LECTURE 7

RADIATION DETECTION & MEASUREMENT
Types of Detectors
TYPES OF DETECTORS

- **Gas-filled detectors** consist of a volume of gas between two electrodes.

- In **scintillation detectors**, the interaction of ionizing radiation produces UV and/or visible light.

- **Semiconductor detectors** are especially pure crystals of silicon, germanium, or other materials to which trace amounts of impurity atoms have been added so that they act as diodes.
Types of Detectors (Cont.)

- Detectors may also be classified by the type of information produced:
  - Detectors, such as Geiger-Mueller (GM) detectors, that indicate the number of interactions occurring in the detector are called **counters**.
  - Detectors that yield information about the energy distribution of the incident radiation, such as NaI scintillation detectors, are called **spectrometers**.
  - Detectors that indicate the net amount of energy deposited in the detector by multiple interactions are called **dosimeters**.
MODES OF OPERATION

- In **pulse mode**, the signal from each interaction is processed individually.
- In **current mode**, the electrical signals from individual interactions are averaged together, forming a net current signal.
1. Gas-filled detectors

- A gas-filled detector consists of a volume of gas between two electrodes, with an electrical potential difference (voltage) applied between the electrodes.
- Ionizing radiation produces ion pairs in the gas.
- Positive ions (cations) attracted to negative electrode (cathode); electrons or anions attracted to positive electrode (anode).
- In most detectors, cathode is the wall of the container that holds the gas and anode is a wire inside the container.
TYPES OF GAS-FILLED DETECTORS

Three types of gas-filled detectors in common use:

1. Ionization chambers
2. Proportional counters
3. Geiger-Mueller (GM) counters

Type determined primarily by the voltage applied between the two electrodes

Ionization chambers have wider range of physical shape (parallel plates, concentric cylinders, etc.)

Proportional counters and GM counters must have thin wire anode
IONIZATION CHAMBERS

- If gas is air and walls of chamber are of a material whose effective atomic number is similar to air, the amount of current produced is proportional to the exposure rate.
- Air-filled ion chambers are used in portable survey meters, for performing QA testing of diagnostic and therapeutic x-ray machines, and are the detectors in most x-ray machine phototimers.
- Low intrinsic efficiencies because of low densities of gases and low atomic numbers of most gases.
**PROPORTIONAL COUNTERS**

- Must contain a gas with specific properties
- Commonly used in standards laboratories, health physics laboratories, and for physics research
- Seldom used in medical centers
GM COUNTERS

- GM counters also must contain gases with specific properties.
- Gas amplification produces billions of ion pairs after an interaction – signal from detector requires little amplification.
- Often used for inexpensive survey meters.
- In general, GM survey meters are inefficient detectors of x-rays and gamma rays.
- Over-response to low energy x-rays – partially corrected by placing a thin layer of higher atomic number material around the detector.
GM COUNTERS (CONT.)

- GM detectors suffer from extremely long dead times – seldom used when accurate measurements are required of count rates greater than a few hundred counts per second.

- Portable GM survey meter may become paralyzed in a very high radiation field – should always use ionization chamber instruments for measuring such fields.
2. **SCINTILLATION DETECTORS**

- Scintillators are used in conventional film-screen radiography, many digital radiographic receptors, fluoroscopy, scintillation cameras, most CT scanners, and PET scanners.

- Scintillation detectors consist of a scintillator and a device, such as a PMT, that converts the light into an electrical signal.
SCINTILLATORS

Desirable properties:

- High conversion efficiency
- Decay times of excited states should be short
- Material transparent to its own emissions
- Color of emitted light should match spectral sensitivity of the light receptor
- For x-ray and gamma-ray detectors, $\mu$ should be large – high detection efficiencies
- Rugged, unaffected by moisture, and inexpensive to manufacture
SCINTILLATORS (CONT.)

- Amount of light emitted after an interaction increases with energy deposited by the interaction.
- May be operated in pulse mode as spectrometers.
- High conversion efficiency produces superior energy resolution.
MATERIALS

- Sodium iodide activated with thallium [NaI(Tl)], coupled to PMTs and operated in pulse mode, is used for most nuclear medicine applications
  - Fragile and hygroscopic
- Bismuth germanate (BGO) is coupled to PMTs and used in pulse mode as detectors in most PET scanners
PHOTOMULTIPLIER TUBES

- PMTs perform two functions:
  - Conversion of ultraviolet and visible light photons into an electrical signal
  - Signal amplification, on the order of millions to billions
- Consists of an evacuated glass tube containing a photocathode, typically 10 to 12 electrodes called dynodes, and an anode
PERSONEL MONITORING
PERSONAL PROTECTIVE EQUIPMENT

- Registrants and licensees shall ensure that workers are provided with suitable and adequate personal protective equipment which meets any relevant regulations or standards (BSS 3.76).
- Protective equipment includes lead aprons, thyroid protectors, protective eye-wear and gloves. The need for these protective devices should be established by the RPO.
PROTECTIVE CLOTHING:

- Gowns, aprons and thyroid protectors made of a material (such as vinyl) which contains lead or other high Z material
- Aprons should be equivalent to at least 0.25 mm Pb if the X Ray equipment operates up to 100 kV and 0.35 mm Pb if it operates above 100 kV
- Aprons may be of the style which is open, or contains less lead, at the back, due to the extra weight of lead required - this assumes, however, that the wearer is always facing the radiation source
- Heavy, leaded gloves have limited value because they are difficult to use
PROTECTIVE DEVICES

SCREEN AND GOGGLES

CURTAIN
PERSONAL PROTECTIVE EQUIPMENT

- Additional protective devices should be available in fluoroscopy and interventional radiology rooms which include:
  - Ceiling suspended protective screens.
  - Protective lead curtains mounted on the patient table.
  - Protective lead curtains for the operator if the X Ray tube is placed in an over couch geometry and if the radiologist must stand near the patient.
PART 13.2: OCCUPATIONAL EXPOSURE
Topic 2: Individual monitoring and exposure assessment
Individual dose monitoring shall be undertaken for workers who are normally exposed to radiation in controlled areas:

- radiologists, medical physicists, the RPO, radiographers and nurses
- Other frequent users of X Ray systems such as endoscopists, anaesthetists, cardiologists, surgeons etc., as well as ancillary workers who work in controlled areas, shall also be monitored.
**INDIVIDUAL MONITORING AND EXPOSURE ASSESSMENT (II)**

- Individual external doses should be determined by using individual monitoring devices:
  - Thermoluminescent or optically stimulated luminescence
  - Film badges
  - Electronic dosimeters

- Worn at breast level, between the shoulders and the waist

- The monitoring period should be **one month**, and **shall not exceed** three months.

- The exchange of dosimeters and report receipt **should not exceed** three months.
PERSONAL DOSIMETRY

Several personal dosimeters are recommended

From: Avoidance of radiation injuries from interventional procedures. ICRP Publication 85
DIFFERENT TYPES OF PERSONAL DOSIMETERS...

- film
- termoluminescence (TLD) and optically stimulated luminescence (OSL) dosimeters
- ”electronic” dosimeters
Films badge

- plastic filter
- metal filters
- open windows

Dectets beta, gamma, X Ray
TLD

13.2: Occupational exposure - Radioprotection measures

Card Dosimeters
For whole body personnel and environmental monitoring, the precision-machined chips are securely fused to sturdy Al carriers. Filter-holders are supplied in gasket-sealed, polarised, tamper-evident forms with attachment to lapel or belt buckle (eg for neutron dosimetry). Different color stripes are available as an aid to recognition or for categorisation into batches as required.
TLDs

whole body

extremity
13.2: Occupational exposure - Radioprotection measures

OSL
INDIVIDUAL MONITORING AND EXPOSURE ASSESSMENT (III)

- Evaluation of dose is an important aspect of radiation protection.
- It is important that workers return dosimeters on time for processing.
- Delays in the evaluation of a dosimeter can result in the loss of the stored information.
- Licensees should make every effort to recover any missing dosimeters.
INDIVIDUAL MONITORING
WHEN A LEAD APRON IS USED (I)

- The dosimeter should be worn under the apron for estimating the effective dose
- The other body areas not protected by the apron will receive higher dose
- One dosimeter worn under the apron will yield a reasonable estimate of effective dose for most instances
- In case of high workload (interventional radiology) an additional dosimeter outside the apron should be considered by the RPO
INDIVIDUAL MONITORING
WHEN A LEAD APRON IS USED (II)

- When expected doses are high, two dosimeters are required:
  - 1 under the apron at waist level
  - 1 over the apron at collar level
- The effective dose $E$ is given by:
  $$ E = 0.5 \ H_w + 0.025 \ H_n $$
  where:
  - $H_w$ : dose at waist level under the apron
  - $H_n$ : dose recorded by a dosimeter worn at neck level over the apron
- Note: The thyroid shielding allows 50% reduction of the $E$
- The dosimeter worn over the apron at collar level gives also an estimation of thyroid and eye lens doses
INDIVIDUAL MONITORING AND EXPOSURE ASSESSMENT (IV)

- In some facilities and for some individuals with a low level of exposure (e.g.: general dental practitioners), area dosimetry to estimate the level of dose per procedure can be an acceptable alternative.

- Some X Ray systems for dental radiography, or others used in surgical theatres which use X Rays on a limited number of occasions a month may not require individual dosimetry for all staff involved although fluoroscopy in surgical theatres may lead to high dose in short time if not properly conducted.

- In these cases, area dosimetry or some other individual dose evaluation per procedure could allow the RPO to estimate the typical level of risk.
SPECIAL ASPECTS OF INDIVIDUAL MONITORING

- In case of loss of a dosimeter, the dose estimation may be carried out from:
  - recent dose history,
  - co-workers dose
  - or, workplace dosimetry

- Individual monitoring devices should be calibrated

- Laboratory performing personnel dosimetry should be approved by the regulatory authority
MONITORING OF THE WORKPLACE (I)

Registrant and licensees shall develop programmes for monitoring of the workplace:

- All survey meters used for workplace monitoring shall be calibrated and this calibration shall be traceable to a standards dosimetry laboratory.
- Initial monitoring should be conducted immediately after the installation of new radiology equipment and shall include measurements of radiation leakage from equipment, and area monitoring of useable space around radiology rooms.
MONITORING OF THE WORKPLACE (II)

- Annual area surveys should be performed.
- All radiation monitors shall be calibrated, and their warning devices and operability should be checked prior to each day of use (BSS 3.76).