# RADIATION QUANTITIES AND UNITS

Bushong, Chapter 1

Carlton / Adler, Chapter 8

Sherer, Chapter 4

## Radiation Quantities

- Objectives:
- Discuss the historical evolution of radiation quantities and units
- List & explain the SI / traditional units for radiation exposure, absorbed dose, equivalent dose, and effective dose
- Determine equivalent dose in SI / traditional units when given the radiation weighting factor & the absorbed dose for different ionizing radiations



## Historical Background

- Historical person:
  - 
- Date:
  - 

## Historical Background

- Experiments with “wonder rays” caused acute biological damage to many of the people investigating these “rays”

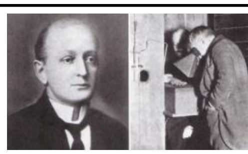


## Historical Background

- 



## Historical Background



- First American radiation fatality
  - 
  - 
  - *In 1910, more physician cancer deaths attributed to x-ray exposure*

<u>Aplastic anemia</u>
• decreased production RBC/WBC/platelets
<u>Leukemia</u>
• over production of white blood cells

## Historical Background

- 1900 to 1930
  - *Units called ________________________*
- 1925: International Commission of Radiation Units and Measurements (ICRU) formed
  - *Accepts the ____________ as the unit of exposure in 1937*



## Historical Background

- 1948 General Conference of Weights and Measures develops the (SI) unit.
- 1980 the ICRU adopts the SI unit.
- 1985 NCRP adopts the SI unit



## Historical Background

- 1900-1930: Skin erythema dose (SED)
- 1930-1950: Tolerance dose (TD)
- 1950-1977: Maximum permissible dose (MPD)
- 1977-1991: Effective dose equivalent
- 1991- present: Effective dose (EfD)

## Historical Background

- Somatic effects:
- Early (Acute)
  - *Nausea*
  - *Fatigue*
  - *Diffuse redness of the skin*
  - *Loss of hair*
  - *Intestinal disorders*
  - *Fever*
  - *Blood disorders*
  - *Shedding*



## Historical Background

- Somatic Effects (cont)
- Late
  -
  -
-



## Overview of Radiation Quantities

**TABLE 4-6 Summary of Radiation Quantities and Units**

| Type of Radiation | Quantity | SI Unit | Measuring Medium | Radiation Effect Measured |
|---|---|---|---|---|
| X-radiation or gamma radiation | Exposure (X)<br>Air kerma | Coulombs per kilogram (C/kg)<br>Gray ($Gy_{-a}$) | Air | Ionization of air |
| All ionizing radiations | Absorbed dose (D)<br>Air kerma | Gray ($Gy_t$)<br>Gray ($Gy_t$) | Any object | Amount of energy per unit mass absorbed by object |
| All ionizing radiations | Equivalent dose (EqD) | Sievert (Sv) | Body tissue | Biologic effects |
| All ionizing radiations | Effective dose (EfD) | Sievert (Sv) | Body tissue | Biologic effects |

## Traditional Nonmetric Units Gradually Becoming Obsolete

- Radiation quantities
  - *Exposure*
  - *Absorbed dose (D)*
  - *Equivalent dose (EqD)*
  - *Effective dose (EfD)*
- Units of measure
  - *R*
  - *Rad*
  - *Rem*
  - *Rem*





## SI Units Presently in Use

- Radiation quantities
  - *Exposure*
  - *Air kerma*
  - *Absorbed dose (D)*
  - *EqD*
  - *EfD*
- Radiation units
  - *Coulombs per kilogram (C/kg)*
  - *Gray (Gy)*
  - *Sievert (Sv)*





## Radiation Quantities

- Exposure:
- Traditional unit
  - 
  - 
- The SI unit for exposure is Coulomb per kilogram (C/kg )

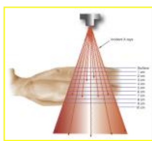
## Radiation Quantities

- Kerma / Air Kerma:
- Kinetic Energy Released per unit MAss
- Air Kerma is the radiation intensity in air
- Would be represented as J/kg
- If absorbed/deposited in air, $Gy_a$
- If absorbed/deposited in tissue, $Gy_t$



## Radiation Quantities

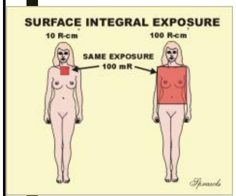
- Absorbed Dose
  - *The amount of energy per unit mass absorbed by the irradiated object*
- Depends on the atomic # of the tissue (Z)
  -
  -
- The ____________________ results in more absorption





## Radiation Quantities

- Surface Integral Dose (SID):
- Total amount of energy absorbed by the body
- Product of exposure value (R or Gy) and the area ($cm^2$ or $m^2$)
- Units of measurement: R-$cm^2$ (traditional) or Gy-$m^2$ (international)
- Dose Area Product (DAP) is also used (Gy-$cm^2$)
  - *Better indicator of risk than dose*
  - *Relates dose to exposure*




Consider the two patients shown here. Both received the same exposure, 100mR. But did they both receive the same amount of radiation? The exposure to the lady on the right was to a much larger area of her body. She received an SIE of 100 R-cm2 compared to only 10 R-cm2 for the lady on the left. Here is a good example of where just knowing the exposure (100 mR), dose not tell the full story. (From Sprawls)



## Radiation Quantities

- Equivalent Dose:
- EqD (equivalent dose) is the product of the average absorbed dose in a tissue or organ and its radiation weighting factor ($W_R$)
- Traditional unit
  - *rem =*



## Radiation Quantities

- Equivalent Dose (cont)
- International unit
  - *Sievert (Sv) = Gy x* $W_R$
  - *1 sievert = 100 rem*
  - *1 rem = 0.01 Sv*

http://www.sprawls.org/resources/RADQU/

## Linear Energy Transfer (LET)

- 
- 
- Alpha and Beta particles are considered ___________
- Gamma and X radiations are ______________



## LET (cont)

- Alpha particles in air travel about 5 cm
  - *Have a great mass and +2 charge*
- Beta particles travel 10 – 100 cm in air
  - *Very light (weight) and negatively (-) charged*



## LET (cont)

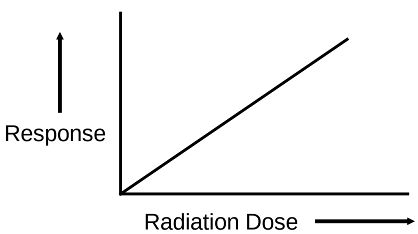
- As LET increases, the ability to produce biologic damage ________________
- With high LET, ionization occurs more frequently and increases the probability of interaction

## Stochastic Effects

- Probability
- Linear
- Non Threshold
- Random
- 



## Linear, Nonthreshold Model






## Radiation Quantities

- Equivalent dose –
  - *Provides a method with which to calculate the effective absorbed dose for all types of radiation.*
- Radiation weighting factor ($W_R$) –
  - 

## Weighting Factors for Different Types of Ionizing Radiation

**TABLE 4-1 Quality Factors for Different Types of Ionizing Radiation**

| Type of Ionizing Radiation | Quality Factor |
|---|---|
| X-ray photons | 1 |
| Beta particles | 1 |
| Gamma photons | 1 |
| Thermal neutrons | 5 |
| Fast neutrons | 20 |
| High-energy external protons | 1 |
| Low-energy internal protons* | 20 |
| Alpha particles | 20 |
| Multiple charged particles of unknown energy | 20 |

## $W_R$ for Different Types and Energies of Ionizing Radiation

**TABLE 4-2 Radiation Weighting Factors for Different Types and Energies of Ionizing Radiation**

| Radiation Type and Energy Range | Radiation Weighting Factor ($W_R$) |
|---|---|
| X-ray and gamma ray photons and electrons (every energy) | 1 |
| Neutrons, energy <10 keV | 5 |
| 10 keV-100 keV | 10 |
| >100 keV-2 MeV | 20 |
| >2 MeV-20 MeV | 10 |
| >20 MeV | 5 |
| Protons | 2 |
| Alpha particles | 20 |

Data adapted from International Commission on Radiological Protection (ICRP): *Recommendations*, ICRP Publication No. 60, New York, 1991, Pergamon Press.





## Radiation Quantities

- Effective Dose:
- The effective dose (EfD) determines the overall harm to biological tissue by incorporating the effect of the type of radiation and the radiosensitivity of the organ or body part.

## Tissue Weighting Factor

- The Tissue Weighting Factor ($W_T$) is a value that denotes the percentage of summed stochastic (cancer plus genetic) risk stemming from irradiation of tissue, assuming that the entire body might be irradiated in a uniform fashion.



## Organ or Tissue Weighting Factors

**TABLE 4-3 Organ or Tissue Weighting Factors**

| Organ or Tissue | Weighting Factor ($W_T$) |
|---|---|
| Gonads | 0.20 |
| Red bone marrow | 0.12 |
| Colon | 0.12 |
| Lung | 0.12 |
| Stomach | 0.12 |
| Bladder | 0.05 |
| Breast | 0.05 |
| Liver | 0.05 |
| Esophagus | 0.05 |
| Thyroid | 0.05 |
| Skin | 0.01 |
| Bone surface | 0.01 |
| Remainder*† | 0.05 |

Data from National Council on Radiation Protection and Measurements (NCRP): *Limitation of exposure to ionizing radiation*, Repor No. 116, Bethesda, Md, 1993, NCRP.

*The remainder takes into account the following additiona tissues and organs: adrenals, brain, small intestine, large intestine kidney, muscle, pancreas, spleen, thymus, and uterus.

†In extraordinary circumstances in which one of the remainde tissues or organs receives an equivalent dose in excess of the highest dose in any of the 12 organs for which a weighting facto ($W_T$) is specified, a $W_T$ of 0.025 should be applied to that tissue or organ and a $W_T$ of 0.025 to the average dose in the othe remainder tissues or organs.



## Radiation Quantities

- Collective Effective Dose:
- The collective effective dose (ColEfD) is a measure of the radiation dose received by an entire population from low doses of different types of ionizing radiation.
  - 
  - 

## SI and Traditional Unit Equivalents

**TABLE 4-5 SI and Traditional Unit Equivalents**

| | |
|---|---|
| 1 SI exposure unit equals | 1. $C/kg = \frac{1}{(2.58 \times 10^{-4})} R$ |
| 1 coulomb equals | 1. 1 ampere-second |
| 1 coulomb per kilogram of air equals | 1. 1 SI unit of exposure<br>2. $\frac{1}{(2.58 \times 10^{-4})} R$ |
| 1 gray equals | 1. 1 J/kg<br>2. 100 rad<br>3. 100 cGy<br>4. 1000 mGy |
| 1 sievert equals | 1. 1 J/kg (for x-radiation, Q = 1)<br>2. 100 rem<br>3. 100 centisievert (cSv)<br>4. 1000 mSv |
| 1 erg equals | 1. $10^{-7}$ J |
| 1 joule equals | 1. $10^{7}$ erg<br>2. 1 newton-meter<br>3. $6.24 \times 10^{18}$ eV |





## RADIATION PROTECTION CONVERSION PROBLEMS

## Conversion of C/kg to R

- The conversion of C/kg to Roentgen is expressed by the relationship
- 1 Roentgen = 2.58 x 10-4 C/kg
- 1 C/kg in air = 3876 Roentgen

## Conversion of rad to Gray (Gy)

- Radiation absorbed dose (rad) in the traditional system can be converted to the international system by the relationship:
- 100 rad =1 Gray (Gy) or;
- 100 rad/Gray (Gy)



## Example

- A patient undergoing radiation therapy receives a total dose of 3000 rads. If the SI system is used, the dose may be recorded as ______ Gy.



## Conversion of rad to Gray (Gy)

## Conversion of Gy to rad

- Assume that an individual received 6.5 Gray of radiation, how may rad is this?



## Conversion of rem to Sievert (Sv)

- Relative energy equivalent in the traditional system can be converted to the international system by the relationship:
- 100 rem =1 Sievert (Sv); or
- 100 rem/Sievert (Sv)



## Example

- A person absorbs 740 rem of radiation. How many Sievert (Sv) is this?

## Conversion of Sv to rem

- A person receives 16.3 Sv. How many rem is this?



## Computing EqD

- Using gray (Gy) and sievert (Sv)
- Example:
  - *An individual received the following absorbed doses: 0.1 Gy of x-radiation, 0.05 Gy of fast neutrons, and 0.2 Gy of alpha particles. What is the total equivalent dose?*



## Computing EqD

- EqD = $(D \times W_R)1 + (D \times W_R)2 + (D \times W_R)3$

| Radiation | D | x | $W_R$ | = EqD |
|---|---|---|---|---|
| X-radiation | 0.1 Gy | x | 1 | = 0.1 Sv |
| Fast neutr. | 0.05 Gy | x | 20 | = 1.0 Sv |
| Alpha | 0.2 Gy | x | 20 | = 4.0 Sv |
| | Total EqD | | | = 5.1 Sv |

## Computing EqD

- Using rad and rem
- Example:
  - *An individual received the following absorbed doses: 12 rads of x-radiation, 7 rads of fast neutrons, and 15 rads of alpha particles. What is the total equivalent dose?*



## Computing EqD

- EqD = $(D \times W_R)1 + (D \times W_R)2 + (D \times W_R)3$
- Radiation D x $W_R$ = EqD



## Computing EfD

- EfD = $D \times W_R \times W_T$
- D = tissue dose
- $W_R$ = Radiation Weighting Factor
- $W_T$ = Tissue weighting factor
- $E = \Sigma \, Di \, W_T$
- E = effective dose; Σ Di = avg. dose to organs; $W_T$ = Tissue weighting factor

## Computing EfD

- A female patient receives 0.05 Gy of x-radiation to her ovaries. What is the effective dose?
- EfD = D x $W_R$ x $W_T$
- EfD =
- EfD =
- EfD =



## Computing EfD

- A male patient receives prostatic radiation implants. The implants are using alpha particles and the patient receives 0.15 Gy to the gonads. What is the effective dose?
- EfD =
- EfD =
- EfD =



## Computing ColEfD

- ColEfD = Average EfD x # of people
- Compute EfD for each individual
- Compute the average for the group
- Multiply the average by the number of persons exposed

## Computing ColEfD

- Example:
- If 200 people receive an average effective dose of 0.25 Sv (25 rem), the collective effective dose is?
-