RADIATION SAFETY IN DIAGNOSTIC RADIOLOGY

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INTRODUCTION

• Medical imaging of the human body requires some form of energy.

• In radiology, the energy used to produce the image must be capable of penetrating tissues.

• Visible light – limited ability to penetrate tissues at depth.

• Visible light images are used in dermatology (skin photography), gastroenterology and obstetrics (endoscopy), and pathology (light microscopy).

• All disciplines in medicine use direct visual observation utilizing the visible light.
• In diagnostic radiology, the electromagnetic spectrum outside the visible region is used for x-ray imaging, including mammography and computed tomography, magnetic resonance imaging and nuclear medicine.

• Mechanical energy in the form of high-frequency sound waves, is used in ultrasound imaging.

• In nuclear medicine imaging, the radioactive agents are injected or ingested and it is the metabolic or physiologic interactions of the agent that give rise to the information in the images.
• The diagnostic utility of a medical image relates to both technical quality of the image and the conditions of its acquisitions.

• Consequently, the image quality that is obtained from medical imaging devices involves compromise.
  - Better x-ray images can be made when the radiation dose to the patient is high,
  - Better magnetic resonance images can be made when the image acquisition time is long and
  - Better ultrasound images result when the ultrasound power levels are large.
• Patient safety and comfort must be considered when acquiring medical images.

• There should be a balance between patient safety and image quality.
• Radiation is small pockets of energy, which travels as waves and transfer energy from one point to another.

• Types of Radiation:
  1. Photons (E.g.) X & γ rays
  2. Particles (E.g.) e, p, n, & α
ELECTROMAGNETIC RADIATION

IONISING RADIATION
(potentially harmful or beneficial to humans)

COSMIC  GAMMA  X RAYS  ULTRAVIOLET  VISIBLE LIGHT  INFRARED  MICROWAVES  RADIO

High frequency  THE ENERGY SPECTRUM  Low frequency
ELECTROMAGNETIC RADIATION

PROPERTIES

• No mass and no charge.

• Unaffected by either electrical or magnetic fields.

• Constant speed in a given medium.

• Does not require any material medium for its propagation.

• Travels with the velocity of light (2.998 x 10^8 m/sec).

• Travels in straight line.

• Interaction with matter occurs either by absorption or scattering.
ELECTROMAGNETIC RADIATION

DUAL NATURE OF EM RADIATION

- Waves

- Particle like units of energy called photons or quanta.
EM WAVE CHARACTERISTICS

- Waves characterized by amplitude, wavelength ($\lambda$), frequency ($\nu$), and period
- Speed ($c$), wavelength, and frequency related by $c = \lambda \nu$
- Wavelengths typically measured in nanometers ($10^{-9}$ m); frequency expressed in hertz (Hz) ($1$ Hz = $1$ cycle/sec = $1$ sec$^{-1}$)
EM Wave Characteristics
When interacting with matter, EM radiation can exhibit particle-like behavior.

Particle-like bundles of energy called photons; energy is given by

\[ E = h \nu = \frac{hc}{\lambda} \]

where \( h = 6.62 \times 10^{-34} \text{ J-sec} \)

Energies of photons commonly expressed in electron volts (eV)
EM radiation of higher frequency than near-ultraviolet region of spectrum carries enough energy per photon to remove bound electrons from atomic shells, producing ionized atoms and molecules. Radiation in this region is called *ionizing* radiation. Eg. UV radiation, X – Rays, Gamma rays etc.

Visible light, infrared, radio and TV broadcasts are called *non ionizing* radiation.
ELECTROMAGNETIC RADIATION

IONISING RADIATION (potentially harmful or beneficial to humans)

COSMIC  GAMMA  X RAYS  ULTRAVIOLET  VISIBLE LIGHT  INFRARED  MICROWAVES  RADIO

High frequency  THE ENERGY SPECTRUM  Low frequency
Particulate Radiation

- **Protons** - found in nuclei of all atoms; single positive charge
- **Electrons** - exist in atomic orbits; emitted by nuclei of some radioactive atoms (referred to as beta-minus particles (\(\beta^-\)), *negatrons*, or simply “beta particles”)
- **Positrons** - positively charged electrons (\(\beta^+\)); emitted from some nuclei during radioactive decay
- **Neutrons** - uncharged nuclear particle; released by nuclear fission and used for radionuclide production
Mass Energy Equivalence

- Einstein’s theory of relativity states that mass and energy are interchangeable

\[ E = mc^2 \]

where \( E \) represents the energy equivalent to mass \( m \) at rest and \( c \) is the speed of light in a vacuum
# Fundamental Properties of Particulate Radiation

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
<th>Relative Charge</th>
<th>Approx. $E$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>$p$</td>
<td>+1</td>
<td>938</td>
</tr>
<tr>
<td>Electron</td>
<td>$e^-$</td>
<td>-1</td>
<td>0.511</td>
</tr>
<tr>
<td>Positron</td>
<td>$e^+$</td>
<td>+1</td>
<td>0.511</td>
</tr>
<tr>
<td>Neutron</td>
<td>$n$</td>
<td>0</td>
<td>940</td>
</tr>
</tbody>
</table>
INTERACTION OF X-RAY WITH MATTER

TYPES OF INTERACTION

- Coherent scattering
- Photoelectric absorption
- Compton scattering
- Pair production
- Photodisintegration
IMPORTANT IN DIAGNOSTIC RADIOLOGY

- Photoelectric absorption
- Compton scattering
In the Compton effect, the incident X-ray interacts with an outer shell electron and ejects it from the atom, thereby ionizing the atom.
COMPTON SCATTERING

- Probability of Compton interaction decreases with as the X-ray energy increases ($\propto 1/E$)
- Probability of Compton effect does not depend on the atomic number
- It occurs in all energies in tissue, important in X-ray imaging
- Predominant interaction in the diagnostic energy range with soft tissue (100keV-10MeV)
Photon (X-rays) interacts with inner shell electrons and it is totally absorbed.

An electron is removed from the atom, called a photoelectron.
PHOTOELECTRIC EFFECT

• The probability of photoelectric interaction is a function of both x-ray energy and atomic number of the interacting atom

  • Probability of P.E. $\propto \frac{1}{E^3}$

  • The x-ray energy should be equal or greater than the electron binding energy (max probability)

  • Probability of P.E. $\propto Z^3$

• Photoelectric interaction is much more likely to occur with high Z atoms than with low Z
<table>
<thead>
<tr>
<th>Quantity</th>
<th>SI Unit</th>
<th>Non-SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>$C$/kg</td>
<td>Roentgen (R)</td>
</tr>
<tr>
<td>Absorbed dose</td>
<td>gray (J/kg)</td>
<td>rad</td>
</tr>
<tr>
<td>Equivalent dose</td>
<td>sievert</td>
<td>Rem</td>
</tr>
<tr>
<td>Activity</td>
<td>becquerel</td>
<td>curie</td>
</tr>
</tbody>
</table>
BIOLOGICAL EFFECTS OF RADIATION

• Radiation deposits energy in tissues

• randomly and rapidly (<10^-10Sec) via

• excitation, ionization & thermal heating

• Production of moving electrons

• Electrons interaction with atoms & molecules

• Chemical & molecular changes

• Mutation → cell kill or Repair
- **Stoppage of Cell Division**
  - Inhibition of mitosis can be temporary or permanent depending on the severity of the radiation dose and Dose rate.

- **Chromosomal aberration**
  - Breakage in chromosomes - result in some part of the genetic material not being transferred to daughter cell.
  - Biological Indicator
  - Employed for Dosimetry to ascertain the genuineness of radiation exposure.
BIOLOGICAL EFFECTS

- **Gene mutation**
  - Change in structure and characteristics of the gene - genetic effects

- **Cell Death**
  - Death of cell due to changes in the physical properties of vital cell structure

Latent period: minutes - years
LAW OF BERGONE & TRIBONDEAU (1906)

- Radiosensitivity was a function of the **metabolic state** of the tissue being irradiated.
- Stem cells (immature) are radiosensitive; mature cells are radioresistant.
- Younger tissues and organs are radiosensitive.
- Tissues with **high metabolic activity** are radiosensitive.
- Cells with **high proliferation rate & tissues with high growth rate** are radiosensitive.
## Radiosensitivity of Cell

<table>
<thead>
<tr>
<th>Radiosensitivity</th>
<th>Cell Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Lymphocytes, Spermatogonia, Erythroblasts, intestinal cells</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Endothelial cells, Osteoblasts, Fibroblasts</td>
</tr>
<tr>
<td>Low</td>
<td>Muscle cells, Nerve cells</td>
</tr>
</tbody>
</table>
BIOLOGICAL EFFECTS

Indirect Action

Radiation

\[ \text{H}^+ \quad \text{OH}^- \]

Ionization and excitation

\[ \text{H}:, \text{OH}\cdot, \text{HO}_2, \text{H}_2\text{O}_2 \]

Free Radicals and Hydrogen Peroxide

Direct Action

Radiation

DNA

Molecular Damage

Mutation

Biological Response

Genetic

Somatic

Teratogenic

Death

10^{-17} \text{ to } 10^{-5} \text{ seconds}

minutes to decades
BIOLOGICAL EFFECTS

• Direct & Indirect interaction

• Direct Action – The sensitive volume in the cell is changed / inactivated by the direct absorption of energy from radiation.

• Indirect Action – The sensitive volume is inactivated by transfer of energy from another volume which has directly or indirectly absorbed energy from radiation.
  - Water molecule
BIO EFFECTS: WATER

- $H_2O \rightarrow H_2O^+, H_2O^- \text{ ion pairs}$
- $H_2O^+ \rightarrow H^+ + OH^*$
- $H_2O^- \rightarrow H^* + OH^-$
- $OH^* + OH^* = H_2O_2$ (hydrogen peroxide)
- $H^* + O_2 = HO_2^*$ (Hydroperoxyl radical)
BIOLOGICAL EFFECTS

- Somatic Effects
  - Manifest in the individual exposed to radiation

- Genetic Effects
  - Manifest in the future generations of persons exposed to radiation - Hereditary effects
Biological effects may result from

• Acute Exposures - High exposure in short periods

• Chronic exposures - Small exposures over long period
Biological effects may also be classified as

- **Immediate effects** – within a few weeks of exposure
- **Delayed effects** – after a few years

<table>
<thead>
<tr>
<th>Immediate effects (Acute exposure)</th>
<th>Delayed effects (Chronic or acute exposure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromosome aberration</td>
<td>Cancer</td>
</tr>
<tr>
<td>Blood changes</td>
<td>Leukaemia</td>
</tr>
<tr>
<td>Nausea</td>
<td>Cataract</td>
</tr>
<tr>
<td>Vomiting</td>
<td>Hereditary effects</td>
</tr>
<tr>
<td>Diarrhea</td>
<td></td>
</tr>
<tr>
<td>Radiation Sickness</td>
<td></td>
</tr>
<tr>
<td>Epilation</td>
<td></td>
</tr>
<tr>
<td>Skin erythema</td>
<td></td>
</tr>
<tr>
<td>Sterility</td>
<td></td>
</tr>
<tr>
<td>Death</td>
<td></td>
</tr>
</tbody>
</table>
Biologic effects

(i). Deterministic effect

(ii). Stochastic effects
A deterministic effect is one “which increases in severity with increasing absorbed dose in affected individuals”

- Appear at higher doses (>0.5 Gy)
- Cell killing → degenerative changes in the exposed tissues
- Soon after the dose is received
DETERMINISTIC EFFECTS

• Have threshold dose, below which the effect is not seen

• Likely in Radiation accidents and patients irradiated in radiotherapy

• Unlikely in diagnostic Radiology (both procedures and occupation)
DETERMINISTIC EFFECTS

- Skin erythema,
- epilation,
- organ atrophy,
- fibrosis,
- cataract,
- blood changes,
- reduction in sperm count etc.,
A stochastic effect is one in which “the probability of occurrence increases with increasing absorbed dose rather than its severity”

- Important at very low levels: <0.5 Gy
- Have no threshold dose
- Chance of occurrence increases with dose
STOCHASTIC EFFECT

- Seen only at a later period (10-30 years)
- Independent of sex and age
- E.g., carcinogenesis and genetic effects
- Likely in diagnostic radiology & Nuclear medicine (low dose radiation)
RADIATION & PREGNANCY

- Radiation effects before, during and after pregnancy
- Interrupted fertility, congenital effects, Genetic effects
- Pre implantation, major organogenesis, fetus
- First trimester is the most radiosensitive period
- Low dose, chronic irradiation does not impair fertility
RADIATION & PREGNANCY

- In utero: Prenatal death, neonatal death, congenital abnormalities, malignancy induction, impairment of growth, genetic effects, mental retardation
RADIATION & PREGNANCY

• It is unlikely that radiation from diagnostic x-ray examinations will result in any deleterious effects on the child, but possibility of a radiation induced effect cannot be entirely ruled out.

• Continue work in x-ray, as long as fetal dose < 1mGy

• Termination of pregnancy <100mGy is not justified (ICRP-84)
BIOLOGICAL EFFECTS & FACTORS

- Radiation type
- Dose
- Dose rate
- Dose fractionation
- Age
- Nature of exposure: whole/partial
- Cell cycle
- Radio-protectors /sensitizers
SAFETY OBJECTIVE

- Prevent the occurrence of deterministic effects
- Minimize the occurrence of stochastic effects
- Keep exposures as low as reasonably achievable (ALARA)
## ANNUAL FATALITY RATE

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Fatal accident rate/10,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trade</td>
<td>0.5</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.6</td>
</tr>
<tr>
<td>Government</td>
<td>0.9</td>
</tr>
<tr>
<td>Transport</td>
<td>2.7</td>
</tr>
<tr>
<td>Construction</td>
<td>3.9</td>
</tr>
<tr>
<td>Agriculture</td>
<td>4.6</td>
</tr>
<tr>
<td>Mining, Quarrying</td>
<td>6.0</td>
</tr>
<tr>
<td>Radiation</td>
<td>0.3</td>
</tr>
</tbody>
</table>

NCRP-91(1987)
REGULATIONS

- International Commission on Radiological Protection (ICRP)-1928
- DRP / RPAD, BARC-1953
- Atomic Energy Act-1962
- Atomic Energy Regulatory Board (AERB)-1983
- Atomic energy (Radiation Protection) Rules -2004
PRINCIPLES OF RADIOLOGICAL PROTECTION

• The Justification of practice
• The Optimization of Protection
• Dose limits

Ref: Annals of ICRP-103
JUSTIFICATION

• All exposure either diagnostic or therapeutic shall be undertaken if the benefit gained out weighs the detriment.

• No practice shall be adopted unless it produces a net positive benefit.
OPTIMIZATION

• All exposures which are justified shall be undertaken with a minimum possible dose

• Every effort shall be taken to reduce the dose to As Low As Reasonably Achievable (ALARA)
DOSE LIMITS

• The equivalent doses to individuals result in from above practices should be subjected to dose equivalent limits.

• These are aimed at ensuring that no individual is expected to radiation risks that are judged to be unacceptable from these practices in normal circumstances.
## DOSE LIMITS

<table>
<thead>
<tr>
<th>Application</th>
<th>Occupational, mSv/year</th>
<th>Public, mSv/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Dose</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Eye Lens</td>
<td>150</td>
<td>15</td>
</tr>
<tr>
<td>Skin</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>Hands &amp; Feet</td>
<td>500</td>
<td>50</td>
</tr>
</tbody>
</table>
RADIATION EXPOSURE CONTROL

Four principal methods by which radiation exposures to persons can be minimized

- Time
- Distance
- Shielding
- Contamination control
**TIME**

- Total dose received by a radiation worker is directly proportional to the total time spent in handling the radiation source.

- Lesser the time spent near the radiation source, lesser will be the radiation dose.

- As the time spent in the radiation field increases, the radiation dose received also increases.
TIME

- Hence minimize the time spent in any radiation area

- Techniques to minimize time in a radiation field should be recognized or practiced

- Diagnostic x-ray machines typically produce high exposure rates over brief time intervals
DISTANCE

• Radiation intensity decreases with distance, due to divergence of the beam

• It is governed by the inverse square law

• The exposure rate from a point source of radiation is inversely proportional to the square of the distance
DISTANCE

• If the exposure rate is $X_1$ at distance $d_1$, then the exposure rate $X_2$ at another distance $d_2$ is given by
  \[ X_2 = X_1 \left(\frac{d_1}{d_2}\right)^2 \]

• Doubling the distance from the x-ray source decreases the x-ray beam intensity by a factor of 4

• Larger the distance, lesser will be the radiation dose
SHIELDING

• When maximum distance and minimum time do not ensure an acceptably low radiation dose, adequate shielding must be provided, so that radiation beam will be sufficiently attenuated.

• Material that attenuates the radiation exponentially is called a shield.

• Shield will reduce exposure to patients, staff and the public.
SHIELDING

- The reduction in intensity depends upon the nature and thickness of the shield and energy of the radiation
- Thicker the shielding, lesser the radiation
- Lead and concrete are the most commonly used materials for shielding
- Lead aprons, gonad shield, lead gloves and lead bricks are also used as shield
THYROID SHIELD
LEAD GLOVES
RADIATION MONITORING

- Radiation exposure must be monitored for both safety & regulatory purposes

- This assessment need to be made over a period of several months (3 months)

- Personnel Monitoring
- Area monitoring
PERSONNEL MONITORING

Three types of radiation recording devices

- Film badge
- Thermoluminescent dosimeter (TLD)
- Pocket dosimeter
• Monitor & control individual doses regularly in order to ensure compliance with stipulated dose limits

• Report & investigate over exposures & recommend necessary remedial measures urgently

• Maintain life time cumulative dose records of the users of the service
Personnel Monitoring provides

(i) Occupational absorbed dose information
(ii) Assurance that dose limits are not exceeded
(iii) Trends in exposure to serve as check on working practice
THERMOLUMINESCENT DOSIMETER (TLD)

- TLD consists of plastic cassette with nickel coated aluminum card
- The card is provided with three holes
- Each hole is fitted with discs of CaSO₄:Dy in Teflon matrix
- Disc dimension: 0.8 mm thick and 13.5 mm dia.
- Card is enclosed by a paper wrapper
THERMOLUMINESCENT DOSIMETER (TLD)

- When TLD material is exposed to ionizing radiation, fraction of the electrons are raised to exited states and trapped there.
- By heating, these trapped electrons are released.
- Electrons fall to low energy states with emission of light.
- Light emission is proportional to radiation exposure.
THERMOLUMINESCENT DOSIMETER (TLD)

Fig. 10.4. TLD badge and Reader
POCKET DOSIMETER

• Film and TLD will not show accumulated exposure immediately

• Pocket dosimeter gives instantaneous radiation exposure

• Useful in non-routine work, in which radiation levels vary considerably (cardiac cath lab)

• Dose can be read off directly by the person after any radiation work
• The assessment of radiation levels at different locations in the vicinity of radiation installation is known as area monitoring or radiation survey.

• These measurements will give an idea about the radiation status of the installation.
AREA MONITORING

• On the basis of measurements taken, one could confirm the adequacy or inadequacy of the existing radiation protection status

• In case the radiation levels are found to be higher than the permissible levels, suitable remedial measures can be taken

• Instruments used for the above purposes are called area monitors or radiation survey meters
RADIATION SURVEY METRS

- Ionization type survey meter
- Geiger-Muller (GM) type
- Gamma zone monitor
- Contamination monitor
WARNING LIGHT & PLACARD

- A suitable warning signal such as **red light**.
- An appropriate **warning placard** shall also be posted outside the x-ray room.
Thank you...!