Introduction to Non Destructive Testing

Outline
- Radiation and radioisotope application in industry
- Overview of NDT
- Magnetic Particle Testing
- Ultrasonic Testing
- Eddy Current Testing
- Summary
- NDT LAB-UoN

John Birir
University of Nairobi
jibirir@gmail.com
0721 96 50 51
Radiation and radioisotope application in industry

• NDT
  – Radiography
• Nuclear analytical techniques
  – Environment monitoring
  – Natural resources exploration and exploitation
• Radiotracers and sealed sources
• Nucleonic gauges or nucleonic control systems (NCS)
• Radiation processing
  – Radiation polymerization
  – Radiation sterilization
• Power Plants
  – Nuclear reactor
Overview

- Definition
- Methods of NDT
- Applications of NDT
- Defects
- Principles
- Benefits
- Selection
Definition

- The use of noninvasive techniques to determine the integrity of a material, component or structure or quantitatively measure some characteristic of an object without impairing its intended use.
Methods of NDT

- Visual
- Impedance monitoring
- Vibration analysis
- Microwave
- Magnetic Particle
- Acoustic Microscopy
- Radiography
- Impact echo
- Magnetic Measurements
- Liquid Penetrant
- Replication
- Ultrasonic
- Laser Interferometry
- Eddy Current
- Tap Testing
- Acoustic Emission
- Shearography
- Flux Leakage
- Ground penetrating radar
Applications of NDT: When?

• Raw materials
  – To screen or sort incoming materials
• Partly finished product during manufacture
  – To monitor, improve or control manufacturing processes
• Completed object before being put to use
  – To verify proper processing such as heat treating
  – To verify proper assembly
  – To assist in product development
• A component in service during routine maintenance
• To inspect for in-service damage
• A failed component before subjecting it to destructive analysis in forensics
Applications of NDT: Examples

• Flaw Detection and Evaluation
• Leak Detection
• Location Determination
• Dimensional Measurements
• Structure and Microstructure Characterization
• Estimation of Mechanical and Physical Properties
• Stress (Strain) and Dynamic Response Measurements
• Material Sorting and Chemical Composition Determination
Industries where NDT is applied

- Aviation & space research (KQ, JKIA, Wilson airport)
- Energy (GDC, KENGEN, )
- Nuclear (KNEB)
- Petrochemical (KPRL, )
- Oil & gas (KPC, )
- Offshore engineering, marine and shipbuilding
- Building and construction
- Research and innovation
- Training and certification (INST, KEBS)
- Medical and bio engineering (CT, Ultrasound, )
Applications of NDT: Aircraft Inspection

- Nondestructive testing is used extensively during the manufacturing of aircraft.
- NDT is also used to find cracks and corrosion damage during operation of the aircraft.
- A fatigue crack that started at the site of a lightning strike is shown below.
Jet Engine Inspection

- Aircraft engines are overhauled after being in service for a period of time.
- They are completely disassembled, cleaned, inspected and then reassembled.
- Fluorescent penetrant inspection is used to check many of the parts for cracking.
Crash of United Flight 232
Sioux City, Iowa, July 19, 1989

A defect that went undetected in an engine disk was responsible for the crash of United Flight 232.
Applications of NDT: Rail Inspection

Special cars are used to inspect thousands of miles of rail to find cracks that could lead to a derailment.
Applications of NDT: Bridge Inspection

• Corrosion, cracking and other damage can all affect a bridge’s performance.

• Bridges get a visual inspection periodically.

• Some bridges are fitted with acoustic emission sensors that “listen” for sounds of cracks growing.
NDT is used to inspect pipelines to prevent leaks that could damage the environment. Visual inspection, radiography and electromagnetic testing are some of the NDT methods used.

Magnetic flux leakage inspection. This device, known as a pig (pipe inspection gauge), is placed in the pipeline and collects data on the condition of the pipe as it is pushed along by whatever is being transported.
Applications of NDT: Wire Rope Inspection

Electromagnetic devices and visual inspections are used to find broken wires and other damage to the wire rope that is used in chairlifts, cranes and other lifting devices.
Defects

• Defects are flaws that affect the integrity of a component
• Locations where stresses and microstructural degradation exist are potential sites for initiation of defects.
• Defect severity is determined by its type, location, size, shape and orientation.
Principles of NDT

• Every NDT methods is based on some unique physical principles.

• Detection and characterization of flaws (defects, stresses, and microstructural degradation) is accomplished by establishing a correlation between a non-destructively measured physical parameter and quantitative information on flaw.
Benefits of NDT

- Safety, quality, reliability
- Increased productivity
- Decrease liability
- Protection of environment
- Save money
- The object can be used after inspection
- It can be done on site
- Relatively cheaper than destructive tests
- Defects can be detected before component failure
- Avoid pre-mature failure of a component or structure
- Advance warning before an accident occurs
- Estimate remaining life
- Extend useful life of a component
Selection of NDT method

• The choice of NDT method to use depends on factors such as applicability, accessibility and suitability based on analysis and previous experience.

• Information about material composition, properties, microstructure, fabrication procedure and environment is essential to identify the potential sites of defects, their nature, probable size and orientation.

• Variables (such as critical flaw size and location, material type etc.) and the crucial nature of the component determine which test method is suitable for examination.

• Sometimes it may become necessary to use a combination of two or more methods for a more reliable inspection result.
Magnetic particle testing (MT)

Outline

- Principles
- Defects
- Equipment
- Techniques
- Applications
- Advantages
- Limitations
Principles of MT (1of3)

• MT involves the application of magnetic field and iron filings to detect surface and near surface defects in ferrous materials.

• The steps involved are:
  – application of magnetic field,
  – sprinkling of ferrous particles,
  – observation for clustering and
  – recording of results.

• Records can be kept using photographs, video or transparent adhesive film.
Principles of MT (2of3)

• When a magnetic field encounters an opening such as crack, the field lines spread out since air does not support as much field lines per unit cross-section area.
• North and south poles are created at the opening.
• When iron particles are sprinkled on the surface, they will be attracted to flux leakage and will cluster around the defect forming a visible indication.
• Iron particles can be either in the form of wet suspension or dry powder.
Principles of MT (3of3)
Defects (1 of 3)
Defects (2of3)
Defects (3of3)
MT Equipment (1of3)

- Prods
- Head shot
- Central conductor
- Yokes
  - Permanent magnets (no arcs, no electricity)
  - Electromagnets
- Coils
- Cables
Magnaflux indication of Lengthwise crack in a Cylindrical Part.

Magnetization using hand held electrodes.
MT Equipment (3of3)

Magnetization using a permanent magnet.

Magnaflux indication of Transverse crack in a Cylindrical Part.
MT Techniques (1of2)

- Magnetic characteristics of material and the size, shape, location and direction of discontinuity affect selection of technique.
  - Longitudinal vs Circular
  - Wet vs dry
  - Fluorescent vs visible
  - AC vs DC
MT Techniques (2of2)

• The selection of MT method depends on factors such as geometry of component, desired direction of magnetic field, expected orientation of defects and whether or not the defects are subsurface.

• AC methods are used to detect surface and near-surface defects due to skin depth effect. AC also has higher detection sensitivity. DC methods are effective for subsurface defects.
Applications of MT

• Castings, Forgings, weldments
• Structural steel, Automotive, Petrochemical, Power generation, Aerospace
• Underwater inspection, offshore structures, underwater pipelines
• Axisymmetric components; tubes, pipes, rods, bars, rounds, billets,
• Irregular components; helicopter rotor blades, gear teeth, artillery projectiles,
• Gas turbine engines, high performance aircraft, helicopters, rocket engines, satellites,
• Inaccessible areas; bolt holes, internal threads (important in military aircraft)
Advantages of MT

• Complex shapes can be inspected
• Portable
• No size limitations
• Inexpensive
• Sensitive to surface and near surface defects
• Moderate skills required of operator
• Instant results hence rapid inspection
• No need of power source when using permanent magnets
Limitations of MT (1of2)

- Limited to ferromagnetic materials (iron, nickel, cobalt)
- Surface must be accessible
- Large source of electric current required when using electromagnets especially on very large parts
- Surface must be cleaned before inspection and good contact made (paint, plating, )
- Local heating and burning of finished parts if not done carefully
- Additional photography equipment required to obtain a permanent record.
- Need to demagnetize object after inspection
  - Avoid wear and tear on rotating components due to pickup of ferromagnetic parts
  - Arc deflection during welding
  - Interference effect on nearby instruments.
Limitations of MT (2of2)

- Limited to surface and near surface defects
- Defect detection is sensitive to magnetic field orientation (45 to 90 degrees). Two or more inspections required in different directions
Ultrasonic Testing (UT)

Outline

- Principles
- Applications
- Waves
- Advantages
- Limitations
- Equipment
- Technique
Principles of UT (1of6)

• UT is a noninvasive method making use of sound waves at high frequencies of 0.5 MHz to 20 MHz to inspect a component (metals) (audible range is 20 Hz to 20 KHz).
• Concrete inspection frequency is in the order of 50 KHz.
• It is important to select wavelength of probe to be comparable to size of defect expected.
• When sound travels through a body, it is spread, absorbed or scattered. Scattering takes place at grain boundaries, cracks and other defects.
• Ultrasonic attenuation is used to determine material properties such as impact strength, fracture toughness, grain size and tensile strength of steels.
• Ultrasonic velocity measurements can be used to determine residual stresses in materials.
Principles of UT (3of6)

Oscilloscope, or flaw detector screen

- initial pulse
- crack echo
- back surface echo

- plate
- crack
Principles of UT (4of6)

- Two methods used in UT are pulse-echo and through transmission.
- In pulse echo screen display we have initial echo, back wall echo and a defect signal in between indicating the exact depth.
- In through transmission, presence of a defect is indicated by reduced or complete loss of signal.
Principles of UT (5of6)

Immersion testing

保温法

表面 = 声音进入
后壁

水延迟

缺陷

Immersion testing

Principles of UT (5of6)
Principles of UT (6of6)

- UT displays can be in any of the three modes namely A-scan, B-scan and C-scan
Applications of UT (1of2)

- Detection of flaws: cracks, seams, laps,
- Thickness measurements
- Determination of mechanical properties and grain structure
- Evaluation of process variables
- Piping and pressure vessels
- Bridges and structures
- Railroad rolling stock
- Machinery
- Nuclear systems
- Motor vehicles
Applications of UT (2of2): Storage Tank Inspection

Robotic crawlers use ultrasound to inspect the walls of large above ground tanks for signs of thinning due to corrosion.
Advantages of UT

- High sensitivity hence detection of minute defects
- High penetration above 7 metres in steel hence thick section inspection
- High accuracy in measuring flaw depth, location and size
- Full volumetric information
- Accurate measure of thickness
- Fast response hence rapid and automatic inspection possible
- Access to only side is needed
- Ability to trend deterioration and estimate remaining service life
- Determination of presence of liquids in tanks and piping
- Portability
Limitations of UT

- Difficult to inspect complicated shapes
- Problems when inspecting coarse grained structure materials
- Inability to pass through air
- Proper coupling required during scanning
- Need for smooth surface
- Expensive equipment
- Highly skilled manpower required
- Flaw orientation is important
- Need for reference standards
UT Equipment

- Thickness gauges
- Automated equipment
- Immersion equipment
- Flaw detectors
- Couplant
- Transducers
UT Techniques

- Straight beam
- Angle beam
- Pulse echo
- Cylindrical guided waves
- Immersion
- Through transmission
- Longitudinal,
- Transverse,
- Surface
- Plate.
Eddy Current Testing (ET)

- Principles
- Applications
- Advantages
- Limitations
- Equipment
- Technique
Principles of ET...

- ET uses the principles of electromagnetic induction to inspect electrically conducting components for detection of flaws.
- AC current flowing through a coil produces an alternating magnetic field around it.
- When this coil probe is brought near a conducting surface to be inspected, it induces an eddy current flow in the component due to electromagnetic induction.
- The direction of eddy current is parallel to the direction of coil winding.
- The presence of a flaw in the component will interfere with the eddy current flow.
- The eddy current generates a magnetic field in the opposite direction.
- This secondary magnetic field is detected either as a voltage in a second coil or as a change of impedance in the original coil.
Eddy Current Testing

- Coil
- Coil's magnetic field
- Eddy current's magnetic field
- Eddy currents
- Conductive material
Principles of ET...

• Impedance change in probe coil is affected by electrical conductivity, magnetic permeability, geometry of material, test frequency, spacing between coil and material, thickness and presence of flaw in material.

• When inspecting for flaws, the amplitude of eddy current signal indicates the severity of defect while phase angle indicates its depth.
Principles of ET...
Applications of ET

- Cracks, inclusions, dents and holes detection
- Metal alloy sorting
- Coating and material thickness measurements
- Grain size/ hardness
- Dimensions and geometry
- Corrosion monitoring
- Liquid sodium level monitoring
- Conductivity, permeability and composition measurements
- Structural integrity of pressure tubes in nuclear reactors
  - Heat exchangers tubing: steam generators, turbine condensers, air conditioning heat exchangers,
Applications of ET: Detection of cracks

- During inspection, eddy currents flow symmetrically when discontinuities are not present.
- However when a crack is present, the eddy current flow is impeded and changed in direction causing significant change in associated electromagnetic field.
Applications of ET: Power Plant Inspection

Periodically, power plants are shutdown for inspection. Inspectors feed eddy current probes into heat exchanger tubes to check for corrosion damage.

Pipe with damage

Probe

Signals produced by various amounts of corrosion thinning.
Eddy current methods were used to measure the electrical conductivity of the Liberty Bell's bronze casing at various points to evaluate its uniformity.
Advantages of ET

• Minimal part preparation
• Very sensitive to small surface and near surface defects
• Instant results hence rapid inspection
• Can be automated
• Surface contact not necessary
• Permanent record kept
• Information on many parameters provided simultaneously
Limitations of ET

- The object must be an electrical conductor
- Surface must be accessible
- Limited depth of penetration
- Skills and training required for operator to interpret results
- Sensitive to many parameters
- Time consuming for manual inspection of large objects
- Sensitive to geometry and orientation of flaw
- Surface roughness can produce non-relevant indications
ET Equipment

- CRT oscilloscopes
- Computerized system
- Absolute or differential coils
- Encircling coils
- Optical disc drivers
- Meters
ET Techniques

• Multi frequency techniques
  – Inspection of installed heat exchanger tubing

• Probe and encircling coils
  – Probe coil for examination of flat surface for cracks

• Multiple coils
Summary

• The principles, applications, advantages/capabilities, limitations, equipment and technique discussed should aid in the selection of an appropriate NDT method for a particular assignment.

• It is also necessary to appreciate the complementary nature of various NDT methods to enable accurate, reliable and cost effective inspection.

• Planar defects (cracks, lack of fusion, etc.) are more detrimental than volumetric defects (porosity, gas holes, round inclusions etc.).

• Depth or height of defect is more serious than its length

• Surface breaking defects are more harmful than totally internal defects
NDT LAB-UoN: Visual Inspection
NDT LAB-UoN: Penetrant Testing
NDT LAB-UoN: Magnetic Particle Testing
NDT LAB-UoN: Radiography Testing
NDT LAB-UoN: Ultrasonic Testing
NDT LAB-UoN: Low frequency Ultrasonic Testing (Concrete)
NDT LAB-UoN: Shmidt Hammer
NDT LAB-UoN: Moisture Density Gauge
NDT LAB-UoN: Rebar Detector
Thank You!
Liquid Penetrant Testing
Introduction

• This method is employed for the detection of open-to-surface discontinuities in any industrial product which is made from a non-porous material.

• It is used to reveal surface breaking flaws by bleed out of a colored or fluorescent dye from the flaw.

• The techniques is based on the ability of a liquid to be drawn into a “clean” surface breaking flaw by capillarity action.

• The advantage that a liquid penetrant inspection (LPI) offers over an unaided visual inspection is that it makes defects easier to see for the inspector.

• It is widely used for testing of non-magnetic materials.
1. **Surface preparation**: the surface must be free of oil, grease, water, or any other contaminants that may prevent penetrant from entering flaws.

2. **Penetrant Application**: the penetrant material is applied by spraying, brushing, or immersing the part in a penetrant bath.

3. **Penetrant Dwell**: The penetrant is left on the surface for a sufficient time to allow as much penetrant as possible to be drawn or to seep into a defect. Dwell times are usually recommended by the penetrant producers or required by the specification being followed. Minimum dwell times typically range from 5 to 60 minutes.

4. **Excess Penetrant Removal**: This is the most delicate step of the inspection procedure because the excess penetrant must be removed from the surface of the sample while removing as little penetrant as possible from defects.
5. Developer Application: A thin layer of developer is then applied to the sample to draw penetrant trapped in flaws back to the surface where it will be visible. Developers come in a variety of forms that may be applied by dusting (dry powders), dipping, or spraying (wet developers).

6. Indication Development: The developer is allowed to stand on the part surface for a period of time sufficient to permit the extraction of the trapped penetrant out of any surface flaws. This development time is usually a minimum of 10 minutes.

7. Inspection: Inspection is then performed under appropriate lighting to detect indications from any flaws which may be present.

8. Clean Surface: The final step in the process is to thoroughly clean the part surface to remove the developer from the parts that were found to be acceptable.
What can & cannot be Inspected

• **What can?**
  • Almost any material that has a relatively smooth, non-porous surface on which discontinuities or defect are suspected.

• **What cannot?**
  • Components with rough surfaces that trap and hold penetrant
  • Porous ceramics
  • Wood and other fibrous materials
  • Plastic parts that absorb or react with the penetrant materials
  • Components with coatings that prevent penetrants from entering defects
Penetrant Testing Materials

- Penetrants
- Solvents
- Emulsifiers
- Developers
- Proper lighting condition
Penetrants

- Penetrants are carefully formulated to produce the level of sensitivity desired by the inspector. The penetrant must possess a number of important characteristics:
  - spread easily over the surface of the material being inspected to provide complete and even coverage.
  - be drawn into surface breaking defects by capillary action.
  - remain in the defect but remove easily from the surface of the part.
  - remain fluid so it can be drawn back to the surface of the part through the drying and developing steps.
  - be highly visible or fluoresce brightly to produce easy to see indications.
  - not be harmful to the material being tested or the inspector.
Classification of penetrants

- Penetrant materials come in two basic types:
  - **Type 1 - Fluorescent Penetrants**: they contain a dye or several dyes that fluoresce when exposed to ultraviolet radiation. (more sensitive).
  - **Type 2 - Visible Penetrants**: they contain a red dye that provides high contrast against the white developer background.

Penetrants are then classified by the method used to remove the excess penetrant from the part. The four methods are:

  - **Method A - Water Washable**: penetrants can be removed from the part by rinsing with water alone.
  - **Method B - Post-Emulsifiable, Lipophilic**: the penetrant is oil soluble and interacts with the oil-based emulsifier to make removal possible.
  - **Method C - Solvent Removable**: they require the use of a solvent to remove the penetrant from the part.
  - **Method D - Post-Emulsifiable, Hydrophilic**: they use an emulsifier that is a water soluble detergent which lifts the excess penetrant from the surface of the part with a water wash.
Penetrants are then classified based on the strength or detectability of the indication that is produced for a number of very small and tight fatigue cracks. The five sensitivity levels are:

- Level ½ - Ultra Low Sensitivity
- Level 1 - Low Sensitivity
- Level 2 - Medium Sensitivity
- Level 3 - High Sensitivity
- Level 4 - Ultra-High Sensitivity

The procedure for classifying penetrants into one of the five sensitivity levels uses specimens with small surface fatigue cracks. The brightness of the indication produced is measured using a photometer.
The role of the developer is to pull the trapped penetrant material out of defects and spread it out on the surface of the part so it can be seen by an inspector.

 Developers used with visible penetrants create a white background so there is a greater degree of contrast between the indication and the surrounding background.

 Developers used with fluorescent penetrants both reflect and refract the incident ultraviolet light, allowing more of it to interact with the penetrant, causing more efficient fluorescence.

 According to standards, developers are classified based on the method that the developer is applied (as a dry powder, or dissolved or suspended in a liquid carrier).
The six standard forms of developers are:

- **Form a** - Dry Powder – least sensitive but inexpensive
- **Form b** - Water Soluble-
- **Form c** - Water Suspendable
- **Form d** - Nonaqueous Type 1: Fluorescent (Solvent Based)
- **Form e** - Nonaqueous Type 2: Visible Dye (Solvent Based)
- **Form f** - Special Applications—used when a permanent record of the inspection is required e.g. plastic developer.
Solvents

- The primary purpose of the solvent removers is removal of excess (non-water-soluble) liquid penetrant prior to application of the developer.
- Solvent removers are often used also for pre-cleaning and post cleaning of test objects to remove penetrant processing residues.
- Solvents are also used as carrier fluid for color and fluorescent type tracer dyes of the penetrant. Such penetrants are thus easily removable from the surface of the test part during the removal process of excess penetrant by the particular solvent used as a cleaner. Usually such cleaners are organic compounds.
There are 3 classes of solvents removers:

- **Class 1**: halogenated solvents remover
- **Class 2**: non halogenated solvent remover
- **Class 3**: specific application solvent remover
**Emulsifier**

- Emulsifier is a liquid that combines with an oily penetrant to make the penetrant water washable.
- In penetrants which are water-washable, this emulsifier is already incorporated into them.
- The emulsifiers are essentially of two types such as oil based (lipophilic) and water-based (hydrophilic)
• Indications is viewed as soon as practicable after developer application with final assessment taking place after a minimum development time has elapsed.
Interpretation of findings

- This is the evaluation of the significance of discontinuities from the standpoint of whether they are detrimental defects or inconsequential blemishes.
- **Relevant Indication** - These are indications caused by discontinuities. The interpretation of an indication as relevant is a matter in observing the indication, eliminating the possibility of it being a false indication and then further determining that it is relevant.
- Only indications with major dimension greater than 1/16 inch (1.6 mm) are considered as relevant.
- Linear indications are those in which the length is more than three times the width.
- Rounded indications on the other hand are those in which the length is equal or less than three times the width.
Any Question?
Radiographic Testing
Introduction

• This method uses X-rays or gamma-rays to produce a radiographic image of an object showing differences in thickness, defects (internal and surface), changes in structure, assembly details etc.

• The usual procedure for producing a radiograph is to have a source of penetrating (ionizing) radiation (X-rays or gamma-rays) on one side of the object to be examined and a detector of the radiation (the film)

• The energy level of the radiation must be well chosen so that sufficient radiation is transmitted through the object onto the detector.
The detector is usually a sheet of photographic film, held in a light-tight envelope or cassette having a very thin front surface that allows the X-rays to pass through easily.

Chemicals are needed to develop the image on film, which is why this process is called the classic or “wet” process.

Nowadays, different kinds of radiation-sensitive films and detectors not requiring the use of chemicals, (“dry” process), to produce images are used increasingly.

These techniques make use of computers, hence the expressions; digital or computer aided radiography (CR) or direct digital radiography (DR).

These through transmission scanning techniques (known as fluoroscopy) the storage of images and image enhancement are continually improved by the gradual implementation of computer technology.
Main properties of X-rays and γ-rays

- invisibility; they cannot be perceived by the senses
- they travel in straight lines and at the speed of light
- they cannot be deflected by means of a lens or prism, although their path can be bent (diffracted) by a crystalline grid
- they can pass through matter and are partly absorbed in transmission.
- they are ionizing- they liberate electrons in matter
- they can impair or destroy living cells
- They affect photographic emulsions
- While passing through a material they are either absorbed or scattered
Absorption and scattering

• The reduction in radiation intensity on penetrating a material is determined by the following reactions:
  ➢ Photoelectric effect
  ➢ Compton effect
  ➢ Pair production

• Which of these reactions will predominate depends on the energy of the incident radiation and the material irradiated
Units

- Until 1978 the conventional radiation units in use were roentgen (R), rad (rd), and curie (Ci).
- Since 1978 the ICRU has recommended the use of the international system units (SI) with special new units for radiation quantities; the Becquerel, Gray, and Sievert.
Radiation Sources

• **X-Ray Tube**
  - The X-ray tube consists of a glass (or ceramic) envelope containing a positive electrode (the anode) and a negative electrode (the cathode) evacuated to an ultra high vacuum.
  - The cathode comprises a filament that generates electrons. Under the effect of the electrical tension set up between the anode and the cathode (the tube voltage) the electrons from the cathode are attracted to the anode, which accelerates their speed.
  - This stream of electrons is concentrated into a beam by a “cylinder” or “focusing cup”.
  - When the accelerated electrons collide with a target on the anode, part of their energy is converted to X-rays
• Fig: Glass envelope X-ray tube
Natural Radioactive

The elements which have been used for the purposes of industrial radiography are radium and mesothorium. They give a very hard radiation and thus suitable for examining very thick objects. However they are very expensive and it is not possible to make them in dimensions small enough for good quality images and still give sufficient activity.

Artificial radioactive source

Obtained by irradiation in a nuclear reactor.
Properties of radioactive sources

- **Activity (source strength)** – This given by the number of atoms of the substance which disintegrate per second and measured in Becquerel (Bq).

- **Specific activity** – This is the activity of this substance per weight unit, expressed in Bq/g.

- **Specific gamma-ray emission factor (k-factor)** – The activity measured at a fixed distance. It indicates the specific gamma-emission (gamma constant) measured at 1 metre distance.
  - The higher the k-factor, the smaller the source can be for a particular source strength.
  - A source of small dimensions will improve the sharpness of a radiograph.
• Radioactive sources used in industrial radiography

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Mass Number</th>
<th>Specific gamma constant k-factor</th>
<th>Average energy level in MeV</th>
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The intensity of a beam of X-rays or gamma-rays undergoes local attenuation as it passes through an object, due to absorption and scattering of the radiation.

On a uniform object attenuation of the primary beam will also be uniform and the film evenly exposed.

If the object contains defects or is of variable thickness, the surface of the film will be unevenly exposed resulting in a shadow image of the object and the defects in it.

When the film is processed the variations in radiation intensity show up as varying film densities; higher radiation intensity producing higher film density resulting in a negative X-ray image.
When the primary beam is partly absorbed in the object, some radiation will be scattered and reach the film as secondary radiation by an indirect path.

The quality of the radiograph is reduced by this scattered radiation, and it is important to keep its effects to a minimum.

Backscatter coming from the object under examination is less hard than the primary radiation that has caused it and can be intercepted by a metal filter between object and film.

Radiation scattered by objects nearby the film can be intercepted by means of a protective sheet of lead at the rear face of the film cassette.
• The effects of scattered radiation can be further reduced by:
  ➢ limiting the size of the radiation beam to a minimum with a diaphragm in front of the tube window
  ➢ using a cone to localize the beam: collimator
  ➢ the use of masks: lead strips around the edges of the object.
The radiographic image is formed by only approximately 1% of the amount of radiation energy exposed at the film. The rest passes through the film and is consequently not used.

To utilize more of the available radiation energy, the film is sandwiched between two intensifying screens.

Different types of material are being used for this purpose:

- Lead screens
- Steel and copper screens
- Fluorescent screens
- Fluorometallic screens
Structural designs for screen
Structure of an X-ray Film

- An X-ray film is made up of seven layers,
  - a transparent cellulose triacetate or polyester base (d).
  
  On both sides of this base are applied:
  - a layer of hardened gelatine (a) to protect the emulsion
  - emulsion layer (b) which is suspended in gelatine, sensitive to radiation
  - a very thin layer called the substratum (c) which bonds the emulsion layer to the base

Photographic emulsion is a substance sensitive to ionizing radiation and light, and consists of microscopic particles of silver halide crystals suspended in gelatine.
Radiographic Image

- When light or X-radiation strikes a sensitive emulsion, extremely small particles of silver halide crystals are converted into metallic silver.
- These traces of silver are so minute that the sensitive layer remains to all appearances unchanged.
- The number of silver particles produced is higher in the portions struck by a greater quantity of radiation and less high where struck by a lesser quantity.
- In this manner a complete, though as yet invisible, image is formed in the light-sensitive layer when exposure takes place, and this image is called the “latent image”.
Developing the latent image

- Development is the process by which a latent image is converted into a visible image.
- This result is obtained by selective reduction into black metallic silver of the silver halide crystals in the emulsion.
- These crystals carry traces of metallic silver and in doing so form the latent image.
- Several chemical substances can reduce the exposed silver halides to metallic silver: these are called “developing agents”
Characteristics of the X-ray film

- **Radiographic Density**
  - Qualitatively, radiographic density is defined as the degree of blackening obtained on a radiograph after processing.
  - The blacker the radiograph the higher is said to be the density of the radiograph.
  - Quantitatively, it is defined by the following relation
    - $density = D = \log_{10} \frac{I_0}{I_t}$
  - Where.
    - $I_0 = \text{the intensity of light incident on the radiograph and,}$
    - $I_t = \text{the intensity of light transmitted through it.}$
• **The Characteristic Curve**
  - Also known as sensitometric curve or the H and D curve
  - It expresses the relation between the exposure applied to a radiographic film and the resulting radiographic density after processing.
  - The curve is obtained by giving a film a series of known exposures, determining the densities produced by these exposures and plotting density against the logarithm of relative exposure.

• **Fog Density**
  - This is the density obtained on the film after processing with no exposure given to a radiographic film.
  - Fog density is because of two reasons:
    - the inherent density of the base of the film, since it is not fully transparent;
    - the chemical fog density, which is due to the fact that some grains are capable of being developed even without exposure.
- **Film Speed**
- Film speed is defined as the reciprocal of the total dose in roentgen of a particular radiation spectrum that produces a given density on the film.
- The film is exposed to densities (above fog) from approximately 0.20 to 3.0, by a well defined source of radiation.
- Each exposure is suitably measured in roentgens by means of an ionization chamber. Densities are then plotted against the logarithm of the exposure and from such a characteristic curve the exposure required to produce a density 1.5 above fog level is determined.
- The speed of the film is taken to be the reciprocal of this exposure.
- The speed of a film depends upon the grain size and the energy of radiation.
- In general, the coarser the grain of the film, the Faster is its speed.
• **Film Contrast/Density**
• Defined as the difference of densities of two adjacent portions of a radiograph.
• The diagram illustrate the effect of using a higher working density on an radiographic film.
• A is the density difference in the image of the cavity after a short exposure. B is the density difference in the image of the cavity after a longer exposure.
• Radiograph B is said to have higher contrast than radiograph A
Types of films

- Films used in industrial radiography are divided into two groups:
  a. Salt screen type films - used with salt intensifying screens and is capable of producing radiographs with minimum exposure.
  b. Direct type films - intended for direct exposure to x-rays or gamma rays, or for exposure using lead screens.

Film manufacturers: Agfa Gevaert, Kodak, Fuji, Dupont
• In industrial radiography it is necessary to determine the exposure so as to meet such requirements as essential image density and penetrameter determined definition.

• An exposure chart is generally used as a guide for determining exposure conditions (e.g. kilovoltage, X-ray tube current, and exposure time).
Processing of Radiographic Films

• The essential stages in processing a radiographic film as follows
  1. Development
  2. Rinsing
  3. Fixing
  4. Washing
  5. Drying
• **Development:** During development the unexposed crystals are not affected or removed at this step, but the developer reacts with the exposed crystals latent image, freeing the compound and depositing it as tiny metallic grains of silver that form the black silver image.

• **Rinsing:** This stops the action of the developer on the film and inhibits the transfer of the developer into the fixing bath.

• **Fixing:** The function of the fixing bath are
  - To stop further development
  - To remove from the emulsion all undeveloped silver salts thereby leaving the developed silver as a permanent image
  - To harden the gelatin of the emulsion so that it will be more stable during subsequent washing, drying and handling operations
• **Washing**- The emulsion of the film carries over some of the fixing bath chemicals from the fixing bath to the wash water. If these chemicals were allowed to remain on the film, they would cause the radiograph to become discolored and fade after a storage period.

• **Drying**- The film should be dried immediately after washing. Water streaks and drops adhere to film surfaces and if they are not removed prior to drying, the areas lying underneath will dry more slowly than the surrounding area thus changing the density of the silver image and resulting in spots.
Film Interpretation

External concavity or insufficient fill.

Excessive penetration.

External undercut.

Internal (root) undercut.
Incomplete or Lack of Penetration
Slag inclusions.
Transverse crack
Longitudinal crack
Any Question?