ICRP Internal Dosimetry Models
Learning Objectives

• Identify the three types of models used in internal dosimetry
• Describe the structure and use of inhalation models
• Identify the differences between the ICRP-2, ICRP-30 and ICRP-66 models
• Explain methods of adjusting model parameters
Dose Calculations

• We never (well, hardly ever) measure internal doses directly.

• Internal dose calculations are based on three types of models:
  – Intake models (inhalation, ingestion, wounds)
  – Systemic biokinetic models (element-specific)
  – Dosimetry models (dose absorbed in a target organ per disintegration in a source organ)
What Intake Models Do

• Describe the entry of radioactive materials into the human body via inhalation, ingestion or contaminated wounds.

• Describe the fraction of the intake that remains at the intake site (“initial deposition”)

• Describe what happens to the initial deposition: how long it is retained at the intake site, and where it goes
What Systemic Biokinetic Models Do

- Describe what happens to radionuclides upon uptake, when they enter the so-called “transfer compartment,” i.e., the blood stream and extracellular fluid such as lymph
- Which organs they deposit in, what fraction of the uptake deposits in each
- How long they are retained in each
- These models are element-specific, not radionuclide-specific, so retention must be modified by the physical half-life of the radionuclide
What Dosimetry Models Do

• Calculate the absorbed dose in each organ per decay of the radionuclide
• The organ containing the radionuclide is the “source organ”
• The organ for which the dose is calculated is the “target organ”
• The source organ is always its own target organ
ICRP Intake Models

- ICRP-2 Respiratory Tract Model (1959)
- ICRP-30 Task Group Lung Model (1979)
- ICRP-26 Gastrointestinal Tract Model (1977)
- ICRP-100 Human Alimentary Tract Model (2006)
- NCRP-156 Wound Model (2006)
Intake Models for Inhalation
STRUCTURE OF ICRP DEPOSITION MODELS

1959

\[ D_{\text{URT}} \]

URT

\[ D_{\text{LRT}} \]

LRT

1979

\[ D_{\text{N-P}} \]

N-P

\[ D_{\text{T-B}} \]

T-B

\[ D_{\text{P}} \]

P

1993

\[ D_{\text{ET}_1} \]

ET\(_1\)

\[ D_{\text{ET}_2} \]

ET\(_2\)

\[ D_{\text{BB}} \]

BB

\[ D_{\text{bb}} \]

bb

\[ D_{\text{Al}} \]

Al
ICRP-2 Respiratory Tract Model

• The respiratory tract is divided into the Upper RT and the Lower RT (lung)
• 25% of the intake is exhaled
• 50% is deposited in the URT and eventually swallowed and cleared through the GI tract
• 25% is deposited in the LRT
  – For “soluble compounds” that 25% is absorbed into the transfer compartment
  – For “insoluble compounds” half (12.5%) is cleared through the GI tract, and the other half stays in the lung with a biological half-life of 120 days and absorbed into the transfer compartment
Uptake Problem

• According to the ICRP-2 model, what fraction of the intake is absorbed into body fluids from the lung, vs. being cleared through the GI tract for soluble and insoluble compounds?

• Answers:
  – Soluble: 25% absorbed, 50% to GI tract
  – Insoluble: 12.5% absorbed, 62.5% to GI tract

• Note: an additional fraction of what enters the GI tract is absorbed into body fluids—more on that later
Task Group Lung Model  
(ICRP 30, 1979)

- Respiratory tract is divided into three regions and one sub-region:
  - Nasal Passage (N-P)
  - Trachea and Bronchi (T-B)
  - Pulmonary Parenchyma (P)
    - Pulmonary Lymphatics (L)
- Dose to N-P region is neglected
- The “lung” consists of the T-B, P and L regions with a total mass of 1000 g
### Lung Clearance Model

#### Region
- **N-P**  
  
  **Compartment**  
  **Class**  
<table>
<thead>
<tr>
<th>D</th>
<th>W</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>a</td>
<td>0.01</td>
<td>0.5</td>
</tr>
<tr>
<td>b</td>
<td>0.01</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- **T-B**  
  
  **Compartment**  
  **Class**  
<table>
<thead>
<tr>
<th>D</th>
<th>W</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>c</td>
<td>0.01</td>
<td>0.95</td>
</tr>
<tr>
<td>d</td>
<td>0.2</td>
<td>0.05</td>
</tr>
</tbody>
</table>

- **P**  
  
  **Compartment**  
  **Class**  
<table>
<thead>
<tr>
<th>D</th>
<th>W</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>e</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>f</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>g</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>h</td>
<td>0.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>

- **L**  
  
  **Compartment**  
  **Class**  
<table>
<thead>
<tr>
<th>D</th>
<th>W</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>i</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>j</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

- **Body Fluids**
  
  **Compartment**  
<table>
<thead>
<tr>
<th>D</th>
<th>W</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>D_{N-P}</td>
<td>D_{T-B}</td>
<td>D_{P}</td>
</tr>
</tbody>
</table>

- **G-I Tract**
Task Group Lung Model (con’t)

• Each region has two or four compartments, which represent specific clearance or transfer pathways
• Particle deposition is each region is a function of particle size
• Particle size is given in terms of Activity Median Aerodynamic Diameter (AMAD)
• AMAD is the diameter of a unit-density sphere that has the same deposition velocity in air as the particle in question
• The default value for particle size is 1.0 micron (µm)
• The model covers particles sizes from 0.1 to 20 µm
Task Group Lung Model (con’t)

• Particle retention in the respiratory tract is a function of particle solubility, which in turn is a function of the chemical form of the radionuclides

• Particles are assigned to one of three solubility classes based on retention time in pulmonary region:
  – Days (D): <10 d, mean 5 d
  – Weeks (W): 10-100 d, mean 50 d
  – Years (Y): > 100 d, mean 500 d
  – Note: there is also a “Super Y” category, 5,000 d
Task Group Lung Model (cont)

• Intake:
  – Initial deposition in each of 3 regions
  – Exhalation of remainder

• Uptake:
  – Compartments a, c, e, and i clear to body fluids (transfer compartment)
  – Compartments b, d, f, & g clear to GI tract, then to body fluids from small intestine

• Deposition:
  – Uptake is deposited in organs per systemic biokinetic model for the element
  – Compartment j represents retention in pulmonary lymph nodes
TGLM Compartments

• a: N-P region absorbed to body fluids
• b: N-P region swallowed to GI tract
• c: T-B region absorbed to body fluids
• d: T-B region swallowed to GI tract
• e: P region absorbed to body fluids
• f: P region rapidly cleared to compartment d
• g: P region slowly cleared to compartment d
• h: P region cleared to lymph nodes
• i: L region absorbed to body fluids
• j: L region that does not clear (retained in lymph nodes)
Task Group Lung Model (con’t)

- Regional deposition for 1 micron AMAD:
  \[ N-P = 30\%, \ T-B = 8\%, \ P = 25\% \]
- For each compartment or pathway, the fraction (F) of the deposit in the region that clears via that pathway and its half-time (T) are given for each class (D, W, Y)
- For any region, \( \sum F = 1.0 \)
## Lung Clearance Model

### Region

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Class</th>
<th>Compartment</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>W</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>F</td>
<td>T</td>
<td>F</td>
</tr>
</tbody>
</table>

### Region Information

- **Region**: N-P (DN-P = 0.30)
- **Region**: T-B (DT-B = 0.08)
- **Region**: P (DP = 0.25)
- **Region**: L

### Class Values

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Class</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>D</td>
<td>0.01</td>
</tr>
<tr>
<td>b</td>
<td>D</td>
<td>0.01</td>
</tr>
<tr>
<td>c</td>
<td>T</td>
<td>0.01</td>
</tr>
<tr>
<td>d</td>
<td>T</td>
<td>0.2</td>
</tr>
<tr>
<td>e</td>
<td>P</td>
<td>0.5</td>
</tr>
<tr>
<td>f</td>
<td>P</td>
<td>n.a.</td>
</tr>
<tr>
<td>g</td>
<td>P</td>
<td>n.a.</td>
</tr>
<tr>
<td>h</td>
<td>P</td>
<td>0.5</td>
</tr>
<tr>
<td>i</td>
<td>L</td>
<td>0.5</td>
</tr>
<tr>
<td>j</td>
<td>L</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

### Body Fluids and G-I Tract

- **DN-P**: D_N-P
- **DT-B**: D_T-B
- **DP**: D_P

### Graphical Representation

- Diagram showing the flow of body fluids through different compartments with arrow directions indicating the movement.
Sample Calculations

1. What fraction of an inhaled class Y, 1 μ AMAD aerosol will be retained in the lymph nodes?

2. What fraction of an inhaled class W, 1 μ AMAD aerosol will pass through the GI tract?
Solutions

1. P = 25%, path h = 15% of P, so 3.75% goes to L. Path j = 10% of L, so the answer is 0.375%

2. NP = 30%, b = 90% of NP, so 27% here
   TB = 8%, d = 50% of TB, so 4% here
   P = 25%, f & g each 40% of P, so 10% each.
   Sum = 27% + 4% + 10% + 10% = 51%
Another Sample Calculation

What fraction of an inhaled class D, 5 \( \mu \) AMAD aerosol will be absorbed directly into body fluids?

To answer this, we need to correct the deposition in each region for particle size using the following graph.
Solution

3. NP = 70%, path a = 50% of NP, so 35%
   TB = 8%, path c = 95% of TB, so 7.6%
   P = 8%, path e = 80%, so 6.4% and
   path h = 20%, so 1.6%
Total = 35% + 7.6% + 6.4% + 1.6% = 50.6%

Could also note that 100% of a class D aerosol is absorbed to body fluids from region P, and not bother with paths e & h
Reference Worker

• Daily work activity
  – 2.5 h sitting (12 breath/m, 0.75 l/breath)
  – 5.5 h light exercise (20 breath/m, 1.25 l/breath)

• Daily intake
  – sitting: 1.35 m³
  – light exercise: 8.25 m³
  – Total: 9.6 m³ (or 1.2 m³ h⁻¹)
ICRP Human Respiratory Tract Model (1993)

- The respiratory tract is divided into 5 regions:
  - Extrathoracic (ET) 1: nose and mouth
  - ET2: pharynx
  - BB: trachea and bronchi (6 generations)
  - bb: bronchioles (generations 7-24)
  - AI: alveolar-interstitial region (terminal bronchioles, alveoli, and connecting tissue)
ICRP Human Respiratory Tract Model (con’t)

• Model covers a larger range of particle sizes: 1 nm to 100 µm
• Includes gases and vapors
• The default particle size for workplace aerosols is 5 µm
• The default particle size for environmental aerosols is 1 µm
• The dose to ET1 and ET2 regions is included
### DEFAULT DEPOSITION VALUES FOR ICRP RESPIRATORY TRACT MODELS

<table>
<thead>
<tr>
<th></th>
<th>1959 (NO SIZE SPECIFIED)</th>
<th>1979 (1.0 µm)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>1993 (5.0 µm)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>1993 (1.0 µm)&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>URT</td>
<td>50</td>
<td>N-P 30</td>
<td>ET&lt;sub&gt;1&lt;/sub&gt; 34</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ET&lt;sub&gt;2&lt;/sub&gt; 40</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T-B 8</td>
<td>BB 1.8</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>bb 1.1</td>
<td>2.1</td>
</tr>
<tr>
<td>LRT</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P 25</td>
<td>AI 5.3</td>
<td>12</td>
</tr>
<tr>
<td>TOTAL</td>
<td>75</td>
<td></td>
<td>63</td>
<td>82</td>
</tr>
</tbody>
</table>

<sup>a</sup>Occupational Exposure  
<sup>b</sup>Environmental Exposure
Aerosol (1 μm) Deposition: Adult Member of Public

<table>
<thead>
<tr>
<th>Region</th>
<th>Publication 30 (%)</th>
<th>Publication 30 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>TB</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>63</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Publication 66 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET₁</td>
<td>14.89</td>
</tr>
<tr>
<td>ET₂</td>
<td>18.97</td>
</tr>
<tr>
<td>BB</td>
<td>1.29</td>
</tr>
<tr>
<td>bb</td>
<td>1.95</td>
</tr>
<tr>
<td>AI</td>
<td>11.48</td>
</tr>
<tr>
<td>Total</td>
<td>48.58</td>
</tr>
</tbody>
</table>

Deposition is f(particle size, respiratory parameters)
COMPETITIVE CLEARANCE PROCESSES
1993 ICRP MODEL
Absorption Types

• Time-dependent absorption function
  – material specific absorption rates
  – determined from experimental studies

• Default absorption Type (absence of above)
  – F (fast) similar to clearance Class D of TGLM
  – M (moderate) “ ” W “ ”
  – S (slow) “ ” Y “ ”
Absorption to Blood

Default absorption parameters (d\(^{-1}\))

<table>
<thead>
<tr>
<th>Parameters</th>
<th>F</th>
<th>M</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>S(_p)</td>
<td>100</td>
<td>10</td>
<td>0.1</td>
</tr>
<tr>
<td>S(_{pt})</td>
<td>0</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>S(_t)</td>
<td>-</td>
<td>0.005</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
Fractional Absorption: Worker

----- Percent of Inhaled Activity\(^a\) -----

**TGLM (ICRP-30; 1 \(\mu m\))**

<table>
<thead>
<tr>
<th>Class</th>
<th>1st Term</th>
<th>2nd Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class D</td>
<td>48 + 15 (f_1)</td>
<td>12 + 51 (f_1)</td>
</tr>
<tr>
<td>Class W</td>
<td>5.4 + 57.6 (f_1)</td>
<td></td>
</tr>
<tr>
<td>Class Y</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**HRTM (ICRP-66; 5 \(\mu m\))**

<table>
<thead>
<tr>
<th>Type</th>
<th>1st Term</th>
<th>2nd Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type F</td>
<td>28.1 + 20.0 (f_1)</td>
<td>6.1 + 42.0 (f_1)</td>
</tr>
<tr>
<td>Type M</td>
<td>0.6 + 47.5 (f_1)</td>
<td></td>
</tr>
<tr>
<td>Type S</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

\(^a\) Sum of direct absorption from lung (1st term) and that via GI-Tract (2nd term); \(f_1\) denotes fraction of ingested activity absorbed from tract.
MODEL OF TIME-DEPENDENT PARTICLE TRANSPORT
1993 ICRP MODEL
## COMPARISON OF EFFECTIVE DOSES CALCULATED WITH ICRP MODELS

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>( \mu \text{Sv/Bq for 1 } \mu \text{m AMAD} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1979 MODEL (PUB.61)</td>
</tr>
<tr>
<td>(^{239}\text{Pu})</td>
<td>W: 70</td>
</tr>
<tr>
<td></td>
<td>Y: 60</td>
</tr>
<tr>
<td>(^{241}\text{Am})</td>
<td>W: 70</td>
</tr>
<tr>
<td>(^{242}\text{Cm})</td>
<td>W: 4</td>
</tr>
<tr>
<td>(^{60}\text{Co})</td>
<td>W: 0.009</td>
</tr>
<tr>
<td></td>
<td>Y: 0.06</td>
</tr>
<tr>
<td>(^{144}\text{Ce-Pr})</td>
<td>W: 0.05</td>
</tr>
<tr>
<td></td>
<td>Y: 0.1</td>
</tr>
</tbody>
</table>