- The radiation source is kept at a distance SFD (Source-to-Film Distance) with an offset from the axis of the weld,
- to avoid the super imposing of the source side weld over the film side weld and to obtain an elliptical image on the film.


(b) Double wall double image

- Here both the source and film side welds can be interpreted from the image.
- Requires min. of two exposures, perpendicular to each other, to cover the entire circumference.

Superimposing technique

- Used when the required offset to obtain double image could not be possible due to site restrictions for the pipes with dia : 90mmOD.
- The source is kept at a distance without offset, thereby the source side weld is superimposed on the film side weld on the film.



(c) Super imposing image

- Requires minimum of 3 exposures each at 120° apart, to cover the entire length of the weld

Different forms of radiographic testing

(i) Fluoroscopy

In the general radiographic process, if the film is replaced by a fluorescent salt screen then the image of the test specimen can be visually seen. The X rays passing through the object excite the fluorescent material producing bright spots in the more heavily irradiated areas. The fluorescent screen may be viewed directly or by means of a mirror or by using a camera and a closed-circuit television. The whole set-up of X ray tube, the test specimen and the fluorescent screen are encased in a protective shielding.

In many cases castings of up to about 10 mm thickness, thin metal parts, welded assemblies and coarse sandwich constructions are screened by this method and castings with obvious large defects are rejected before usual inspection using film radiography.

Plastic parts may be checked for the presence of metal particles or cavities. Other applications include inspection of electrical equipment such as switches, fuses, resistors, capacitors, radio tubes, cables and cable splices in which breaks of metal conductors, short circuiting or wrong assembly may cause troublesome electrical testing. Ceramics, fire bricks and asbestos products lend themselves perfectly to fluoroscopy. Packaged and canned foods are examined for the amount of filling and for the presence of foreign objects.

(ii) Microradiography

Specially prepared thin samples are radiographed at extremely low energies (e.g. 5 KV) on an ultrafine grain film. The radiograph when enlarged gives the structural 92 details of the specimen. Micro-radiography is mainly applied in metallurgical studies.

(iii) Enlargement radiography

In some situations, an enlarged image of an object is desired. To get the enlargement of the image the object to film distance is increased. To overcome the penumbral effects a source of an extremely small size is used.

(iv) High speed or flash radiography

For the radiography of moving objects, the exposure time should be very small and, at the same time, the intensity of the X rays should be extremely high. This is achieved by discharging huge condensers through special X ray tubes which give current of the order of thousands of amperes for a short time (of the order of a millionth of a second). This technique is normally applied in ballistics.

(v) Autoradiography

In this case the specimen itself contains the material in radioactive form. When a film is placed in contact with the specimen, an autoradiograph is obtained showing the distribution of the radioactive material within the specimen. The technique is mainly used in the field of botany and metallurgy

(vi) Electron transmission radiography

A beam of high energy X rays is used to produce photo-electrons from a lead screen. These electrons after passing through the specimen (of very low absorption like paper, etc.) expose the film and an electron radiograph is obtained.

(vii) Electron emission radiography

In this case a beam of X rays is used to produce photoelectrons from the specimen itself. These electrons expose the film which is placed in contact with the specimen. Since emission of electrons depends upon atomic number of an element, the electron emission will give the distribution of elements of different atomic numbers.

(viii) Neutron radiography

In this case a neutron beam is used to radiograph the specimen. The recording system will, therefore, not be a photosensitive film since it is insensitive to neutrons. The following methods are used to record the image:

(1) A gold foil is used which records the image, in terms of the activity produced. This image can be transferred onto a film by taking an autoradiograph of the foil. Some other suitable materials such as indium and dysprosium can replace gold.

(2) The metallic foil upon neutron bombardment does not become radioactive but instead emits spontaneous gamma rays which expose the film placed in contact with it. Examples of metals suitable for this are lithium and gadolinium.

(3) Neutrons transmitted through the specimen are made to strike a thin neutron scintillator plate. The scintillations thus produced expose the film which is in contact with the scintillator.

In certain cases, neutron radiography is advantageous as compared to X or gamma radiography, for example:

(a) If the specimen is radioactive.
(b) If the specimen contains thermal neutron absorbers or light elements.
(c) Two elements whose atomic number is not very different may be easily distinguished.

(ix) Proton radiography

For special type of studies, a proton beam can also be used. The number of protons transmitted through a specimen whose thickness is close to the proton range is very sensitive to exact thickness. This helps in detecting very small local variations in density and thickness.

(x) Stereo radiography

Two radiographs of the specimen are taken from two slightly different directions. The angle between these directions is the same as the angle subtended by the human eyes while viewing these radiographs. In the stereo viewer the left eye sees one radiograph and the right eye the other. In this way a realistic three-dimensional effect is obtained giving the visual assessment of the position of the defect.

(xi) Xero radiography

This is considered as a "dry" method of radiography in which a xerographic plate takes the place of X ray film. The plate is covered with a selenium powder and charged electrostatically in the dark room. Exposure to light or radiation causes the charge to decay in proportion to the amount of radiation received and a latent image is formed.

The developing powder is sprayed on the plate in a light-tight box. The particles are charged by friction while passing through the spray nozzle. White powders have best contrast with the black selenium surface but present problems in transferring the picture to paper. Coloured powders on transfer produce negative images while fluorescent powder gives the same picture as white powder and can be viewed under black light both before and after transfer.

Personal safety and radiation protection

Nuclear radiations are harmful to living tissues. The damage done by radiations is sinister as human senses are not capable of detecting even lethal doses of radiation. The dose of radiations absorbed by human body is expressed in mSv (1 mSv = 100 rem = U/kg) which takes into account the biological effectiveness of different types of radiations such as alpha particles, gamma rays, X rays and neutrons, etc. The overall outcome of exposure to radiation is initiated by damage to the cell which is the basic unit of the organism. The effects of radiation may be deterministic or stochastic, early or late, of somatic or genetic type.

Somatic effects depend upon three main factors.

(a) First of these factors is the rate at which the dose is administered. Cells begin the repair processes as soon as some degree of damage has been received. When the body is able to keep up with the damage, no injury or pathological change will be seen in the irradiated individuals. However, the same amount of radiation given all at once would produce a more severe reaction.

(b) The second is the extent and part of the body irradiated. It is known that certain cells are more sensitive to radiation than others. Hence the overall effect of radiation depends on the extent and part of the body irradiated.

(c) The third important factor is the age of the affected individual, persons growing physically are in an accelerated stage of cells reproduction and most of the cells in the body are dividing and hence sensitive to radiation. For this reason, an exposure of a given amount should be considered more serious for a young person than for an adult.

The somatic effects can either be immediate or delayed. Given below is a summary of immediate effects when the whole body is acutely irradiated with a range of radiation doses:

Applications of radiographic testing method

Radiographic testing is mainly applied for the detection of flaws such as cracks, porosity, inclusions, lack of root penetration, lack of fusion, laps, seams, shrinkage, corrosion, etc. in weldments and castings, in pressure vessels, containers for industrial liquids and gases, pipelines, steel bridges, steel and aluminium columns and frames and roofs, nuclear reactors and nuclear fuel cycle, boiler tubes, ships and submarines, aircraft and armaments. In most of these cases weld inspection is involved. Welds in plates are tested using an arrangement more or less similar to the one shown in above Figure 3. However, there are a number of different techniques for inspection of welds in pipes. These are illustrated in Figure 3.15. The welds in small diameter pipes are inspected usually using source-outside film- outside technique. Medium diameter pipes may also be inspected as in above Figure where source-inside-film outside technique is utilized. When the diameter of pipes becomes large enough, the circular welds may be examined using a panoramic technique. In this the source is placed at the centre inside the pipe and the film is wrapped all around the weld on the outside. Thus, in this case the whole weld can be radiographed in a single exposure while for all other situations in above figure multiple exposures are required for full coverage.

Radiography is also extensively used for the inspection of castings and forgings. The regular shaped and uniformly thick specimens can be inspected as usual like welds in plates while special considerations need to be made for testing of specimens of varying thickness. Double film technique is usually employed wherein two films of different speeds are used for a single exposure. In this way correct density is obtained under the thick sections on the faster film whereas the slower films record correct images of the thin sections.

Radiography is used in inspection of explosives contained within casings, sealed boxes and equipment. In the field of electronics, it is employed for the inspection of printed circuit boards and assemblies for checking adequacy of connections.

Range and limitations of radiographic testing

Radiographic testing method is generally applicable for the inspection of all types of materials, e.g. metallic, non-metallic and plastics, magnetic and non-magnetic, conductors and non-conductors, etc. as long as both sides of the test specimen are accessible for placement of source and the film on either side. The film needs to be placed in contact with the specimen and whenever this is not possible due to the geometry of the test specimen, radiographs of poorer quality will result.

The penetration of the radiation through the test specimen depends upon its thickness and density. For high density materials, as well as for larger thickness of the same material, higher energies are needed. Although, in principle, these higher energies are now available from betatrons and linear accelerators, these sources of radiation are extremely expensive and therefore not available for common use. Table 3.1 shows that among the commonly available radiation sources including the commercial X ray machines of up to about 420 KV, the strongest source is that of cobalt-60 which can be used for radiography of steel of thickness up to about 150mm.

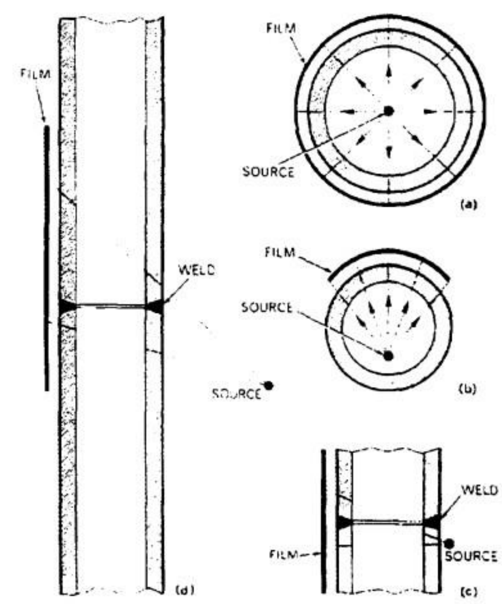


Figure 3.15: Various techniques for weld inspection.

The factors affecting radiographic quality and consequently the sensitivity of flaw detection by radiographic testing method need to be carefully considered while selecting the technique for a particular test. For example, for high sensitivity or to be able to detect smaller flaws, it is recommended that largest possible source-to film distance is used with a source of the smallest possible dimensions, the slowest and fine-grained film should be used and film processing should be done as per recommendations of the manufactures (usually for 5 minutes at 20°C). The lowest energy compatible with the thickness and density of the test specimen should be chosen. In practice a compromise has to be made between these ideal requirements to achieve an optimum level of sensitivity. But a radiograph made with a technique of poor sensitivity will need a more critical inspection, since defect images will not be so easily seen and may in fact be missed. There is a definite tendency to make a more cursory examination when defect images are only faintly seen. Similarly, very small defects below the sensitivity limits of the technique employed may be missed. Such a situation can also arise due to improper viewing conditions and the training and experience of the interpreter. Sensitivity of flaw detection decreases with an increase in thickness of the test specimen.

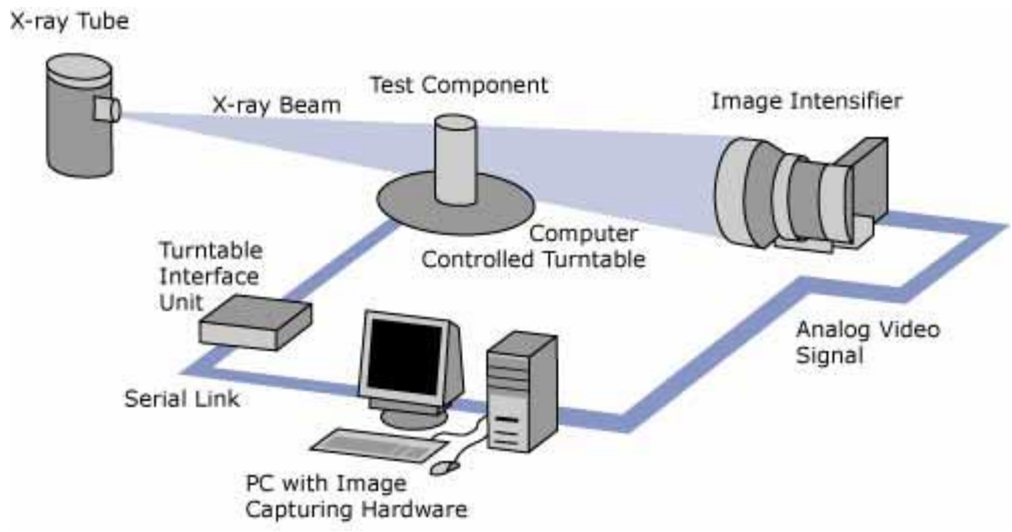
Radiographic picture is a two-dimensional shadow of a three-dimensional defect. The orientation of the defect with respect to the direction of the beam is therefore an important consideration. Thus planar defects such as cracks, laminations, lack of fusion in welds or similar defects may not be detected if their plane is at right angles to the incident beam. Elongated defects like pipes and wormholes may show up and be misinterpreted as spherical defects. Smaller defects located behind the larger ones in the direction of the beam will not be detected.

A serious limitation with the radioisotope sources used for radiography is the fact that even unused their activity decreases with time. While they have the distinct advantage of needing no power for field radiography applications, they need special shielded enclosures to house them and the radiographic sensitivity achievable with them is usually inferior to that for X rays.

Lastly, exposure to radiations can be dangerous for human health and therefore special precautions are required which may include construction of specially shielded enclosures and cordoning off of the area where radiography is being performed. Mostly it involves either stopping of all other work and removal of the workers from the work place while carrying out radiography or to do the radiographic testing work during off hours.

Computed Tomography:

Computed Tomography (CT) is a powerful nondestructive evaluation (NDE) technique for producing 2-D and 3-D cross-sectional images of an object from flat X-ray images. Characteristics of the internal structure of an object such as dimensions, shape, internal defects, and density are readily available from CT images. Shown below is a schematic of a CT system.



The test component is placed on a turntable stage that is between a radiation source and an imaging system. The turntable and the imaging system are connected to a computer so that x-ray images collected can be correlated to the position of the test component. The imaging system produces a 2-dimensional shadowgraph image of the specimen just like a film radiograph. Specialized computer software makes it possible to produce cross-sectional images of the test component as if it was being sliced.

Industrial computed tomography (CT) scanning is any computer-aided tomographic process; usually computed tomography that uses irradiation to produce three-dimensional internal and external representations of a scanned object. Industrial CT scanning has been used in many areas of industry for internal inspection of components. Some of the key uses for industrial CT scanning have been flaw detection, failure analysis, metrology, assembly analysis and reverse engineering applications.[1][2]Just as in medical imaging, industrial imaging includes both nontomographic radiography (industrial radiography) and computed tomographic radiography (computed tomography).

Types of scanners:

Line beam scanning is the traditional process of industrial CT scanning. X-rays are produced and the beam is collimated to create a line. The X-ray line beam is then translated across the part and data is collected by the detector. The data is then reconstructed to create a 3-D volume rendering of the part.

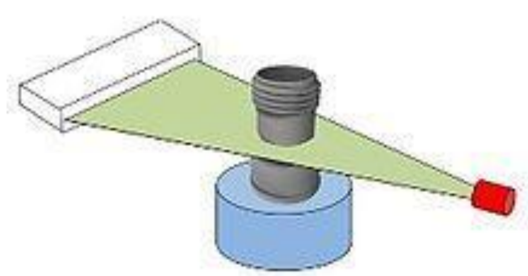


Fig: Line beam scanning

In *cone beam scanning*, the part to be scanned is placed on a rotary table. As the part rotates, the cone of X-rays produce a large number of 2D images that are collected by the detector. The 2D images are then processed to create a 3D volume rendering of the external and internal geometries of the part.

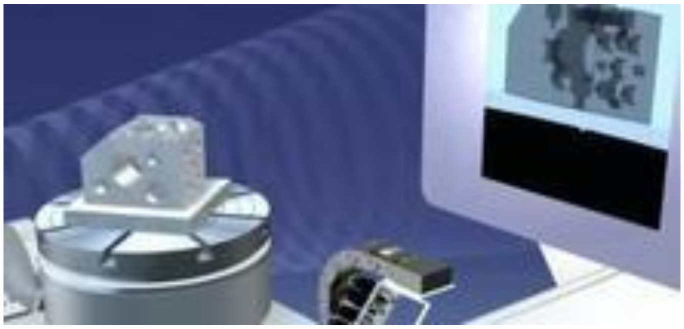


Fig: Cone beam scanner

Analysis and inspection techniques:

Various inspection uses and techniques include part-to-CAD comparisons, part-to-part comparisons, assembly and defect analysis, void analysis, wall thickness analysis, and generation of CAD data. The CAD data can be used for reverse engineering, geometric dimensioning and tolerance analysis, and production partapproval

Assembly:

One of the most recognized forms of analysis using CT is for assembly, or visual analysis. CT scanning provides views inside components in their functioning position, without disassembly. Some software programs for industrial CT scanning allow for measurements to be taken from the CT dataset volume rendering. These measurements are useful for determining the clearances between assembled parts or the dimension of an individual feature.

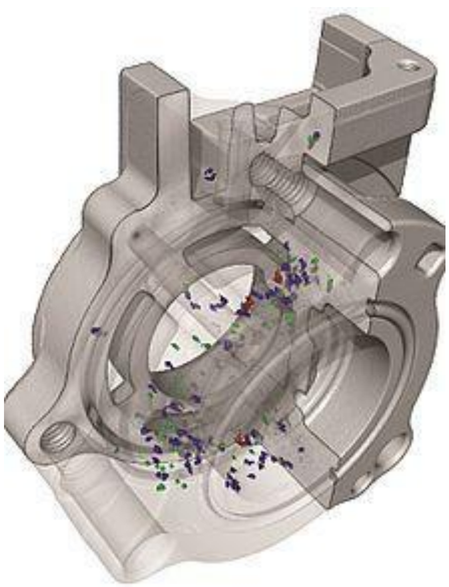


Fig: An industrial computed tomography (CT) scan conducted on an aluminum casting to identify internal failures such as voids. All color coordinated particles within casting are voids/porosity/air pockets, which can additionally be measured and are color coordinated according to size.

Void, crack and defect detection:

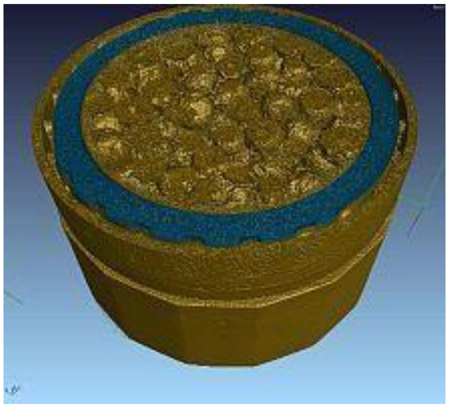


Fig: Flight through a 3D reconstruction of a disposable pepper grinder. Glass in blue.

Traditionally, determining defects, voids and cracks within an object would require destructive testing. CT scanning can detect internal features and flaws displaying this information in 3D without destroying the part. Industrial CT scanning (3D X-ray) is used to detect flaws inside a part such as porosity,[7]an inclusion, or a crack.

Metal casting and moulded plastic components are typically prone to porosity because of cooling processes, transitions between thick and thin walls, and material properties. Void analysis can be used to locate, measure, and analyze voids inside plastic or metal components.

Geometric dimensioning and tolerancing analysis:

Traditionally, without destructive testing, full metrology has only been performed on the exterior dimensions of components, such as with a coordinate-measuring machine (CMM) or with a vision system to map exterior surfaces. Internal inspection methods would require using a 2D X-ray of the component or the use of destructive testing. Industrial CT scanning allows for full non-destructive metrology. With unlimited geometrical complexity, 3Dprinting allows for complex internal features to be created with no impact on cost, such features are not accessible using traditional CMM. The first 3D printed artefact that is optimised for characterisation of form using computed tomography CT

Image-based finite element methods

Image-based finite element method converts the 3D image data from X-ray computed tomography directly into meshes for finite element analysis. Benefits of this method include modelling complex geometries (e.g. composite materials) or accurately modelling "as manufactured" components at themicro-scale.

Applications of Computed Tomography (CT):

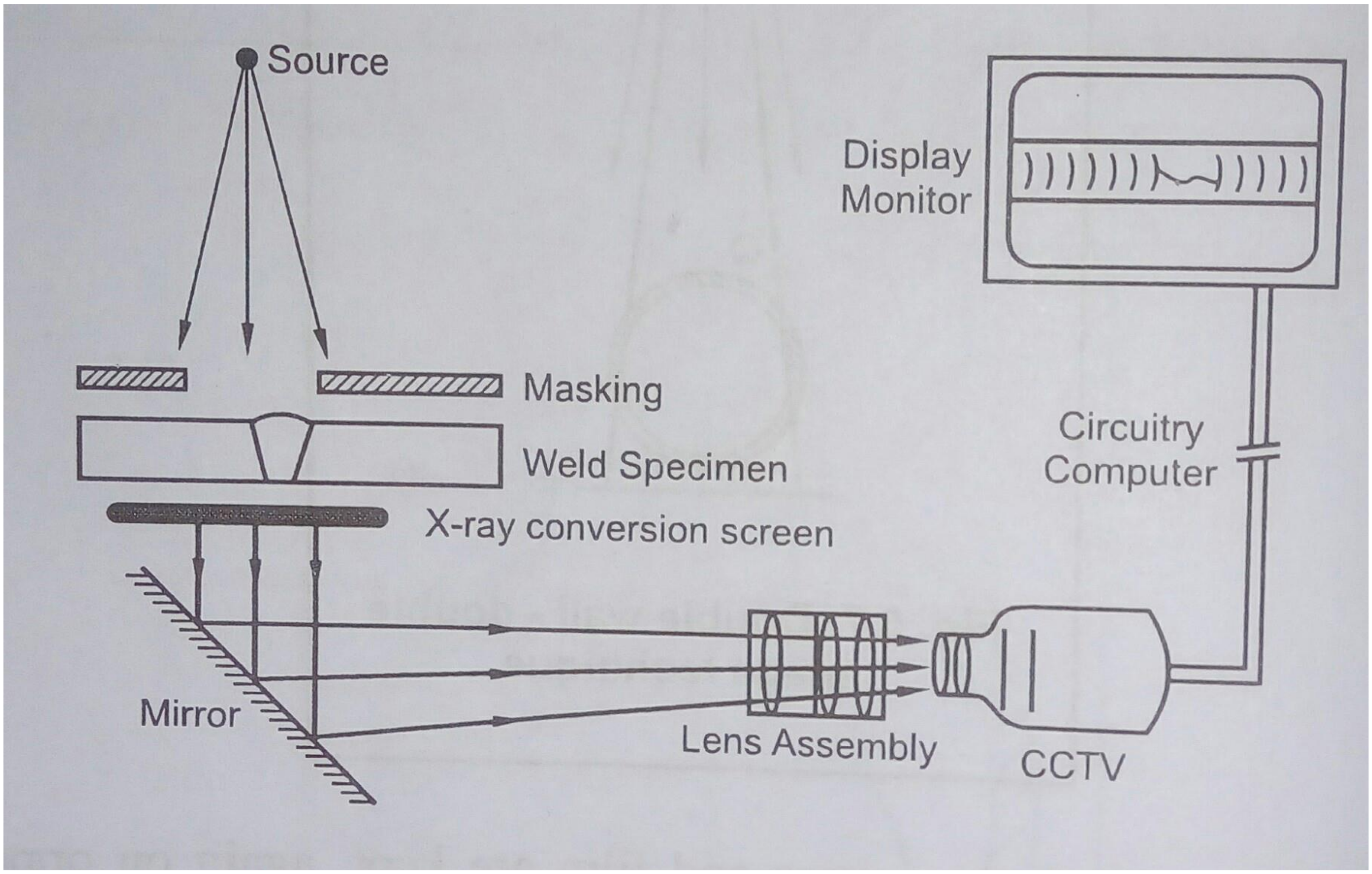
The number of industrial applications of Computed Tomography (CT) is large and rapidly increasing. After a brief market overview, the paper gives a survey of state of the art and upcoming CT technologies, covering types of CT systems, scanning capabilities, and technological advances. The paper contains a survey of application examples from the manufacturing industry as well as from other industries, e.g., electrical and electronic devices, inhomogeneous materials, and from the food industry. Challenges as well as major national and international coordinated activities in the field of industrial CT are also presented.

Fluoroscope

Real Time Radiography also known as **fluoroscope** is a special imaging device that produces viewable X-rays without the need to take or develop X-ray photographs. The machine **works** by passing a continuous X-ray beam through the body part being examined.

The process of the image of the object by converting the Xrays into light on the fluorescent screen is known as fluoroscopy or real time radiography.

Arrangement and working principle

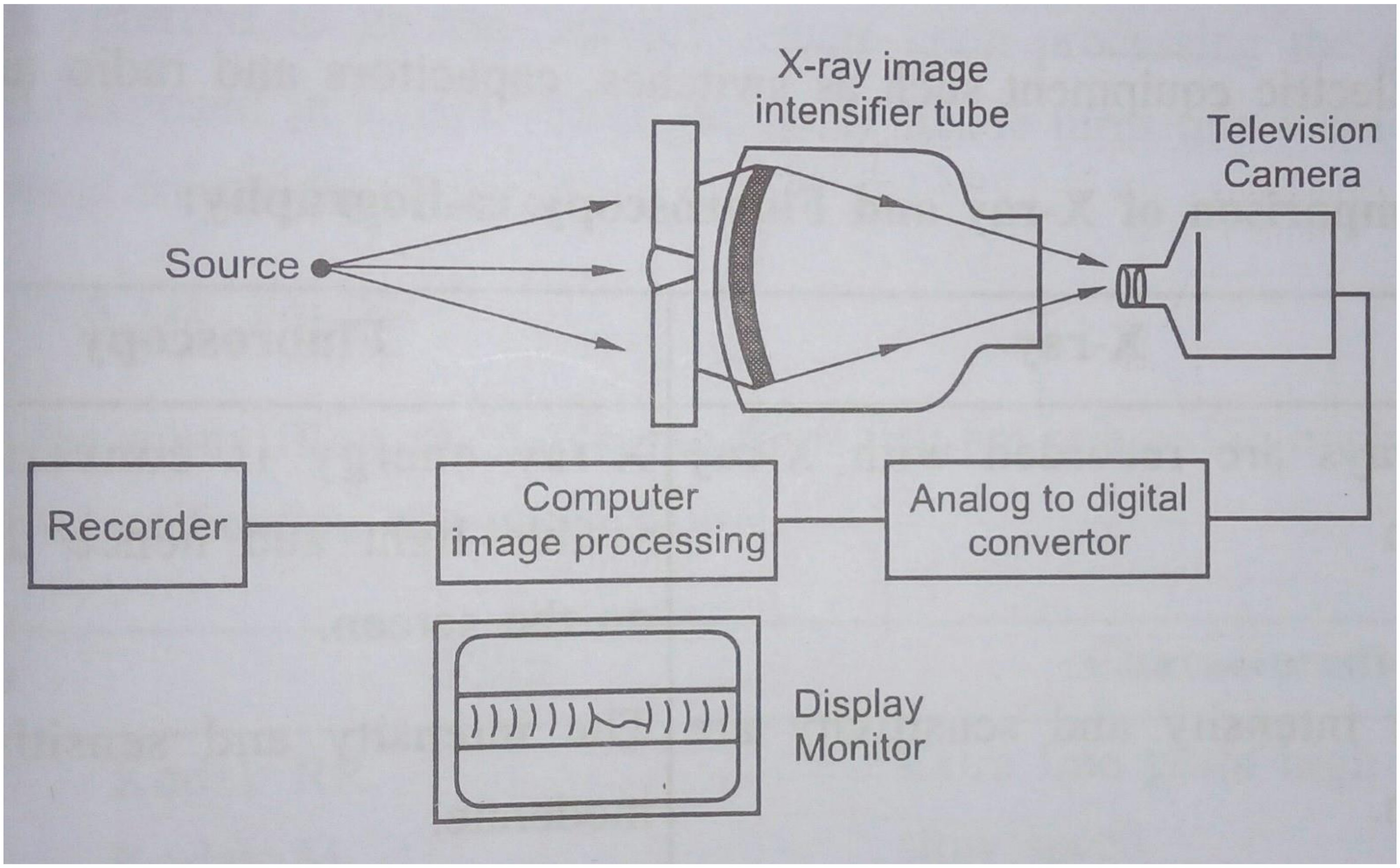


Arrangement and working of Real Time Radiography

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 mplification 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 systems greatly enhances the versality and sensitivity of the real-time radiographic setup



RTR with Intensifier

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

Xeroradiography

Various methods have been introduced for obtaining radiographs among which xeroradiography is a method of imaging which uses the Xeroradiographic copying process to record images produced by diagnostic X-rays.

It is a method of X ray imaging in which a visible electrostatic pattern is produced on the surface of a photoconductor

Components of Xeroradiography

• Xerographic plate

• Corotron

• Cassette

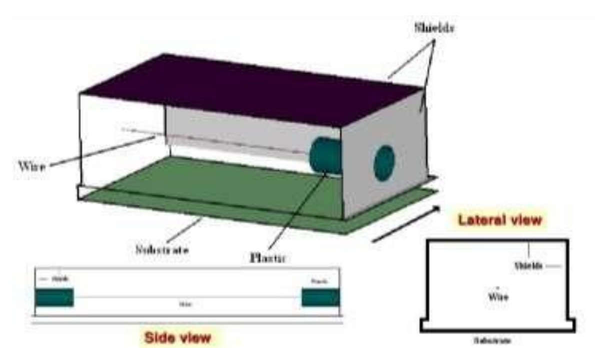
• Toner

• Special paper

- The XR plate is charged to a high positive potential by corotron
- It is then placed in a cassette and used in a manner similar to that with conventional film in its cassette
- When x rays strike the selenium, photoconduction occurs and this produces a charge image of the part examined.
- The image is made visible by bringing into proximity to the plate charged developer or toner particles
- The resultant powder image is subsequently transferred to paper and fused providing an opaque XR for interpretation and storage

PROCEDURE:

- The first step in xeroradiographic process is to sensitise the selenium layer by applying a uniform electrostatic charge to its surface in the dark.
- It is done by making the plate to move at a uniform rate under the stationary charging device which may be a scorotron or corotron and produces a charge on the surface of photoconductor



- Thus the layer of selenium on one side become charged with a uniformly distributed positive charge (600—1200V) which is retained as long as it remain in the dark due to great resistance of the layer
- The charged plate is then enclosed in a cassette which is light tight and is rigid enough to provide mechanical protection to the delicate plate. The plate cassette combination is used just as one would use an X ray film in its cassette.

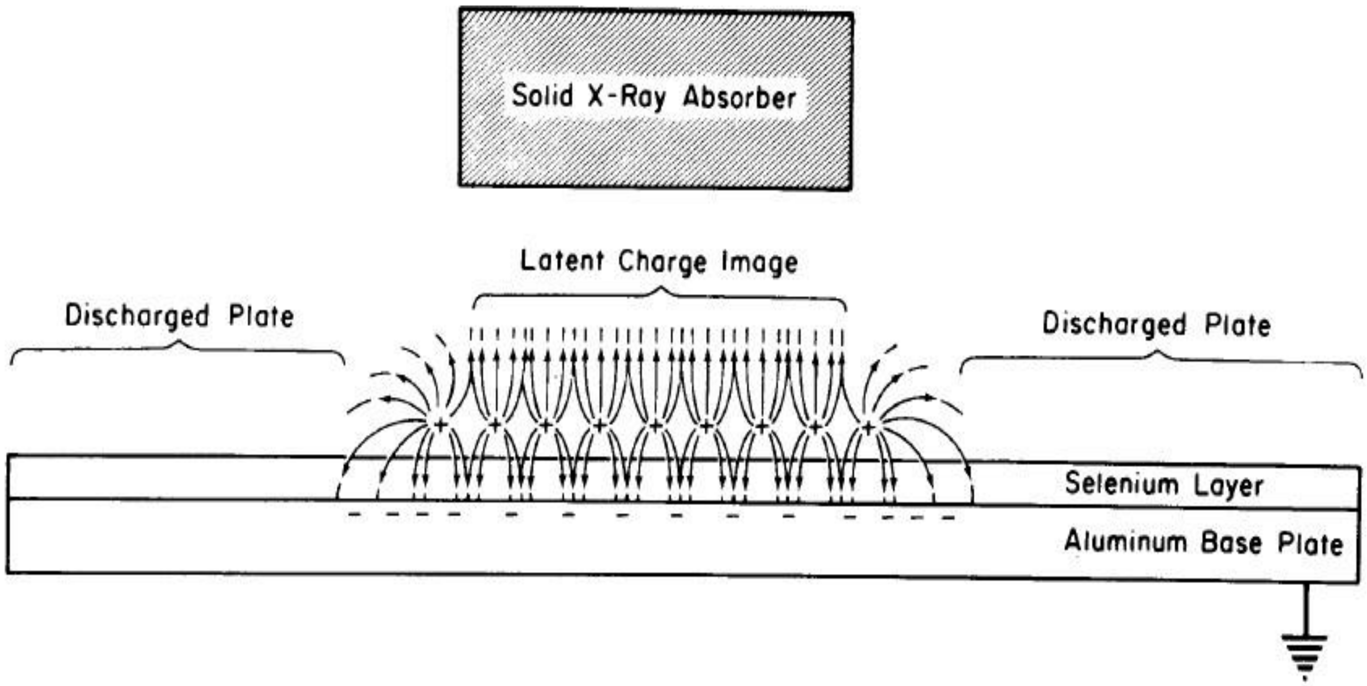


Fig. 1. Schematic Representation of Electrostatic Field. The positive charge along the surface of the selenium plate and the negative electrons in the aluminum base plate set up an electrostatic field. At the margins of the field the lines of force are not perpendicular. The fringing electrostatic fields at the margins causes attraction of additional toner particles at these interfaces. This results in enhancement of the edges and increased delineation of the margins of differences in x-ray absorption (tissue interfaces for example).

- When the charged selenium plate is exposed to X rays, electron hole pairs are formed.
- As X ray photons impinges on this amorphous coat of selenium, charges diffuse out, in proportion to energy content of X ray. This occurs as a result of photoconduction
- The resultant imprint is made visible (developed) by exposing the surface of the selenium plate to the fine charged powder particles called toner which usually is a pigmented thermoplastic material of dark blue colour
- The exposed xerographic plate placed on the top of a dark box into which an aerosol of charged toner particles is sprayed through a nozzle, the process being called triboelectrification or contact electrification.
- The powder picture on the surface of the xeroradiographic plate is then transferred to a special paper and fixed there to form a permanent image.
- The paper is slightly coated with a slightly deformable layer of plastic such as low molecular weight polyethylene material.
- When it is pushed against the powder image under relatively high mechanical pressure, the toner particles become slightly embedded in plastic

- The paper is then peeled off the plate, and the loosely held powder image is made into a permanent bonded image by heating the paper to a temperature of about 47.5^{0} F.
- The heat softens the plastic coating on the paper and allows toner particles to sink into and and become bonded to plastic
- The toner particles do not melt or flow. After fixing, also called fusing, the imaging portion of the xeroradiographic process is completed. The completed image is delivered from the processor ready for viewing
- On a xeroradiographic image, the areas which receive little X-ray exposure appear light blue. If a charged plate is inadvertently exposed to room light and then developed, the paper will almost devoid of toner
- After transfer of toner to the paper, some of it remains on the plate surface. All of the toner must be removed before the plate can be reused. This is done by exposing the plate to a light source that reduces the bond holding residual tone to the plate.
- A preclean corotron then exposes the plate to an alternating current which serves to neutralize the electrostatic forces holding the toner to the plate.
- The residual toner is then brushed off from plate using a clean brush. The plate then can be reused. It is not charged during storage

Applications:

- The xeroradiography has found application in soft tissue imaging:
- in radiographic examination of the mammary glands, muscles, tendons and ligaments

Advantage

- The main advantage of xeroradiography include enhanced visualisation of the borders between images of different densities (edge effect), low contrast which enables differentiation between fat, muscle and bones and wide exposure latitude

Disadvantages

- The technique cannot be used for very thick parts as very high exposure is required
- Technical difficulties, Fragile selenium coat, Transient image retention, Slower speed,
- **Technical limitations**: low density of selenium plate which recquires increased doses of X rays administered make the technique not to be considered as a total substitute for halide radiograph

Computed radiography (CR)

- ❖ Computed radiography (CR) also commonly known as Photostimulable phosphor (PSP) imaging.
- ❖ It employs reusable imaging plates and associated hardware and software to acquire and to display digital projection radiographs.
- ❖ It is cassette based system like analog film and is more commonly considered to be a bridge between classical

radiography and digital radiography

- ❖ CR is used almost exactly like conventional Imaging plate in a cassette which must be processed in CR reader after X-ray exposure for conversion to digital images.

CR system consists of

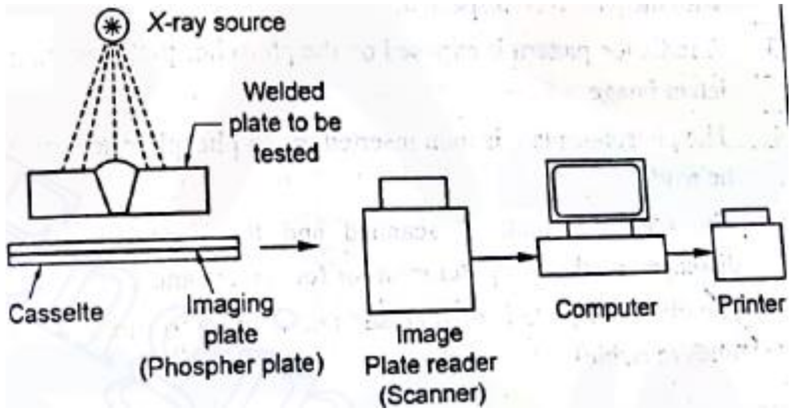
- ❖ Image plate (photostimulable phosphor) PSP
- ❖ X ray or gamma ray source
- ❖ Image reader/digitizer/scanner
- ❖ Photomultiplier tube (PMT), ADC (analoge to digital converter)
- ❖ Computer console or workstation, software, monitors, and a printer.

Image reader can be

- ❖ Single-plate readers (each cassette is loaded manually and read separately)
- ❖ Multiple-plate readers (multiple plates up to 10 can be stacked and loaded automatically)

Principle of Operation

- ❖ In computed radiography, the imaging plates are inserted in a radiographic table's cassette holder and are exposed to X-rays or gamma rays.
- ❖ The energy of the incoming radiation is stored in a special phosphor layer, electrons in the phosphor plate are excited into a higher energy state, forming a latent image.
- ❖ Then a specialized machine known as a scanner is then used to read out the latent image from the plate by stimulating it with a very finely focused laser beam.
- ❖ During which the trapped electrons absorb the laser energy and they emit blue light with intensity proportional to the amount of radiation received during the exposure as they return to their ground state.
- ❖ The light is collected by a light guide and transmitted to a highly sensitive analog device known as a photomultiplier tube (PMT) and converted to a digital signal using an analog-to-digital converter (ADC).
- ❖ The generated digital X-ray image can then be digitally stored and viewed on a computer monitor and evaluated.
- ❖ After an imaging plate is read, it is erased by a high-intensity light source that removes residual radiation and can immediately be re-used.
- ❖ Imaging plates can typically be used up to 1000 times or more depending on the application.



Steps Involved

- ❖ X ray image received on phosphor plate subjecting to X ray exposure
- ❖ After the image has been captured on an image plate by a standard x-ray system, the plate is taken to an image-plate reader to extract the image.
- ❖ The cassette is loaded (manually or automatically) into the reader.
- ❖ Image extracted from phosphor plate by laser (Raw image)
- ❖ Raw image processed for quality improvement
- ❖ The digital image is then produced in 30-120 seconds and downloaded to an image-processing system, usually a computer workstation, for display and manipulation.
- ❖ Digital image can be either printed burned on CD, or sent to PACS (Picture Archiving and Communication System)

Advantages

- CR technology can be considered as the digital replacement of conventional X-ray film.
- Post-processing, manipulation & storage of images is easy.
- Repeat examinations are reduced due to wide exposure latitude.
- Image Plate is reusable.
- Ability to produce consistent high-quality images.
- Ability to deliver images quickly to those who need to make critical decisions.

Disadvantages

- Initial cost
- Additional cost (Service and maintenance)
- Plate is sensitive to fogging: use grid, need to be erased daily
- Dose-creep: since, exposure latitude is wide, high exposure technique is used which increases the patient dose which is called dose-creep.