Chapter 7

External and Internal Dosimetry
Objectives

- Discuss factors influencing external and internal doses
- Define terms used in external dosimetry
- Discuss external dosimeters such as TLDs, film badges, OSL dosimeters, pocket chambers, and electronic dosimetry
Objectives

- Define terms used in internal dosimetry
- Discuss dose units and limits
- Define the ALI, DAC and DAC-hr
- Discuss radiation signs and postings
Objectives

- Discuss types of bioassays
- Describe internal dose measuring equipment and facilities
- Discuss principles of internal dose calculation and work sample problems
External Dosimetry
Gamma, beta or neutron radiation emitted by radioactive material outside the body irradiates the skin, lens of the eye, extremities & the whole body (i.e. internal organs).
External Dosimetry (cont.)

- Alpha particles cannot penetrate the dead layer of skin (0.007 cm)
- Beta particles are primarily a skin hazard. However, energetic betas can penetrate the lens of an eye (0.3 cm) and deeper tissue (1 cm)
- Beta sources can produce more penetrating radiation through bremsstrahlung
- Primary sources of external exposure are photons and neutrons
- External dose must be measured by means of appropriate dosimeters
Whole Body -
everything except extremities

Skin of the Whole Body -
skin covering everything except extremities

Skin of the Extremities -
skin covering extremities

Extremities -
Elbows, and arms below elbows
knees, and legs below knees
The dose to the lens of the eye is measured at a depth of 0.3 cm.

The shallow (skin) dose is measured at a depth of 0.007 cm.

The deep (whole body) dose is measured at a depth of 1 cm.
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDE</td>
<td>Deep Dose Equivalent, or</td>
</tr>
<tr>
<td>EDE</td>
<td>Effective Dose Equivalent (for external sources)</td>
</tr>
<tr>
<td></td>
<td>“Whole Body Dose”</td>
</tr>
<tr>
<td>LDE</td>
<td>Lens Dose Equivalent</td>
</tr>
<tr>
<td></td>
<td>“Eye Dose”</td>
</tr>
<tr>
<td>SDE\textsubscript{ME}</td>
<td>Shallow Dose Equivalent to the Maximum Extremity</td>
</tr>
<tr>
<td></td>
<td>“Extremity Skin Dose”</td>
</tr>
<tr>
<td>SDE\textsubscript{WB}</td>
<td>Shallow Dose Equivalent to the Whole Body</td>
</tr>
<tr>
<td></td>
<td>“Skin Dose”</td>
</tr>
</tbody>
</table>
Effective Dose Equivalent (EDE)

- The whole body is not always exposed to uniform external radiation fields.
- A method to determine Effective Dose Equivalent (EDE) for external sources that are non-uniform is by wearing dosimeters on the front and back of the body (EPRI Method).

Dosimeter results are weighted as follows:

\[
EDE = \frac{3}{4} \text{Hi} + \frac{1}{4} \text{Lo}
\]

RG 8.40 also allows EDE to be used for medical personnel wearing protective aprons during radiology procedures.

Some NRC Agreement States have approved use of EDE in calculating external dose to hospital staff during medical x-ray fluoroscopy procedures.

In one approach, for example, the EDE = 0.04C + 1.5W, where C is the unshielded collar dosimeter reading and W is the shielded waist dosimeter reading (under the protective lead apron).
Dosimeter Locations

♥ Torso (belt or breast pocket) - measures whole body dose (DDE) (covers most important organs) and skin dose (DDE & SDE$_{WB}$) Note: Front and Back dosimeters can be worn to determine EDE for non-uniform rad. fields.

♠ Collar - measures lens of eye (LDE) also thyroid and head which are part of whole body (DDE & SDE$_{WB}$) - usually used when lead apron worn

♦ Wrist - measures extremity skin dose (SDE$_{ME}$) assuming fairly uniform dose pattern over hand and lower arm

♣ Finger - measures extremity (SDE$_{ME}$) assuming most dose to the hand and fingers - if dose originates in palm (e.g. from holding a source), the dosimeter should be worn on the inside of the finger (opposite to how a ring is normally worn)
Thermoluminescent Dosimeters (TLDs)

- Common TLD materials are LiF, CaF (near air/tissue equivalent – energy independent from 10 – 10k keV)
- Irradiated TLD material’s electrons are raised and trapped at a higher energy state (band theory of solids)
- Emission of light (300-600 nm) when crystalline material is heated by reader
- Total light output (intensity) is proportional to the absorbed dose
- Glow curve provides permanent record
- TLD has wide, linear dose-response range (10 mrad to 1000 rad)
- TLD is accurate (some fading), small and rugged
- With Li-6 or B-10, they may provide neutron dose
- Can provide: SDE, LDE, and DDE
“Finger Ring” TLDs

- LiF chip

- Dose Range:
  - Photon (>15keV): 30 – 1000 mrem
  - Beta (>200 keV): 40 – 1000 mrem
Film Dosimeters

- Similar to x-ray film (silver bromide)
- Film is darkened by radiation (metallic silver)
- Dose is determined by measuring the optical density of the film
- Film response depends on type, energy and amount of incident radiation
- Permanent record
- Not useful for low-energy beta emitters such as H-3 or C-14
Optically Stimulated Luminescence Dosimeters (OSLs)

Filter Pack

Al₂O₃

Imaging Filter

Static Exposure

Dynamic Exposure

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Optically Stimulated Luminescence Dosimeters (OSLs)

- OSLs (aluminum oxide) store energy much like TLDs, but use green light from a laser or LED to de-excite the electrons to determine the absorbed dose.
- The amount of blue light created is proportional to the dose received.
- OSLs can be read multiple times.
- Dose measurement range:
  - photon (5 keV – 40 MeV): 1 mrem – 1000 mrem
  - beta (150 keV – 10 MeV): 10 mrem – 1000 mrem
- To measure neutron dose, an optional detector, CR-39 (solid-state track detector), must be used.
Pocket Dosimeters

- Small gas-filled cylinders used to measure X and gamma radiation
- Primary advantage is that they provide real-time radiation dose information to workers
- Typical dosimeters range from 0-200 mR, 0-500 mR, 0-5 R, and 0-50 R
- Should normally not be used as dose of record and should always be used with TLD or film badge
For personnel working in radiation areas, Direct Reading Dosimeters provide an accurate and instantaneous indication of accumulated exposure.

Accurate to 10% of True Dose. Less than 2% leakage/24 hours. Hermetically sealed.

Resembling fountain pens in size and appearance, they contain a quartz fiber electrometer and compound microscope.

The fiber is set at zero with a battery operated charger. As X- or gamma rays strike the charged Dosimeter, the fiber moves up scale in proportion to the radiation exposure.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Price</th>
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<tbody>
<tr>
<td>019-200</td>
<td>200 mR Dosimeter</td>
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</tr>
<tr>
<td>019-500</td>
<td>500 mR Dosimeter</td>
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</tr>
<tr>
<td>019-100</td>
<td>1 R Dosimeter</td>
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<td>019-611</td>
<td>5 R Dosimeter</td>
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<td>019-110</td>
<td>10 R Dosimeter</td>
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<tr>
<td>019-001</td>
<td>100 R Dosimeter</td>
<td>$135.00</td>
</tr>
<tr>
<td>019-002</td>
<td>200 R Dosimeter</td>
<td>$135.00</td>
</tr>
<tr>
<td>019-006</td>
<td>600 R Dosimeter</td>
<td>$135.00</td>
</tr>
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</table>

Figure 8-2. Direct Reading Pocket Dosimeter
Electronic Dosimeters

- Electronic dosimeters have replaced pocket chambers at commercial nuclear facilities.
- Based on solid state diode detector.
- More rugged than pocket chambers and can be set to alarm.
- Measure gamma dose from 0.1 mrem to 1000 rem.
- Some models also measure neutron radiation.
Internal Dosimetry
Internal Dosimetry Program

- An internal dosimetry program is part of an overall radiation protection program at a site.
- Air sampling and bioassay programs are utilized to control internal dose to workers.
- Effectiveness of engineering and administrative controls are evaluated by the program.
Internal dosimetry is an art based on science

Dosimetrists must quantify the amount of radioactive material within the body

Radionuclides distribute differently in the body (e.g. iodine seeks the thyroid, while strontium seeks the bone)
Internal Dosimetry

- Internal dose is defined as dose from radiation released by radioactive materials deposited inside the body.

- Radioactive materials enter the body through:
  - Inhalation
  - Ingestion
  - Absorption (through skin or wounds)

Inhalation
- ALI (Annual Limit on Intake)
- DAC (Derived Air Concentration)

Ingestion
- ALI (Annual Limit on Intake)
Internal Radiation Dose

Alpha, beta or gamma radiation emitted by radioactive material inside the body exposing any internal organ such as:

- Thyroid
- Bone
- Lung
- GI System
In 1977, ICRP-26 recommended tissue weighting factors for the various tissues and organs of the human body based upon their susceptibility to radiation damage (stochastic, deterministic or hereditary effects).

The tissue or organ dose from an intake is related to uniform whole body irradiation by use of the tissue weighting factors.
Internal Dose Terms

CDE  Committed Dose Equivalent

CEDE  Committed Effective Dose Equivalent
Committed Dose Equivalent (CDE)

The dose from internal sources can be accrued over many years. The dose delivered decreases as time passes due to the radioactive decay and biological elimination.
Committed Dose Equivalent (CDE)

- The radiation dose delivered to a worker’s organ(s) over 50 years after the initial intake

- It is administratively convenient to assign the dose (CDE and CEDE) in the year of intake
CEDE is related to CDE in the following way:

$$CEDE = \sum w_T \times CDE_T$$

\(w_T\) is the tissue weighting factor that relates the risk to the organ \((T)\) to an equivalent whole body risk.

To obtain the effective whole body dose \((CEDE)\) we must sum the doses to all of the different organs.
### Risk-Based Tissue Weighting Factors

**ICRP-26 / 10CFR20 Values**

<table>
<thead>
<tr>
<th>Tissue or Organ</th>
<th>Risk Weighting Factor</th>
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</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>0.25</td>
</tr>
<tr>
<td>Breast</td>
<td>0.15</td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
</tr>
<tr>
<td>Red Bone Marrow</td>
<td>0.12</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.03</td>
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<tr>
<td>Bone Surfaces</td>
<td>0.03</td>
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<tr>
<td>Remainder</td>
<td>0.30</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1.00</strong></td>
</tr>
</tbody>
</table>
CEDE Calculation

Example:

After an accidental intake of radioactive material, the CDE to the worker’s thyroid is determined to be 1000 mrem. Calculate the worker’s CEDE.

\[ \text{CEDE} = \sum w_T \times \text{CDE}_T \]

\[ \text{CEDE} = 0.03 \times 1 \text{ rem} = 0.03 \text{ rem or 30 mrem} \]

(Dose of 1 rem to thyroid has same risk as a dose of 30 mrem to whole body)
Dose Limits
Occupational Dose - 10CFR20.1003

**Occupational dose** means the dose received by an individual in the course of employment in which the individual’s assigned duties involve exposure to radiation or to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person. Occupational dose does not include doses received from background radiation, from any medical administration the individual has received, from exposure to individuals administered radioactive material and released under § 35.75, from voluntary participation in medical research programs, or as a member of the public.
<table>
<thead>
<tr>
<th>Dose Term</th>
<th>Annual Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDE</td>
<td>15 rem</td>
</tr>
<tr>
<td>SDE&lt;sub&gt;ME&lt;/sub&gt;</td>
<td>50 rem</td>
</tr>
<tr>
<td>SDE&lt;sub&gt;WB&lt;/sub&gt;</td>
<td>50 rem</td>
</tr>
<tr>
<td>DDE + CDE = TODE</td>
<td>50 rem</td>
</tr>
<tr>
<td>EDE + CEDE = TEDE</td>
<td>5 rem</td>
</tr>
<tr>
<td>Minor</td>
<td>10% of adult limits</td>
</tr>
<tr>
<td>Dose to E/F of DPW</td>
<td>0.5 rem</td>
</tr>
<tr>
<td>Public TEDE</td>
<td>0.1 rem = 100 mrem</td>
</tr>
</tbody>
</table>

**Occupational**

- **Minor** 10% of adult limits
- **Pregnancy**

**Public TEDE**

- **0.1 rem**

**Slides**: Slide 37
Secondary and Derived Limits
Annual Limit on Intake, ALI

- The amount (e.g. \( \mu \text{Ci} \)) of radioactive material taken into the body that would result in a CEDE of 5 rem or a CDE of 50 rem

Derived Air Concentration, DAC

- The concentration (e.g. \( \mu \text{Ci} / \text{mL} \)) of a given radionuclide in air which, if breathed by reference man for a working year, results in an intake of one ALI
10 CFR Part 20
Appendix B
Annual Limit on Intake (ALI)

- Derived for each radionuclide and selected chemical forms

- Two types of ALIs - stochastic and non-stochastic (deterministic)
  - Stochastic ALI = CEDE of 5 rem/year (whole body)
  - Deterministic ALI = CDE of 50 rem/year (organ)
Derived Air Concentration (DAC)

\[
DAC = \frac{(ALI \ \mu\text{Ci/y})}{(2000 \ \text{hr/y} \times 1.2 \times 10^6 \ \text{mL/hr})}
\]

Where:

- DAC = $\mu\text{Ci/mL}$
- 2000 hrs = occupational year (40 hrs/wk x 50 wk/y)
- 1.2 x 10^6 mL/hr = breathing rate for Reference Man
DAC-hours

- Breathing air at a concentration of 1 DAC for 1 hour results in an exposure of 1 DAC-hr

- For DACs derived from stochastic ALIs:
  
  2000 DAC-hrs = 5 rem CEDE  
  1 DAC-hr = 2.5 mrem CEDE

- For DACs derived from deterministic ALIs:
  
  2000 DAC-hrs = 50 rem CDE  
  1 DAC-hr = 25 mrem CDE
Dose Calculation Using 10CFR20 ALIs

CDE = \((\text{Intake} / \text{ALI}) \times 50\) rem

CEDE = \((\text{Intake} / \text{ALI}) \times 5\) rem

Where the intake is in units \(\mu\text{Ci}\)
Problem

A worker inhales 25 μCi of Iodine-131.

Calculate CDE to the thyroid and the CEDE.

Given:

Iodine-131 deterministic ALI for thyroid = 50 μCi
Iodine-131 stochastic ALI = 200 μCi
Solution

\[
CDE = \left( \frac{25 \ \mu\text{Ci}}{50 \ \mu\text{Ci}} \right) \times 50 \ \text{rem} = 25 \ \text{rem to thyroid}
\]

\[
CEDE = \left( \frac{25 \ \mu\text{Ci}}{200 \ \mu\text{Ci}} \right) \times 5 \ \text{rem} = 0.625 \ \text{rem}
\]
Bioassay
The purpose of bioassay measurements are to:

- confirm the adequacy of radiological controls
- determine compliance with the occupational dose limits
Bioassay

Two types of bioassay:

- **In-vitro bioassay** (measures radioactivity in urine, feces, blood, tissue, etc.)

- **In-vivo bioassay** (measures radiation emitted from the body, using an external detector)
In-vitro Bioassay
Cytogenetic Biodosimetry

http://www.orau.org/media-center/videos/programs/cyto-lab-orau.htm?keepThis=true&TB_iframe=true&height=450&width=645

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See Handout
In-vivo Bioassay

Most common in-vivo bioassay methods are:

- whole-body counting
- thyroid counting (specifically for iodine)
- lung counting
Frequency of Bioassays

- Baseline, at initial hire
- When it is suspected that an intake occurred (e.g., presence of contamination in nasal swabs)
- At some established frequency or at discretion of health physics staff (e.g., random bioassays)
- At termination of employment
Whole-Body Counting

- Best method for detecting photon emitters if neither the radionuclide nor its location in the body is known

- Geometric configurations include chair, linear, fixed, and scanning whole-body counters

- Possible to detect pure beta emitters (e.g. P-32) by measuring bremsstrahlung
Individual Organ Counting

- Designed for those radionuclides that tend to concentrate in a particular body organ:
  - Iodine in thyroid gland
  - Insoluble radionuclides that concentrate in lungs or intestines, liver or kidney, brain or bone

- Geometry is optimized for a particular part of the body for a particular radionuclide
Wound Monitoring

- Direct bioassay method if the skin has been penetrated by contamination

- As with organ counters, wound counting generally results in optimum geometry

- Quantification of the radionuclide is difficult since the geometry of the wound may not be well known and the distribution of the contamination may not be readily determined
Measurement Equipment

Typical NaI whole-body counter

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Lung Counting

- Specialized form of organ counting
- Heavy metals such as Am, Cm, U and Pu are often alpha and beta emitters that also emit low yield gammas or X-rays
- Photon attenuation in chest wall must be accounted for
Chair counters usually have a thyroid detector and one or more detectors to view either the GI tract, or the torso.

Chair counters are designed to exclude from view parts of the body with high potential for contamination, e.g., hands, hair, and knees.

Designed to maximize detection efficiency for certain parts of the body.
1) Collect bioassay samples

2) From bioassay results, estimate intake

3) Then calculate dose (CDE and CEDE) using either:
   - 10 CFR Part 20 Appendix B
   - EPA Federal Guidance Report #11
   - ICRP 30
Airborne Monitoring
Airborne Monitoring

Surveys for airborne radioactive material are conducted to:

- evaluate the adequacy of engineering controls
- assign appropriate protective measures for personnel
- assess the dose to personnel
Airborne Monitoring

Airborne surveys may be for particulate material or for radioactive gases.

- Particulate material is assessed by sampling air through a filter media, such as filter paper
- Airborne radioactive iodine is sampled using charcoal or silver zeolite filters
- Volumetric gas samples are collected for radioactive gases such as Ar-41, Xe-133, Kr-85
Dose Determination from Air Sampling

- Air sample determines air concentration (e.g. Bq/m\(^3\))

- Multiply the air concentration times the volume of air inhaled to determine the activity inhaled (e.g. Bq)

- Then apply a dose conversion factor for the radionuclide(s) involved (Sv/Bq).

- Dose = (Concentration) (Time) (Breathing rate) (Dose Conversion Factor) (Conversion Factors)
Signs and Postings
Signs and Posting

- **Radiation Area**
  > 5 mrem/hr @ 30 cm

- **High Radiation Area**
  > 100 mrem/hr @ 30 cm

- **Very High Radiation Area**
  > 500 rad/hr @ 1 meter

- **Airborne Radioactivity Area**
  > 1 DAC or 0.6% ALI =
  12 DAC-hours in a week

\[ 0.006 \times 2000 \text{ DAC-hrs} = 12 \text{ DAC-hrs} \]
QUESTIONS?

END OF PERSONNEL DOSIMETRY AND DOSE ASSESSMENT
## Dose Units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Traditional Unit</th>
<th>SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>absorbed dose</td>
<td>rad</td>
<td>gray (Gy)</td>
</tr>
<tr>
<td>dose equivalent activity</td>
<td>rem</td>
<td>sievert (Sv)</td>
</tr>
<tr>
<td></td>
<td>curie (Ci)</td>
<td>becquerel (Bq)</td>
</tr>
</tbody>
</table>

### Conversions

- 100 rad = 1 Gy
- 100 rem = 1 Sv
- 1 Ci = $3.7 \times 10^{10}$ Bq
Internal Dose Calculation Principles

- Stochastic weighting factors from ICRP 26 & 30 (1977) are used to calculate committed effective dose equivalent

- The Table on the next slide lists the ICRP weighting factors for various tissues/organs of concern
<table>
<thead>
<tr>
<th>Tissue</th>
<th>Effect</th>
<th>Stochastic Risk Coefficient (rem⁻¹)</th>
<th>ICRP 26 Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>Hereditary</td>
<td>4.0 x 10⁻⁵</td>
<td>0.25</td>
</tr>
<tr>
<td>Breast</td>
<td>Cancer</td>
<td>2.5 x 10⁻⁵</td>
<td>0.15</td>
</tr>
<tr>
<td>Red Bone Marrow</td>
<td>Leukemia</td>
<td>2.0 x 10⁻⁵</td>
<td>0.12</td>
</tr>
<tr>
<td>Lung</td>
<td>Cancer</td>
<td>2.0 x 10⁻⁵</td>
<td>0.12</td>
</tr>
<tr>
<td>Thyroid</td>
<td>Cancer</td>
<td>5.0 x 10⁻⁶</td>
<td>0.03</td>
</tr>
<tr>
<td>Bone Surface</td>
<td>Cancer</td>
<td>5.0 x 10⁻⁶</td>
<td>0.03</td>
</tr>
<tr>
<td>Remainder</td>
<td>Cancer</td>
<td>5.0 x 10⁻⁵</td>
<td>0.3</td>
</tr>
<tr>
<td>Total</td>
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<td>1.65 x 10⁻⁴*</td>
<td>1.0</td>
</tr>
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</table>

* The new value is 4 x 10⁻⁴
CEDE = \sum CDE_T \times w_T

- where CDE = 50 year integrated committed dose equivalent to each organ or tissue, T

- \( w_T \) = weighting factor for the corresponding organ or tissue
Inhalation

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Class/f_1</th>
<th>Gonad</th>
<th>Breast</th>
<th>Lung</th>
<th>R Marrow</th>
<th>B Surface</th>
<th>Thyroid</th>
<th>Remainder</th>
<th>Effective</th>
</tr>
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<tbody>
<tr>
<td>I-120</td>
<td>D 1.0</td>
<td>1.07 10^{-11}</td>
<td>1.28 10^{-11}</td>
<td>4.33 10^{-10}</td>
<td>1.28 10^{-11}</td>
<td>1.17 10^{-11}</td>
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\[ CEDE = \sum (CDE_T \times w_T) = (2.53E-11 \times 0.25) + (7.88E-11 \times 0.15) + (6.57E-10 \times 0.12) + (6.26E-11 \times 0.12) + (5.73E-11 \times 0.03) + (2.92E-7 \times 0.03) + (8.03E-11 \times 0.06) \times 5 = \]
CEDE = $\Sigma CDE_T \cdot w_T =$

\[
(2.53E-11 \cdot 0.25) + (7.88E-11 \cdot 0.15) + (6.57E-10 \cdot 0.12) + (6.26E-11 \cdot 0.12) +
(5.73E-11 \cdot 0.03) + (2.92E-7 \cdot 0.03) + (8.03E-11 \cdot 0.06) \times 5 =
\]

\[
6.325E-12 + 1.182E-11 + 7.884E-11 + 7.512E-12 + 1.719E-12 + 8.76E-9
+ 4.818E-12 \times 5 =
\]

\[
6.325E-12 + 1.182E-11 + 7.884E-11 + 7.512E-12 + 1.719E-12 + 8.76E-9
+ 2.409E-11 = 8.89E-9 \text{ Sv/Bq}
\]

\[
8.89E-9 \text{ Sv/Bq} \times 100 \text{ rem/Sv} \times 1000 \text{ mrem/rem} \times 3.7E4 \text{ Bq/\text{\textmu Ci}} = 32.893 \text{ mrem/\textmu Ci}
\]
Review Questions

- List three factors influencing external radiation dose
- List three types of radiation that can be an external source of dose
- What type of radiation is usually associated with dose to the skin and lens of eye?
What type of ionizing radiation cannot penetrate the dead skin layer and thus is not an external hazard?

Define the terms “Skin”, “Extremities”, and “Whole Body”

Define the terms DDE, LDE, $SDE_{ME}$, and $SDE_{WB}$
Review Questions

- At what depth in human tissue is the DDE measured? The LDE? The SDE?

- State two common TLD materials

- Is film dosimetry useful for low energy beta emitters such as H-3 or C-14?
Review Questions

- Explain how dose is determined with OSL dosimeters.
- What is one primary advantage of pocket dosimeters?
- Should pocket dosimeters be used as the dose of record?
- State two advantages of electronic dosimeters over pocket chambers
Review Questions

- List three pathways by which radioactive materials can enter the body

- List three types of ionizing radiation that can produce an internal dose

- What is the weighting factor for the lung?
Review Questions

- What is the weighting factor for the thyroid?
- Define the terms CDE, CEDE, TEDE, and TODE
- What is the special unit for absorbed dose? The SI unit?
- What is the special unit for dose equivalent? The SI unit?
Review Questions

- What is the special unit for activity? The SI unit?
- One Gy equals _________ rad
- One Sv equals ______________ rem
- One Ci equals _____________ Bq
Review Questions

- What is the occupational dose limit for DDE?
- What is the occupational dose limit for CDE?
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- What is the occupational dose limit for TODE?
Review Questions

- What is the occupational dose limit for a minor?
- What is the dose limit for an embryo/fetus of a DPW?
- What is the TEDE limit to a MOP?
- What is the $SDE_{ME}$ dose limit?
Review Questions

- What is the SDE\textsubscript{WB} dose limit?
- Are weighting factors used to calculate CDE?
- What is the mathematical relationship between CDE and CEDE?
- Define the terms ALI and DAC. What is their relationship?
Review Questions

- One ALI equals _____________ DAC-hrs
- For DACs derived from stochastic ALIs, one DAC-hr equals ____________ mrem CEDE
- For DACs derived from deterministic (i.e. non-stochastic) ALIs, one DAC-hr equals ____________ mrem CDE
Review Questions

- 1 sALI equals ________________ rem CEDE

- 1 nALI equals ________________ rem CDE to the maximum exposed organ

- What posting is required in an area where the dose rate is 65 mrem/hr at 30 cm from the source?

- What posting is required in an area where the dose rate is 120 mrem/hr at 30 cm from the source?
Review Questions

- Define Very High Radiation Area
- What posting is required in an area where a worker would receive 20 DAC-hrs per week?
- What two primary programs should be in place to control internal dose to workers?
- Radioiodine primarily seeks this organ?
Review Questions

- Sr-90 primarily seeks this organ?

- Determination of internal dose is dependent on what three concepts?

- __________ and __________ were derived to limit intakes of radioactive material to ensure that workers do not exceed NRC dose limits
Review Questions

- The most common way for workers to intake radioactive materials is through ____________?

- List three NRC-endorsed methods that licensees can use to calculate internal dose

- State the ICRP 60 cancer mortality risk coefficients for workers and the public, respectively
Review Questions

- State the two principal types of bioassays
- Whole body counting is what type of bioassay method?
- Can external contamination on the body affect a whole body counting result?
- Why is it a good idea for a licensee to conduct baseline whole body counting on a new employee?
How can a pure beta emitter (e.g. P-32) be detected in the body using whole body counting?

One useful direct bioassay method if the skin has been penetrated by contamination is ________________

List two principal types of detectors for whole body counting

When is individual organ counting beneficial?
Review Questions

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