Filtration in an X-ray Tube
(Detailed Notes)

Definition

Filtration in an X-ray tube is the process of removing low-energy (long-wavelength) X-ray photons from the X-ray beam before it reaches the patient. This is achieved by placing absorbing materials, usually aluminum, in the path of the X-ray beam. Low-energy photons are unable to penetrate the patient's body and would only increase the patient's radiation dose without contributing to image formation. Therefore, filtration improves the quality of the X-ray beam by allowing mainly high-energy, more penetrating X-rays to pass through.

In radiography, filtration is an essential radiation protection measure because it hardens the X-ray beam, reduces unnecessary radiation exposure, and improves the efficiency of imaging.

Principle of Filtration

Filtration works on the principle of differential absorption.

- Low-energy X-ray photons are absorbed by the filter material.
- High-energy X-ray photons have greater penetrating power and pass through the filter.
- The average energy of the remaining X-ray beam increases.
- This process is known as beam hardening.

Why Filtration is Necessary

Without filtration:

- Many low-energy X-rays are absorbed by the patient's skin.
- Patient radiation dose increases.
- No improvement in image quality occurs because low-energy photons do not reach the image receptor.

With filtration:

- Skin dose is reduced.
- Beam quality improves.
- More useful X-rays reach the image receptor.
- Patient safety is increased.

Types of Filtration

1. Inherent Filtration

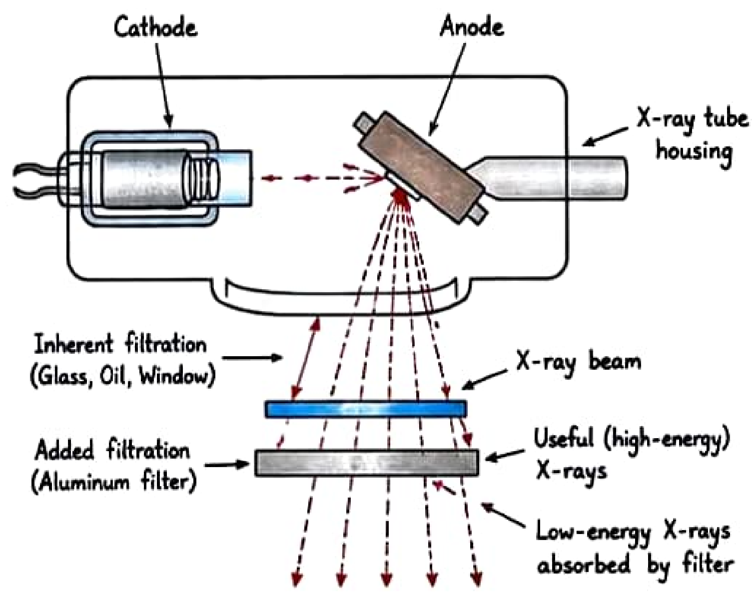
Inherent filtration is provided by components already present in the X-ray tube assembly.

It includes:

- Glass envelope of the X-ray tube
- Insulating oil
- Tube housing exit window
- Protective tube window

Typical value:

- Approximately 0.5–1.0 mm Aluminum (Al) equivalent



2. Added Filtration

Added filtration consists of aluminum sheets intentionally placed in the path of the X-ray beam.

Common materials:

- Aluminum (most common)
- Copper (used in high-energy imaging)
- Rare-earth filters (special applications)

Purpose:

- Removes remaining low-energy X-rays
- Further hardens the beam
- Improves beam quality

3. Total Filtration

Total filtration is the sum of:

Total Filtration = Inherent Filtration + Added Filtration

Example:

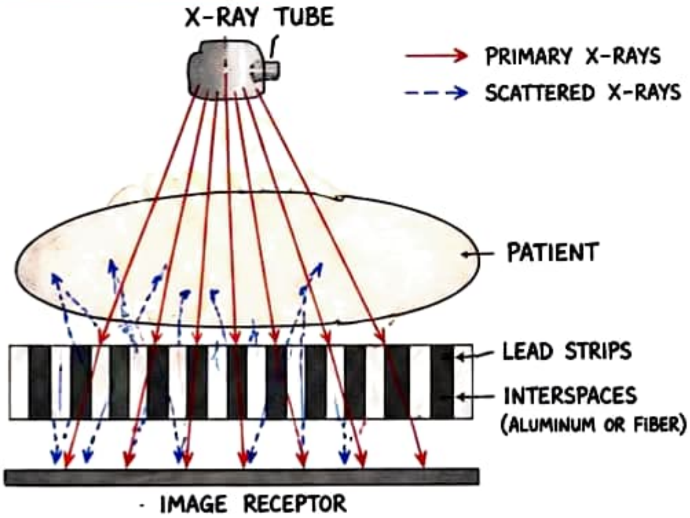
- Inherent filtration = 1.0 mm Al
- Added filtration = 1.5 mm Al

Total filtration = 2.5 mm Al equivalent

Production of X-rays

X-rays are produced when fast moving electrons are stopped by means of a target material. The moving electrons posses kinetic energy. When the electron is suddenly stopped, its kinetic energy is converted into heat & X-rays. This conversion is taking place in the target material. Therefore, the interaction of electron with the target is the basis for X-ray productio

GRID (ANTI-SCATTER GRID)



A grid is a radiographic device made of thin lead strips separated by radiolucent interspaces (usually aluminum or fiber). It is placed between the patient and the image receptor to absorb scattered X-rays while allowing most primary X-rays to pass through.

Principle

The grid works on the principle that:

- Primary X-rays travel in a straight line and pass through the grid.
- Scattered X-rays travel in different directions and are absorbed by the lead strips.
- This reduces scatter reaching the detector, producing a higher-contrast image.

Construction

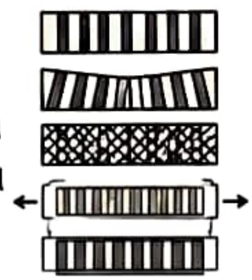
- Thin lead strips
- Radiolucent interspace material (aluminum or fiber)
- Protective cover
- Outer casing

Parts of a Grid

- Lead strips
- Interspace material
- Cover plates
- Grid frame

Types of Grids

1. Parallel grid
2. Focused grid
3. Crossed (cross-hatched) grid
4. Moving (Potter-Bucky) grid
5. Stationary grid



Grid Ratio

Grid Ratio = Height of lead strips ÷ Distance between lead strips

Common grid ratios:

- 5:1
- 6:1
- 8:1
- 10:1
- 12:1
- 16:1

Higher grid ratios remove more scatter but require greater exposure and more accurate positioning.

Grid Frequency

The number of lead strips per centimeter or per inch.

- High-frequency grids reduce visible grid lines.

Advantages

- Improves image contrast
- Reduces scatter radiation
- Produces sharper diagnostic images
- Essential for thick body parts

Disadvantages

- Requires higher mAs (higher patient dose)
- Incorrect positioning can cause grid cutoff
- More expensive than non-grid imaging

Indications

Use a grid when:

- Body part thickness is greater than 10 cm
- Tube voltage is above 70 kVp
- Imaging the abdomen, pelvis, spine, skull, or chest (depending on patient size and technique)

Grid Cutoff

Grid cutoff is the loss of primary X-rays, causing reduced image density due to improper grid use.

Causes

- Off-level grid
- Off-center positioning
- Incorrect SID
- Upside-down focused grid

Unit = 8

Grids

+ Definition & types

These are devices ~~with~~ which consist of series of alternate strips of lead (or tungsten) & wood (or similar radiolucent material). These strips are so constructed that they are deeper than wide and are arranged in a segment of a circle with a focal spot of 36-48 inches. In other words, the plane of each strip is in the plane of the primary beam

+ Types

→ Grids are mainly of two types:

× Stationary grids.

× Moving grids.

The stationary grids are also known as Lysholm Grid.

→ The moving grids are of three types:

× Reciprocating grid

× Oscillating grid

→ The stationary grid having 4 types of grid

- × Linear grid
- × Crossed grid
- × Focused grid
- × Parallel grid

- Moving grid

→ Moving grid invented by Dr. Hollis & Potter

→ Moving grid was called as potter bucky grid.

→ When a focus and parallel grid is used each lead strip will appear on radiograph as very fine line. These line may spoil the information in film. However these lines removed by moving the grid during the radiographic exposure. This is called potter bucky grid.

→ Generally focused grid used as moving grid, this grid may be move to continuously in one direction.

→ The grid motion is timed by exposure control of x-ray machine.

→ It start just before the x-ray machine are turned on and continuously to move even after the exposure is off.

→ There are 2 types of moving grid.

- × Reciprocating grid
- × Oscillating grid

(-) Reciprocating grid

-> Reciprocating grid is driven by a motor and the grid moves back and forth several time during exposure.

-> The distance travelled may be 2 cm

(-) Oscillating grid

-> In oscillating grid the grid is kept in a frame which has 2-3 cm clearance on all sides

-> An electro magnet pulls and release the grid before the exposure.

-> Grid oscillate in circular path about frame and come to rest after 20-30 second.

- Moving grid advantages :-

-> They eliminate the grid lines from the film

-> These grid produce film with better contrast

-> Grid are generally used to form body greater than 12 cm thickness or technique is greater than 70 kVp.

- Moving grid disadvantages :-

-> They are costly

-> Subject failure, may vibrate the x-ray table

-> Put a limit on minimum exposure time because they move ~~so~~ slowly

-> They increase patient dose

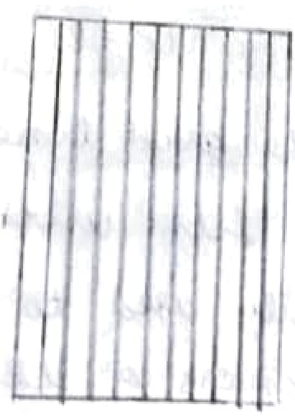
- Stationary grid :- An x-ray grid that does not move or oscillate during the exposure of a radiographic film ..

(-) Linear grid :-

-> In linear grid, the grid strips are parallel to one another in their longitudinal axis.

-> Most of the x-ray table are equipped with linear grid.

-> Their major advantages is that they allow us to angle the x-ray tube along the length of the grid without loss of primary radiation from grid cut off.



Linear grid

(-) Crossed grid :-

-> Made up of lead strips that are parallel to the axis and short axis of the grid.

-> It is designed with 2 parallel grids that are perpendicular to each other.

-> Grid radio of crossed grid equal to the sum of the two parallel grid.

-> These are efficient in removing scatter radiation and has higher contrast improvement factor and high grid ratio

-> It is useful in high kvp and tilt table exposure

-> Disadvantages include difficulty in positioning, proper alignment of table and tube, higher patient dose.

crossed grid

(-) Focused grid

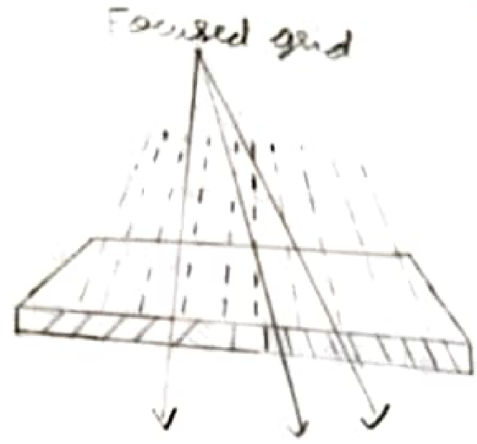
-> It is made mainly to reduce grid cut off.

-> The lead strip lies in an imaginary line of a circle whose centre is focal spot.

-> Strips are parallel to the divergence of X-ray beam.

-> The grid are marked with focal distance and side facing the target.

-> It is reverse grid cut of off may occur hence enough care is needed to positioning



(-) Parallel grid

-> In parallel grid the lead strip are parallel to each other in their longitudinal axis.

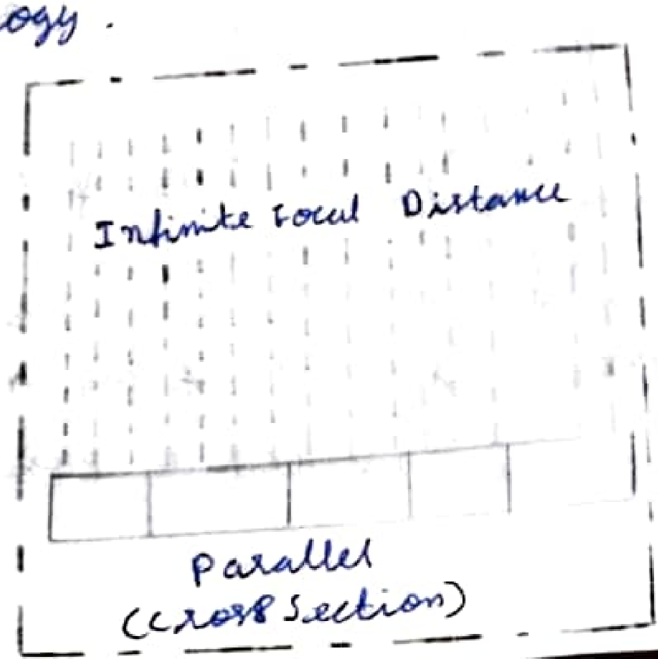
-> Simplest types of grid used in most of the x-ray table. It can be used with small x-ray field.

-> They are focused at infinity so they do not have a convergent line.

-> Only clean up scatter in one direction

-> Advantages is inexpensive, easy to make.

-> They are used in fluoroscopy, and modern radiology.

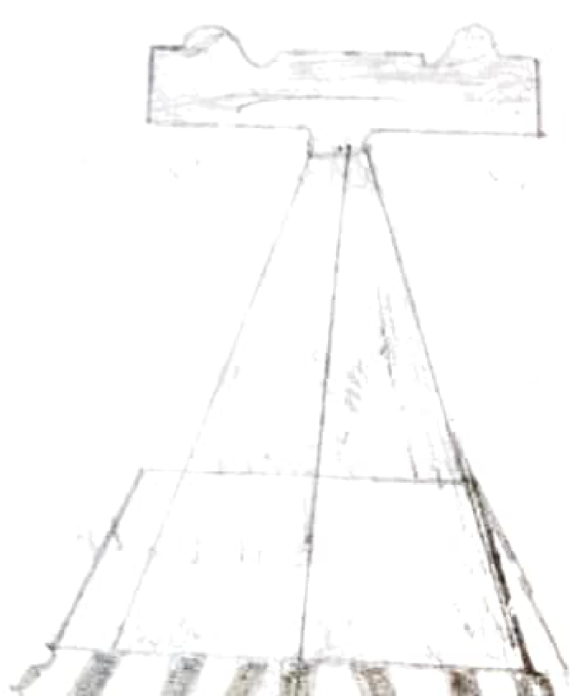


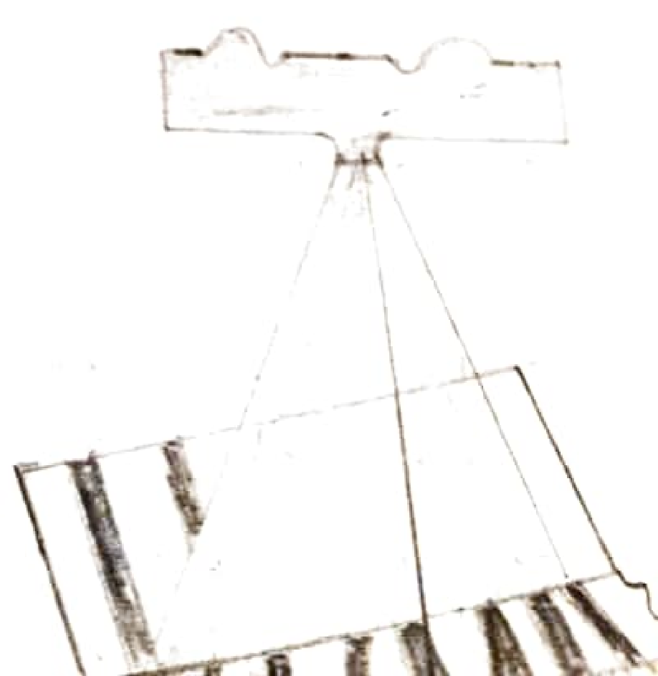
+ Function and uses of grid :-

- Used to reduce scatter radiation thereby increasing radiographic contrast.
- Grid generally used in radiography of abdomen, skull, spine except cervical lateral.
- Used in contrast study like IVP, barium studies, etc.
- Used in Breast (mammography)

+ Grid cut off :-

- Grid cut off means grid is not aligned with x-ray beam.
- It loses primary radiation as a result of undesirable absorption.
- It has too light so less contrast image.





Unit = 7

X-ray beam restrictors

+ Definition

X-ray beam restrictors is a device that is attached to the X-ray tube housing to regulate the size and shape of the X-ray beam.

+ Functions of restrictors

-> Reduce irradiated tissue volume
-> Reduce patient dose
-> Improve contrast

+ Types - application

- It can be classified as 3 categories

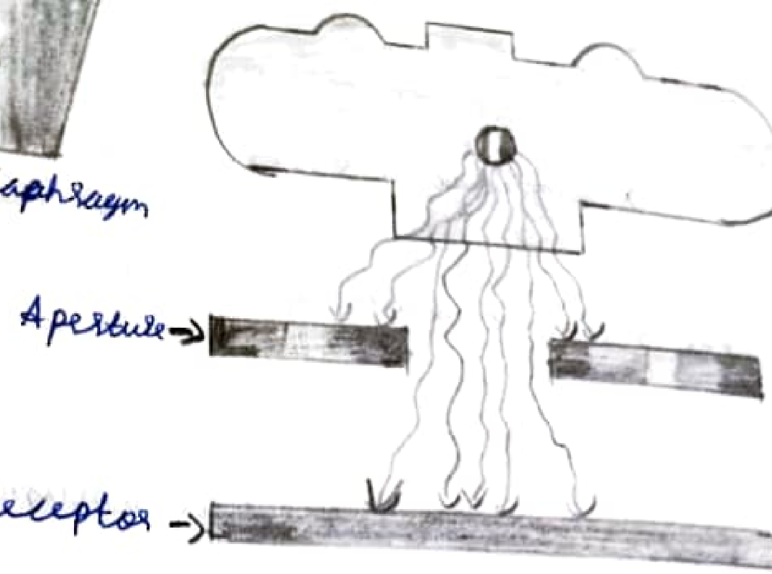
* Aperture diaphragm
* Cones & cylinders
* Collimators

(-) Aperture diaphragm

-> It consist a sheet of lead with a hole in the center.
-> The size of the hole determine size and shape of the X-ray beam.
-> The disadvantages of aperture diaphragm is that produ

→ Aperture diaphragm used in dental radiography with rectangular collimataion and also used in trauma & chest radiograph.

Aperture diaphragm



(–) Cones and Cylinders

→ It is a beam restricted device.

→ The use of cone and cylinder will reduce large penumbra.

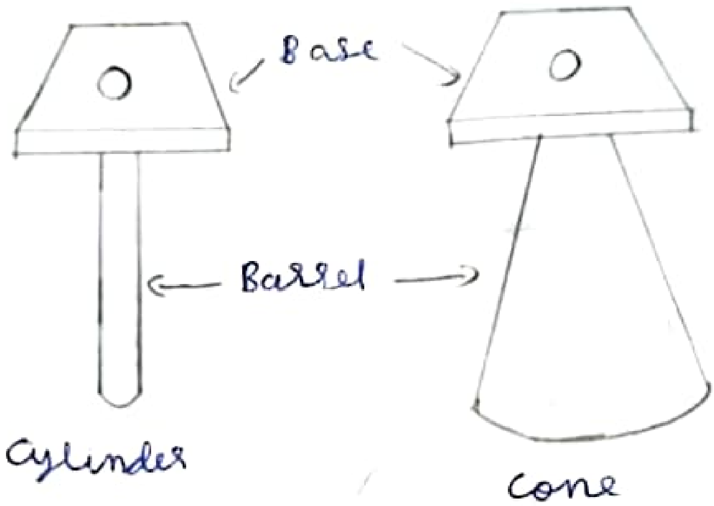
→ Both have extended metal structures that restrict the useful circular beam to require size.

→ Cone is ideal beam restrictor it provide only limited number of field size.

→ Cones are typically used in dental radiography

→ Cones attached to the bottom of the collimator housing.

→ cylinder used in bladder radiography and reproductive system procedure.



collimators are 'beam direction' or beam restricted devices provide adjustable rectangular field or circular field.

It is used in the X-ray tube housing, along with an arrangement of mirrors & lights, in such a way that the light & x-ray fields match each other.

They are made of lead shutters which completely absorb the photons, and thus reduce the patient dose as well as focus the radiation accordingly to the area of interest.

They allow different projection of x-ray fields.

Proper collimation reduce the volume of tissue irradiated, reduce patient dose.

If proper collimation not done the other part of the body will unnecessary exposed & of investigation part may not be clearly visualised.

Types of Radioactive Emissions

1. Alpha (α) Particles

- Consist of 2 protons and 2 neutrons.
- Positive charge (+2).
- Low penetrating power.
- Stopped by a sheet of paper or skin.

2. Beta (β) Particles

- High-speed electrons or positrons.
- Charge: −1 (β^-) or +1 (β^+).
- Moderate penetrating power.
- Stopped by aluminium.

3. Gamma (γ) Rays

- High-energy electromagnetic waves.
- No mass and no charge.
- Very high penetrating power.
- Stopped by thick lead or concrete.

Laws of Radioactive Decay

- Radioactive decay is **spontaneous and random**.
- It cannot be affected by temperature, pressure, or chemical reactions.
- Each radioactive substance has a fixed **half-life**.

Half-Life

Definition: The **half-life** is the time required for **half of the radioactive atoms** in a sample to decay.

Uses of Radioactivity

- Diagnostic imaging (Nuclear Medicine)
- Cancer treatment (Radiotherapy)
- Sterilization of medical equipment
- Medical research
- Industrial radiography

Hazards of Radioactivity

- Radiation burns
- Cancer
- Genetic mutations
- Bone marrow damage
- Cataracts

Radiation Protection

- Minimize exposure **time**.
- Maximize **distance** from the source.
- Use **shielding** (lead aprons, lead barriers).
- Follow the **ALARA** principle.

Viva Points

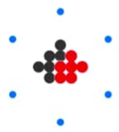
- **Atom consists of:** Protons, neutrons, and electrons.
- **Atomic number:** Number of protons.
- **Mass number:** Protons + neutrons.
- **Most penetrating r[illegible]on:** Gamma rays.
- **Least penetrating radiation:** Alpha particles.

Atomic Structure and Radioactivity (10 Marks – MIT/Radiology Notes)

Part A: Atomic Structure

Definition

An **atom** is the smallest unit of an element that retains its chemical properties. It consists of a **nucleus** containing protons and neutrons, with electrons revolving around the nucleus in shells.



Learn more

Structure of an Atom

1. **Protons (p^+)**
   - Positively charged particles.
   - Present in the nucleus.
   - Mass = 1 amu.

   - No electric charge.

Learn more

Structure of an Atom

1. **Protons (p^+)**
   - Positively charged particles.
   - Present in the nucleus.
   - Mass = 1 amu.
2. **Neutrons (n^0)**
   - No electric charge.
   - Present in the nucleus.
   - Mass = 1 amu.
3. **Electrons (e^-)**
   - Negatively charged particles.
   - Revolve around the nucleus in shells.
   - Very small mass (1/1836 amu).

Important Terms

◦ Very small mass (1/1836 amu).

Important Terms

- **Atomic Number (Z):** Number of protons in the nucleus.
- **Mass Number (A):** Total number of protons + neutrons.
- **Isotopes:** Atoms of the same element with the same atomic number but different mass numbers.
- **Isobars:** Atoms with the same mass number but different atomic numbers.
- **Isotones:** Atoms with the same number of neutrons.

Electron Shells

- **K shell:** Maximum 2 electrons
- **L shell:** Maximum 8 electrons
- **M shell:** Maximum 18 electrons
- **N shell:** Maximum ctrons

• **Isotones:** Atoms with the same number of neutrons.

Electron Shells

- **K shell:** Maximum 2 electrons
- **L shell:** Maximum 8 electrons
- **M shell:** Maximum 18 electrons
- **N shell:** Maximum 32 electrons

Part B: Radioactivity

Definition

Radioactivity is the **spontaneous disintegration of an unstable atomic nucleus** with the emission of **alpha (α), beta (β), or gamma (γ) radiation** to become more stable.

Types of Radioactive Emissions

1. Alpha (α) Particles

• Positive charge (+2)

Thermoluminescent Dosimeter (TLD) – 10 Marks Notes

Definition

A **Thermoluminescent Dosimeter (TLD)** is a **personal radiation monitoring device** used to measure the **dose of ionizing radiation** received by radiation workers such as radiographers, radiologists, and nuclear medicine staff.

Principle

A TLD works on the principle of **thermoluminescence**.

- When exposed to ionizing radiation, the TLD crystal stores energy.
- On heating, the stored energy is released as visible light.
- The amount of light emitted is **proportional to the radiation dose** received.

Construction

A TLD badge consists of:

1. Plastic holder (badge)
2. Thermoluminescent crystal (e.g., **Lithium Fluoride (LiF)** or **Calcium Sulphate: Dysprosium ($CaSO_4$:Dy)**)
3. Metal filters (Aluminium, Copper, Plastic)
4. Identification label

Working

1. The worker wears the TLD badge during work.
2. Radiation exposure causes the crystal to store energy.
3. After the monitoring period (usually 1–3 months), the badge is sent to a TLD reader.
4. The reader heats the crystal.
5. The crystal emits light.
6. The emitted light is measured to calculate the radiation dose.

Advantages

- Highly accurate.
- Reusable after reading.
- Sensitive to low radiation doses.
- Small, lightweight, and easy to wear.
- Not affected by normal light or humidity.

Disadvantages

- Cannot provide an instant dose reading.
- Requires a special TLD reader.
- Improper heating may affect accuracy.

Applications

- Monitoring radiation exposure of radiographers.
- Monitoring radiologists and X-ray technicians.
- Nuclear medicine departments.
- Radiotherapy departments.
- Radiation research laboratories.

Precautions

- Wear the badge on the chest outside the lead apron (or as per institutional protocol).
- Do not exchange badges with others.
- Keep away from heat, sunlight, and moisture.
- Return the badge for regular dose analysis.

Viva Points

- **Full form:** Thermoluminescent Dosimeter.
- **Principle:** Thermoluminescence.
- **Purpose:** Measures personal radiation dose.
- **Common crystal:** L[illegible] Fluoride (LiF).
- **Read by:** TLD reader.

Radiation hazards and protection

Radiation Hazards and Protection (10 Marks – MIT/Radiology Notes)

Definition

Radiation hazards are the harmful effects caused by exposure to ionizing radiation.
Radiation protection consists of measures used to reduce radiation exposure to patients, workers, and the public.

Radiation Hazards

1. Hazards to Patients

- Skin erythema (redness)
- Radiation burns
- Hair loss (epilation)
- Cataract
- Infertility
- Increased risk of cancer
- Genetic effects in future generations

2. Hazards to Radiation Workers

- Chronic radiation exposure
- Bone marrow suppression
- Cataract
- Skin damage
- Leukemia and other cancers
- Reduced fertility

3. Hazards to the Fetus

- Congenital abnormalities
- Growth retardation
- Mental retardation
- Increased risk of childhood cancer
- Fetal death (at very high doses)

Factors Affecting Radiation Hazards

- Radiation dose
- Exposure time
- Distance from the source
- Type and energy of radiation
- Age and health of the person
- Radiosensitivity of tissues

Radiation Protection

Principle of Radiation Protection (ALARA)

ALARA – As Low As Reasonably Achievable

- Keep radiation exposure as low as possible while obtaining the required diagnostic information.

Cardinal Principles of Radiation Protection

1. Time

- Reduce the exposure time.
- Less time = Less radiation dose.

2. Distance

- Increase the distance from the radiation source.
- Follows the **Inverse Square Law** (radiation intensity decreases as distance increases).

3. Shielding

- Use protective barriers to absorb radiation.
- Examples:
  - Lead apron
  - Lead gloves
  - Thyroid shield
  - Lead goggles
  - Lead barriers

Personal Protective Devices (PPE)

- Lead apron (0.5 mm lead equivalent)
- Thyroid collar
- Lead gloves
- Lead goggles
- Gonadal shields

Monitoring Devices

- Thermoluminescent Dosimeter (TLD)
- Film badge
- Electronic personal dosimeter (EPD)

Protection of Patients

- Justify every X-ray examination.
- Use the lowest exposure factors.
- Proper collimation.
- Use filtration.
- Shield sensitive organs whenever possible.
- Avoid unnecessary repeat exposures.

Protection of Radiation Workers

- Wear a dosimeter.
- Stand behind a protective barrier during exposure.
- Never hold the patient unless absolutely necessary.
- Follow ALARA principles.
- Undergo regular health check-ups.

Radiation Warning Signs

- Display radiation hazard warning symbols.
- Restrict access to X-ray rooms during exposure.

Viva Points

- **ALARA:** As Low As ...nably Achievable.
- **Three cardinal principles:** Time, Distance,

Biological Effects of Radiation (10 Marks – MIT/ Radiology Notes)

Definition

Biological effects of radiation are the harmful changes that occur in living cells, tissues, or organs when they are exposed to **ionizing radiation**. These effects may appear immediately or many years after exposure.

Mechanism of Radiation Damage

1. Ionizing radiation passes through the body.
2. It ionizes atoms and molecules.
3. Free radicals are produced (especially from water).
4. DNA and cell structures are damaged.
5. The cell may repair, die, or mutate.

Types of Biological Effects

1. Somatic Effects

Definition

Effects that occur in the **exposed individual** only and are **not inherited** by future generations.

Examples

- Skin erythema (redness)
- Hair loss (epilation)
- Cataract
- Radiation burns
- Bone marrow suppression
- Cancer (leukemia, thyroid cancer)

2. Genetic (Hereditary) Effects

Definition

Effects caused by damage to the **reproductive cells (sperm or ova)** and passed on to future generations.

Examples

- Genetic mutations
- Congenital abnormalities
- Inherited disorders

Classification of Radiation Effects

A. Deterministic (Non-stochastic) Effects

Definition

Effects that occur **only after a threshold dose** is exceeded. The **severity increases with dose**.

Characteristics

- Threshold dose present.
- Severity depends on radiation dose.

Examples

- Skin burns
- Cataract
- Sterility
- Radiation sickness
- Bone marrow depression

B. Stochastic Effects

Definition

Effects that **have no threshold dose**. The **probability increases with dose**, but the severity does not.

Characteristics

- No threshold dose.
- Chance of occurrence increases with dose.

Examples

- Cancer
- Leukemia
- Genetic mutations

Acute Radiation Syndrome (ARS)

Occurs after exposure to a **high dose of radiation** over a short period.

Symptoms

- Nausea and vomiting
- Fatigue
- Diarrhea
- Fever
- Hair loss
- Bleeding and infections

Factors Affecting Biological Effects

- Radiation dose.
- Dose rate.
- Type of radiation.
- Area of the body exposed.
- Age of the patient.
- Cell sensitivity.

Radiation Protection Measures

- **Time:** Minimize exposure time.
- **Distance:** Maximize distance from the source.
- **Shielding:** Use lead aprons, lead barriers, and lead gloves.
- Follow the **ALARA (As Low As Reasonably Achievable)** principle.
- Wear personal dosimeters.

Applications of Radiation (Beneficial Effects)

- Diagnostic X-ray imaging.
- CT scanning.
- Cancer radiotherapy.
- Sterilization of medical equipment.
- Medical research.

Viva Points

- **Most radiosensitive cells:** Bone marrow, gonads, intestinal lining.
- **Most radioresistant tissue:** Muscle and nerve tissue.
- **Deterministic effect:** Has a threshold dose.

Each sub topic separately

1. Coherent (Classical) Scattering

Definition

Coherent scattering is an interaction in which a **low-energy X-ray photon changes its direction without losing energy**. No electron is ejected, so **no ionization** occurs.

Mechanism

1. Low-energy X-ray photon interacts with the whole atom.
2. The atom becomes temporarily excited.
3. The atom immediately releases the same X-ray photon.
4. The photon travels in a different direction but with the **same energy**.

Characteristics

- No ionization.
- No energy loss.
- Low-energy interaction.
- Causes scattered radiation.

Importance

- Contributes very little to image formation.
- Slightly increases image fog.

2. Photoelectric Effect

Definition

The photoelectric effect is an interaction in which an **X-ray photon transfers all its energy to an inner-shell electron**, causing the electron to be ejected.

Mechanism

1. X-ray photon strikes an inner-shell electron.
2. The electron absorbs all the photon energy.
3. The electron is ejected as a **photoelectron**.
4. The X-ray photon disappears completely.

Characteristics

- Complete absorption of the X-ray photon.
- Produces ionization.
- Common in bone and high atomic number materials.
- More common at low kVp.

Importance

- Produces image contrast.
- Increases patient radiation dose.
- Essential for diagnostic imaging.

3. Compton Scattering

Definition

Compton scattering is an interaction in which an **X-ray photon transfers part of its energy to an outer-shell electron**, producing a scattered photon.

Mechanism

1. X-ray photon strikes an outer-shell electron.
2. Part of the energy ejects the electron.
3. Remaining energy continues as a scattered photon.

Characteristics

- Partial energy loss.
- Produces ionization.
- Most common interaction in diagnostic radiology.
- Occurs mainly in soft tissues.

Importance

- Reduces image contrast.
- Produces image fog.
- Increases radiation exposure to staff.

4. Pair Production

Definition

Pair production is an interaction in which a **high-energy X-ray photon (greater than 1.02 MeV)** is converted into an **electron and a positron** near the nucleus.

Mechanism

1. High-energy photon passes near the nucleus.
2. The photon disappears.
3. An electron and a positron are formed.

Characteristics

- Requires energy above **1.02 MeV**.
- Produces ionization.
- Not seen in diagnostic radiology.

Importance

- Occurs in radiation therapy and nuclear physics.
- Not used in routine X-ray imaging.

5. Photodisintegration

Definition

Photodisintegration is an interaction in which a **very high-energy X-ray photon (above 10 MeV)** is absorbed by the nucleus, causing it to emit nuclear particles.

Mechanism

1. High-energy photon strikes the nucleus.
2. The nucleus absorbs the energy.
3. A proton or neutron is emitted.

Characteristics

- Requires energy above **10 MeV**.
- Nuclear interaction.
- Does not occur in diagnostic X-ray imaging.

Importance

- Seen in radiotherapy with high-energy linear accelerators.
- Not used in routine diagnostic radiology.

Important Viva Questions

- **No ionization:** Coherent scattering.
- **Best image contrast:** Photoelectric effect.
- **Most common interaction in diagnostic radiology:** Compton scattering.
- **Occurs above 1.02 MeV:** Pair production.
- **Occurs above 10 MeV:** Photodisintegration.

Matter (10 Marks – MIT/ Radiology Notes)

Definition

Interaction of X-rays with matter is the process by which X-ray photons pass through a material and are **absorbed, scattered, or transmitted**. These interactions determine image quality and patient radiation dose.

Types of X-ray Interactions

1. Coherent (Classical) Scattering

- Low-energy X-rays interact with an atom.
- No ionization occurs.
- The X-ray changes direction without losing energy.
- Contributes little to image formation.

2. Photoelectric Effect

- The X-ray photon transfers all its energy to an inner-shell electron.
- The electron is ejected as a **photoelectron**.
- The X-ray photon disappears completely.
- Produces **high image contrast**.
- More common at **low kVp** and in materials with a **high atomic number** (e.g., bone).

3. Compton Scattering

- The X-ray photon interacts with an outer-shell electron.
- Part of the photon energy is transferred to the electron.
- A scattered photon with lower energy is produced.
- Causes **image fog** and increases **radiation exposure** to staff.
- Most common interaction in diagnostic radiology.

4. Pair Production

- Occurs only when X-ray energy is **greater than 1.02 MeV**.
- The photon disappears and forms an **electron and a positron**.
- Not seen in routine diagnostic X-ray imaging.

5. Photodisintegration

- Occurs at very high photon energies **(above 10 MeV)**.
- The photon is absorbed by the nucleus, causing emission of nuclear particles.
- Seen in **radiotherapy**, not diagnostic radiology.

Factors Affecting X-ray Interaction

- Energy of the X-ray beam (kVp).
- Atomic number (Z) of the material.
- Density and thickness of the object.
- Number of X-ray photons.

Importance in Radiology

- Determines image contrast.
- Influences patient radiation dose.
- Helps differentiate bone and soft tissue.
- Scattered radiation affects image quality and radiation safety.

Viva Points

Rectifiers (For 10 Marks – MIT/Radiology)

Definition

A **rectifier** is an electrical device that **converts alternating current (AC) into direct current (DC)**. In an X-ray machine, rectifiers ensure that electrons flow **only from the cathode to the anode,** allowing X-rays to be produced.

Principle

A rectifier works by allowing electric current to flow in **one direction only** while blocking the reverse direction.

Need for Rectification in X-ray Machines

- X-ray tubes require **direct current (DC)**.
- Prevents reverse electron flow from anode to cathode.
- Ensures continuous and efficient X-ray production.
- Protects the X-ray tube from damage.

Types of Rectifiers

1. Half-Wave Rectifier

- Uses only one half-cycle of AC.
- Blocks the negative half-cycle.
- Produces low X-ray output.
- Rarely used in modern X-ray machines.

2. Full-Wave Rectifier

- Uses both positive and negative half-cycles of AC.
- Produces a continuous DC output.
- Gives higher X-ray output than a half-wave rectifier.
- Commonly used in diagnostic X-ray units.

3. Three-Phase Rectifier

- Converts three-phase AC into DC.
- Produces nearly constant voltage.
- Used in high-capacity X-ray equipment.

Working

1. AC is supplied from the transformer.
2. The rectifier converts AC into DC.
3. Electrons flow only from the **cathode to the anode**.
4. X-rays are produced when electrons strike the tungsten target.

Advantages

- Converts AC to DC efficiently.
- Improves X-ray output.
- Protects the X-ray tube.
- Produces better image quality.

Disadvantages

- Half-wave rectifiers have low efficiency.
- Rectifiers generate heat during operation.
- Faulty rectifiers reduce X-ray output.

Applications

- Diagnostic X-ray machines.
- Dental X-ray units.
- CT scanners.
- Fluoroscopy systen

Transformer Notes (For 10 Marks – MIT/Radiology)

Definition

A **transformer** is an electrical device that **transfers electrical energy from one circuit to another by electromagnetic induction.** It is used to **increase (step-up)** or **decrease (step-down)** alternating current (AC) voltage.

Principle

A transformer works on the principle of **mutual electromagnetic induction.**

Construction

1. **Primary Coil** – Connected to the AC power supply.
2. **Secondary Coil** – Delivers the output voltage.
3. **Iron Core** – Laminated soft iron core that provides a path for magnetic flux and reduces energy loss.

Working

1. AC flows through the **primary coil**.
2. A changing magnetic field is produced in the iron core.
3. This magnetic field induces voltage in the **secondary coil.**
4. The output voltage depends on the number of turns in the primary and secondary coils.

Types of Transformers

1. Step-up Transformer

- Increases voltage.
- Secondary coil has **more turns** than the primary coil.
- Used to supply **high voltage to the X-ray tube (kVp)**.

2. Step-down Transformer

- Decreases voltage.
- Secondary coil has **fewer turns** than the primary coil.
- Used to heat **the tungsten filament** in the X-ray tube.

3. Autotransformer

- Has a **single winding** acting as both primary and secondary.
- Used to adjust and select the required **kVp**.

Uses of Transformers in X-ray Machines

- Increase voltage for X-ray production.
- Decrease voltage to heat the filament.
- Regulate and control tube voltage (kVp).
- Ensure proper operation of the X-ray circuit.

Advantages

- High efficiency.
- No moving parts.
- Reliable and long-lasting.
- Provides safe and controlled voltage.

Disadvantages

- Works only with **AC**, not DC.
- Generates heat during operation.
- Can be bulky and heavy.

Applications

- X-ray machines.
- CT scanners.
- MRI power systems.
- Electrical power transmission and distribution.
- Medical electronic ment.

X-ray Circuit Notes (10 Marks)

Definition

The **X-ray circuit** is the electrical system of an X-ray machine that supplies the required voltage and current to the X-ray tube for the production of X-rays.

Block Diagram

```
Power Supply
     |
Main Switch
     |
Autotransformer
     |
High Voltage Transformer ———→
Rectifier ———→ X-ray Tube
     |
Filament Transformer ——————→
Cathode Filament
```

Components of the X-ray Circuit

1. Main Switch

- Turns the X-ray machine ON and OFF.
- Controls the power supply.

2. Autotransformer

- Adjusts the input voltage.
- Used to select the required **kVp (kilovoltage peak)**.

3. High Voltage Transformer

- Increases voltage from about **220–240 V** to **40–150 kV**.
- Provides the high voltage needed to accelerate electrons.

4. Filament Transformer

- Reduces voltage to about **6–12 V**.
- Increases current to heat the tungsten filament.

5. Rectifier

- Converts alternating current (AC) into direct current (DC).
- Ensures electrons flow only from the cathode to the anode.

6. X-ray Tube

- Contains the **cathode** and **anode**.
- Converts electrical energy into X-rays.

7. Timer

- Controls the duration of X-ray exposure.
- Ensures accurate radiation dose.

8. Control Panel

- Used to select **kVp, mA, and exposure time.**
- Monitors machine operation.

Working of the X-ray Circuit

1. The main switch supplies power to the machine.
2. The autotransformer adjusts the required **kVp.**
3. The high-voltage transformer increases the voltage.
4. The filament transformer heats the tungsten filament.
5. The heated filament releases electrons **by thermionic emission.**
6. The rectifier converts AC to DC.
7. Electrons travel from the cathode to the anode.
8. When electrons strike the tungsten target, **X-rays are produced.**

Functions of the X-ray Circuit

- Supplies electrical power to the X-ray tube.
- Produces high voltage for electron acceleration.
- Heats the filament.
- Controls kVp, mA, and exposure time.
- Ensures safe and efficient X-ray production.

Advantages

- Provides stable X-ray output.
- Produces good-quality images.
- Allows precise exposure control.
- Improves patient safety by controlling radiation dose.

Viva Points

- **kVp** controls the pe[illegible]ating power (quality) of X-rays.
- mA controls the number (quantity) of X-rays

Rotating Anode X-ray Tube (10 Marks Notes)

Definition

A **rotating anode X-ray** tube is an X-ray tube in which the **anode (target) rotates at high speed** during X-ray production. Rotation spreads the heat over a larger area, allowing higher tube loading and better image quality.

Diagram

```
              Glass Envelope
          ___________________________
         /                           \
   Cathode (-)                    Rotating
   Anode (+)
    _________
   ________________
   |Filament |  Electron ---> | Tungsten
   Track|
   |Focusing |     Beam      |   (Disc)
   |
   | Cup     |                |
   _______________|
   |_________|                      |
                                    |
                                 Rotor
   (inside)
                                    |
                               Glass
   Envelope
                                    |
                                Stator
   (outside)
```

Construction

1. Cathode

- Tungsten filament
- Molybdenum focusing cup
- Produces and focuses electrons.

2. Anode

- Rotating tungsten-rhenium target (focal track)
- Molybdenum disc with copper support
- Rotates at **3,000–10,000 rpm** (or higher in modern tubes).

3. Rotor

- Located inside the glass envelope.
- Attached to the anode stem.
- Rotates the anode.

4. Stator

- Located outside the glass envelope.
- Produces a rotating magnetic field that spins the rotor.

5. Glass Envelope

- Maintains a high vacuum for electron movement.

6. Protective Housing

- Lead-lined metal casing.
- Filled with insulating oil for cooling and electrical insulation.

Working

1. The filament is heated, causing **thermionic emission** of electrons.
2. The stator creates a rotating magnetic field.
3. The rotor spins the anode at high speed.
4. High voltage accelerates electrons from the cathode to the rotating anode.
5. Electrons strike the tungsten focal track.
6. About **99% of the energy is converted into heat** and **1% into X-rays.**
7. Rotation spreads heat over a larger surface, preventing target damage.

Advantages

- Excellent heat dissipation.
- Can withstand high tube current (high mA).
- Suitable for short exposure times.
- Produces better image quality.
- Longer tube life.

Disadvantages

- Expensive.
- Complex construction.
- Requires more maintenance.
- Rotor or bearing failure may occur.

Applications

- General diagnostic radiography.
- Fluoroscopy.
- Computed Tomography (CT).
- Angiography.
- Interventional radiology.

Differences Between Stationary and Rotating Anode

Stationary Anode	Rotating Anode
Fixed target	Rotating target
Low heat capacity	High heat capacity
Used for dental and portable X-ray units	Used for diagnostic and fluoroscopy
Low cost	High cost
Simple design	Complex design

Viva Points

- **Target material:** Tungsten–Rhenium alloy.

Stationary Anode X-ray Tube (Short Note for 10 Marks)

Definition

A **stationary anode X-ray tube** is an X-ray tube in which the **anode remains fixed** and does not rotate. It is mainly used in **dental X-ray machines, portable X-ray units, and small diagnostic units**.

Diagram

```
Cathode (-)
Anode (+)
 ___________
______________
| Filament  |  Electron beam --> |
Tungsten     |
| Focusing  |--------------------->|
Target       |
| Cup       |                     |
(Copper stem)|
|___________|                     |
______________|

\_______________________________/
             Glass vacuum envelope
```

Construction

1. **Cathode**
   - Tungsten filament
   - Focusing cup (molybdenum)
2. **Anode**
   - Fixed (stationary) tungsten target
   - Copper stem for heat dissipation
3. **Glass envelope**
   - Maintains a vacuum for electron travel
4. **Protective housing**
   - Lead-lined casing with insulating oil
   - Provides radiation shielding and cooling

Working

1. Electric current heats the tungsten filament.
2. Electrons are emitted by **thermionic emission**.
3. A high voltage accelerates electrons toward the anode.
4. Electrons strike the tungsten target.
5. About **99% of the energy is converted into heat** and **1% into X-rays**.
6. X-rays exit through the tube window and are used for imaging.

Advantages

- Simple construction
- Low cost
- Reliable and easy to maintain
- Suitable for low-output X-ray examinations

Disadvantages

- Poor heat dissipation
- Limited tube loading capacity
- Not suitable for high mA or repeated exposures
- Shorter tube life under heavy use

Applications

- Dental radiography
- Portable X-ray machines
- Mobile X-ray units
- Industrial X-ray inspection

Viva Points

- **Target material:** Tu...en

1. Coherent (Classical) Scattering

Definition

Coherent scattering is an interaction in which a **low-energy X-ray photon changes its direction without losing energy**. No electron is ejected, so **no ionization** occurs.

Mechanism

1. Low-energy X-ray photon interacts with the whole atom.
2. The atom becomes temporarily excited.
3. The atom immediately releases the same X-ray photon.
4. The photon travels in a different direction but with the **same energy**.

Characteristics

- No ionization.
- No energy loss.
- Low-energy interac

compromising the diagnostic accuracy. However, the appropriate annual dose limits recommended by regulatory bodies should not be exceeded for individuals from planned exposure situations other than medical exposure of patients, regardless of the benefits.

24.1 SOURCES OF MEDICAL RADIATION–PRIMARY AND SECONDARY RADIATION

Primary radiation/useful beam: It includes X-ray beam emitted directly by the X-ray

of 1 m from the patient for a field area of **(20 × 20) sq cm**. Leakage radiation consists of the radiation emanating from the tube housing and consists of high energy photons (Fig. 24.1).

24.2 RADIATION EXPOSURE CONTROL

The radiation exposure to persons can be minimized by adopting four methods—**reducing time of exposure, increasing distance, shielding, and controlling contamination by radioactive material.**

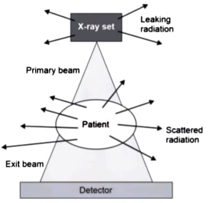


Fig. 24.1: Types of radiation

Time: The first goal is to minimize the time spent with radiation. For this, only persons whose presence is necessary shall be present inside the room during radiological investigation. The amount of time spent by a radiation worker in handling a radiation equipment determines the radiation dose received by him and some equipment have higher exposure rate over short periods of time like X-ray and some have in the other way, low exposure rate over long periods of time like nuclear medicine. Thus, minimizing the time spent with radiation, reduces the dosage by radiation.[3] Radiation dose is proportional to the time of exposure provided the dose rates are same.

Total dose (mSv) = Dose rate (mSv/h) × time

Distance: The second goal is to maximize the distance the radiation worker maintains from X-ray tube and patient. The X-ray beam intensity decreases as it moves away from the target due to the divergence of the beam.[3] This decrease in intensity is directly proportional to the square of the distance from the target, which is known as the inverse square law (Fig. 24.2)

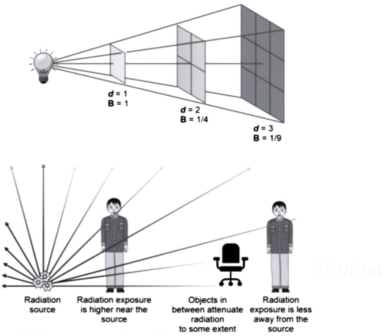


Fig. 24.2: Inverse square law (d–distance; B-X-ray beam intensity)

Shielding: The third goal is to provide adequate shielding so that radiation beam will be sufficiently attenuated.[3] Thickness of protective shielding determines the exposure rate from any radiation equipment (Table 24.1). The relationship between intensity of radiation at a point without radiation shield (I_0) and intensity (I) with a shield of thickness (t) is given by $I_0 = I, e^{-\mu t}$, where μ is the linear attenuation coefficient of the shielding material.

Half-value layer (HVL): Thickness of a designated material that can diminish the initial intensity of a given radiation beam to half of its original value.

$$HVL = 0.693/\mu \qquad \mu = 0.693/t^{1/2}$$

Tenth-value layer (TVL): Thickness of a specified material which, when introduced into the path of a given beam of radiation, reduces its initial intensity to one tenth.[3]

$$\mu = 2.303/t^{1/10}$$

24.3 RADIATION PROTECTION ACCESSORIES

Radiation protection accessories are shown in Fig. 24.3 and discussed as follow:

- **Lead aprons:** A lead apron or leaded apron is a type of protective clothing that acts as a radiation shield which contains lead or equivalent material and is sufficiently flexible to wrap around as protection from ionizing radiation. It is used to shield patient and personnel during radiological procedure. It is made up of lead equivalence of 0.5 mm in front side and 0.25 mm in back side. The weight of lead aprons often causes discomfort and fatigue during prolonged exposure.
- **Zero-gravity aprons:** Heavy lead aprons lead to progressive back pain and can eventually cause irreversible damage to the spine. The zero-gravity suspended radiation protection is flexible and designed to increase the level of radiation protection while at the same time eliminating the weight burden to the operator, without compromising radiation protection. Lightweight environmentally friendly composite lead free aprons, i.e. (^{50}Sn), antimony (^{51}Sb), or tungsten (^{74}W) are called "lead-free" aprons.
- **Thyroid shield:** Thyroid shield or thyroid guard is a protective gear made of lead that encircles the neck area to block the radiation produced during X-ray imaging. Since thyroid is highly susceptible to radiation and any thyroid-related ailments can lead to severe health issues, lead collars are employed to shield this delicate gland from harmful exposure.
- **Gonads shield**: A specialized shield that is either in contact with the patient or placed in the shadow of the primary radiation beam to protect the reproductive organs during radiographic procedures. This shield is typically used for patients who may be of reproductive age, especially women under the age of 40.

Table 24.1: Material and thickness of radiation protection shields

	Material	Thickness
Thyroid shield	Lead	0.5 mm
Lead apron thick	Lead	0.25–0.50 mm
Zero-gravity radiation protection system	Lead	1 mm
Non-lead elastic tab apron	Antimony/bismuth/barium	0.35 mm/0.5 mm/1 mm lead equivalence
Head cap	Lead	0.5 mm
Gonad shield	Lead	Solid—2 mm Flexible—0.5 mm
Goggles	Lead	0.75 mm