Annual Limit on Intake (ALI)

- Activity of a radionuclide, which if taken in alone, would irradiate an individual to the limit set by the ICRP for each year of occupational exposure
  - Intake rate: quantity per year
  - Pure parent assumption
  - Can have an ALI each year
  - No time constraint set on exposure period
    - (rate can be instantaneous or up to a year)
  - Two limits – stochastic and nonstochastic considered.
Annual Limit on Intake (ALI)

To meet the ICRP 26 basic limits for exposure to workers the \textit{intakes} of radioactive material in any year must be limited to satisfy the following conditions (assuming only internal exposure):

\[ I \sum_{T} w_{T} H_{T,50,(p.i.u.a.)} \leq 0.05 \text{ Sv} \]

\[ I H_{T,50,(p.i.u.a.)} \leq 0.5 \text{ Sv} \]

Where

\( I \) (Bq) is the annual intake of the specified radionuclide (by ingestion or inhalation).

\( S \) = stochastic limit

\( N \) = nonstochastic limit

\( H_{T,50} \) per unit intake (Sv Bq\(^{-1}\)) is the committed dose equivalent in tissue (T) from the intake of unit activity of the nuclide by the specified route.
Where

\( I_s (Bq \, y^{-1}) \leq \frac{0.05 \, Sv \, y^{-1}}{\sum_T w_T H_{50,T} (p.i.u.a.)} \)

\( I_N (Bq \, y^{-1}) \leq \frac{0.5 \, Sv \, y^{-1}}{H_{50,T} (p.i.u.a.)} \)

- \( I_s \) (Bq) is the annual intake of the specified radionuclide (by ingestion or inhalation).
- \( S = \) stochastic limit
- \( N = \) nonstochastic limit
- \( H_{T,50} \) per unit intake (Sv Bq\(^{-1}\)) is the committed dose equivalent in tissue (T) from the intake of unit activity of the nuclide by the specified route.
Dosimetric Model for Respiratory Track, ICRP66

Fig. 16.6 Anatomical regions of the respiratory tract model in the 1994 ICRP Publication 66. (Courtesy International Commission on Radiological Protection.)

Turner, P521
### Respiratory Model by ICRP30

#### Figure 8.3: Respiratory tract clearance model used in ICRP 30 and 10 CFR 20 for calculating dose from inhaled particulate radioactivity. The values for the removal half-times, $T_{a-j}$, and compartmental fractions, $F_{a-j}$, are given in the tabular portion of the figure for each of the three classes of retained materials. The values given for $D_{NP}$, $D_{TB}$, and $D_p$ (left column) are the regional depositions based on an aerosol with an AMAD of 1 μm. The schematic drawing identifies the various clearance pathways in the model $a-j$ in relation to the deposition $D_{NP}$, $D_{TB}$, $D_p$ and the three respiratory regions, NP, TB, and P. The entry “n.a.” indicates not applicable. (From S. B. Watson and M. R. Ford: *A User's Manual to the ICRP Code: A Series of Computer Programs to Perform Dosimetric Calculations for the ICRP Committee 2 Report*. ORNL, TM-6980, Feb., 1980.)

<table>
<thead>
<tr>
<th>REGION</th>
<th>CLASS</th>
<th>D</th>
<th>W</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T</td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>N-P</td>
<td>a</td>
<td>0.01</td>
<td>0.5</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>0.01</td>
<td>0.5</td>
<td>0.40</td>
</tr>
<tr>
<td>T-B</td>
<td>c</td>
<td>0.01</td>
<td>0.95</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>d</td>
<td>0.2</td>
<td>0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>P</td>
<td>e</td>
<td>0.5</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>n.a.</td>
<td>n.a.</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>g</td>
<td>n.a.</td>
<td>n.a.</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>h</td>
<td>0.5</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>i</td>
<td>0.5</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>j</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

#### Percentage of inhaled 1μm AMAD particles in different regions

- **Nasopharyngeal region (NP)**
- **Tracheobronchial region (TB)**
- **Pulmonary region (TB)**

#### Removal half-life
Dosimetric Model for Gastrointestinal System, ICRP30

Respiratory Model (ICRP 30, 1979)

Figure 8.3 is a graphic representation of the ICRP 30 dosimetric lung model used to calculate the inhalation ALIs in ICRP 30, ICRP 61, and in the U.S. NRC's 1991 revision of its 10 CFR 20 regulations. This lung model consists of three regions where inhaled aerosols may be deposited: The nasopharyngeal region (NP), the tracheobronchial region (TB), and the pulmonary region (P) representing the deep respiratory tract where gas exchange occurs. The NP region is divided into two compartments, $a$ and $b$. Compartment $a$ represents that part in which the dust deposited in the NP region dissolves and is absorbed directly into the blood. Compartment $b$ represents the region from which dust is cleared into the gastrointestinal tract by swallowing. The TB region is also represented by two compartments, $c$ and $d$, from which deposited particles are cleared by the same two mechanisms as above. Compartment $c$ represents the region in which dissolution and absorption into the blood takes place, whereas the mechanical transfer by way of the ciliary escalator to the throat and into the GI tract by swallowing is represented by compartment $d$. The pulmonary region, P, is modeled by four compartments. One of these compartments $e$, represents dissolution and absorption into the blood. Compartments $f$ and $g$ represent transfer of undissolved particles into the GI tract via the upper respiratory tract (the TB region). Compartiment $f$ is cleared by mechanical transport, presumably by unbalanced forces during respiratory excursions, and compartment $g$ is cleared by alveolar macrophages that migrate into the TB region. Compartment $h$ empties into the pulmonary lymph nodes. The pulmonary lymph nodes are represented by two compartments, $i$ and $j$. Compartment $i$ empties into the bloodstream after the particles have dissolved, while compartment $j$ permanently retains some highly insoluble particles.

Cember, Page 300
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

Cs-137:

- Activity median aerodynamic diameter: 1um.
- 63% of the inhaled dust deposited and 37% exhaled.
- Materials deposited in the NP region does not contribute to the intrapulmonary dose; it contributes to the lung dose only by virtue of its presence in the rest of the body.
- Within the 63% of the inhaled dust deposited in the body, 38% directly deposited in the lung and 25% distributed uniformly through the rest of the body. Both contribute to the dose to the lung.

ALI can be determined with the following steps:

- Calculate the dose to the lung from Cs-137 deposited in the lung and from Cs-137 distributed in the rest of the body.
- Calculate the total body dose from the inhaled activity.
- Derive the radiation limits using the following equation
Calculating ALI (stochastic and nonstochastic)

\[ ALI_S \equiv I_s \left( Bq \, y^{-1} \right) = \frac{0.05 \, Sv \, y^{-1}}{\sum_T w_T H_{50,T}(p.i.u.a.)} \]

\[ ALI_N \equiv I_N \left( Bq \, y^{-1} \right) = \frac{0.5 \, Sv \, y^{-1}}{H_{50,T}(p.i.u.a.)} \]

ALI can be determined by considering the following:

- Dose equivalent to the lung from Cs-137 deposited in the lung, and from Cs-137 distributed in the rest of the body.
- Total body effective dose equivalent (EDE) from the inhaled activity.
- Derive the radiation limits using the above equations.
Step 1:
Dose to the lung from the radioactivity deposited in the lung
Figure 8.3. Respiratory tract clearance model used in ICRP 30 and 10 CFR 20 for calculating dose from inhaled particulate radioactivity. The values for the removal half-times, $T_{a-j}$, and compartmental fractions, $F_{a-j}$, are given in the tabular portion of the figure for each of the three classes of retained materials. The values given for $D_{NP}$, $D_{TB}$, and $D_{P}$ (left column) are the regional depositions based on an aerosol with an AMAD of 1 $\mu$m. The schematic drawing identifies the various clearance pathways in the model $a-j$ in relation to the deposition $D_{NP}$, $D_{TB}$, $D_{P}$ and the three respiratory regions, NP, TB, and P. The entry “n.a.” indicates not applicable. (From S. B. Watson and M. R. Ford: A User's Manual to the ICRP Code: A Series of Computer Programs to Perform Dosimetric Calculations for the ICRP Committee 2 Report. ORNL, TM-6980, Feb., 1980.)
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

- Total committed dose equivalent to the lung

For the purpose of ALI calculation, we assume that all cesium particle compounds are rapidly cleared from the lung. The amount of activity deposited in each of the lung compartments following an inhalation of 1 Bq, together with the corresponding removal rate is shown in Table below.

<table>
<thead>
<tr>
<th>Compartment</th>
<th>$A_s(0)$, t/s</th>
<th>$T_{1/2}$, day</th>
<th>$\lambda_E$, per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>c (TB→blood)</td>
<td>0.076</td>
<td>0.01</td>
<td>69.3</td>
</tr>
<tr>
<td>d (TB→GI)</td>
<td>0.004</td>
<td>0.2</td>
<td>3.47</td>
</tr>
<tr>
<td>e (P→blood)</td>
<td>0.200</td>
<td>0.5</td>
<td>1.39</td>
</tr>
<tr>
<td>f (P→LN)</td>
<td>0.050</td>
<td>0.5</td>
<td>1.39</td>
</tr>
<tr>
<td>LN</td>
<td>0.050</td>
<td>0.5</td>
<td>1.39</td>
</tr>
</tbody>
</table>
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

Total committed dose equivalent to the lung

The committed dose to the lung due to the activity accumulated in the same organ after deposition of 1 Bq of Cs-137.

$$H_{50,T} = 1.6 \times 10^{-13} \frac{J}{\text{MeV}} \times \sum_i \tilde{A}_{si} \times \frac{\text{SEE}(T \leftarrow S)_i}{\text{Bq} \cdot \text{s}} \times 1 \frac{\text{J}}{\text{kg} \cdot \text{Gy}} \times 1 \frac{\text{transf.}}{\text{Bq} \cdot \text{s}} \times W_{RI}. \quad (8.7)$$

where $\tilde{A}_{si} =$ cumulated activity, Bq \cdot s, in the various source organs;
$\text{SEE}_i =$ specific effective energy, MeV per transformation per kilogram; and
$W_R =$ quality factor of the radiation, Sv/Gy.
Specific Effective Energy (SEE)

- \( \text{SEE} (T \leftarrow S) = \sum \text{SEE} (T \leftarrow S)_i \)
- For any radionuclide \( j \), \( \text{SEE} (T \leftarrow S)_j \) for target \( T \) and source \( S \) is given by:

\[
\text{SEE}_j (T \leftarrow S) = \sum_i \frac{Y_i E_i AF (T \leftarrow S)_i}{M_T} 
\]

\( MeVg^{-1} \) per transformation
Partial Absorption of Gamma Ray Energy – MIRD Method

To account for the partial absorption of gamma ray energy in organs and tissues, the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine has developed a formal system for calculating the dose to a target organ or tissue from a source organ containing a uniformly distributed radioisotope.

The absorption fraction – the fraction of the energy radiated by the source organ which is absorbed by the target organ.
Partial Absorption of Gamma Ray Energy – MIRD Method

The absorbed fraction are calculated by the application of Monte Carlo methods.

\[
\text{Absorbed fraction} = \varphi = \frac{\text{energy absorbed by target}}{\text{energy emitted by source}}
\]

<table>
<thead>
<tr>
<th>Mass, kg</th>
<th>0.020, MeV</th>
<th>0.030, MeV</th>
<th>0.040, MeV</th>
<th>0.060, MeV</th>
<th>0.080, MeV</th>
<th>0.100, MeV</th>
<th>0.160, MeV</th>
<th>0.364, MeV</th>
<th>0.662, MeV</th>
<th>1.460, MeV</th>
<th>2.750, MeV</th>
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<tbody>
<tr>
<td>0.3</td>
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<td>0.191</td>
<td>0.109</td>
<td>0.086</td>
<td>0.085</td>
<td>0.087</td>
<td>0.099</td>
<td>0.096</td>
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<td>0.4</td>
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<td>0.388</td>
<td>0.212</td>
<td>0.121</td>
<td>0.096</td>
<td>0.093</td>
<td>0.097</td>
<td>0.108</td>
<td>0.108</td>
<td>0.099</td>
<td>0.083</td>
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<td>0.412</td>
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<td>0.131</td>
<td>0.104</td>
<td>0.099</td>
<td>0.104</td>
<td>0.116</td>
<td>0.117</td>
<td>0.104</td>
<td>0.089</td>
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<tr>
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<td>0.745</td>
<td>0.431</td>
<td>0.244</td>
<td>0.140</td>
<td>0.111</td>
<td>0.105</td>
<td>0.111</td>
<td>0.122</td>
<td>0.124</td>
<td>0.109</td>
<td>0.093</td>
</tr>
<tr>
<td>1.0</td>
<td>0.780</td>
<td>0.486</td>
<td>0.289</td>
<td>0.167</td>
<td>0.135</td>
<td>0.125</td>
<td>0.130</td>
<td>0.142</td>
<td>0.144</td>
<td>0.125</td>
<td>0.106</td>
</tr>
<tr>
<td>2.0</td>
<td>0.818</td>
<td>0.559</td>
<td>0.360</td>
<td>0.212</td>
<td>0.173</td>
<td>0.160</td>
<td>0.162</td>
<td>0.174</td>
<td>0.173</td>
<td>0.153</td>
<td>0.127</td>
</tr>
<tr>
<td>3.0</td>
<td>0.840</td>
<td>0.600</td>
<td>0.405</td>
<td>0.245</td>
<td>0.201</td>
<td>0.188</td>
<td>0.186</td>
<td>0.197</td>
<td>0.195</td>
<td>0.174</td>
<td>0.143</td>
</tr>
<tr>
<td>4.0</td>
<td>0.856</td>
<td>0.629</td>
<td>0.438</td>
<td>0.271</td>
<td>0.222</td>
<td>0.209</td>
<td>0.205</td>
<td>0.216</td>
<td>0.213</td>
<td>0.190</td>
<td>0.154</td>
</tr>
<tr>
<td>5.0</td>
<td>0.868</td>
<td>0.652</td>
<td>0.464</td>
<td>0.294</td>
<td>0.241</td>
<td>0.227</td>
<td>0.222</td>
<td>0.231</td>
<td>0.228</td>
<td>0.204</td>
<td>0.167</td>
</tr>
<tr>
<td>6.0</td>
<td>0.876</td>
<td>0.671</td>
<td>0.485</td>
<td>0.312</td>
<td>0.258</td>
<td>0.241</td>
<td>0.236</td>
<td>0.245</td>
<td>0.240</td>
<td>0.216</td>
<td>0.177</td>
</tr>
</tbody>
</table>

*The principal axes of the small spheres and thick ellipsoids are in the ratios of 1/1/1 and 1/0.667/1.333.

Standard data on the absorbed dose for photons of various energies for point isotropic sources and for uniformly distributed sources are published by MIRD in several Supplements to the Journal of Nuclear Medicine.
Internally Deposited Radioisotope (I)
Corpuscular Radiation (revisited)

The energy absorbed per unit mass in the target, as the result of a single transformation in the source is called the **specific effective energy** (SEE).

For (a) alpha and beta radiation and when the source is also the target, SEE is simply the average energy of the radiation divided by the mass of the tissue in which it is distributed.

\[
SEE \ (\alpha \ or \ \beta) = \frac{\langle E(\alpha \ or \ \beta) \rangle \ MeV}{m/t} \quad /kg
\]
SEE cont’d

\[ SEE_j(T \leftarrow S) = \sum_i \frac{Y_i E_i AF(T \leftarrow S)_i}{M_T} \]

\( \text{MeVg}^{-1} \text{ per transformation} \)

\( Y_i \) is the yield of radiations of type \( i \) per transformation of radionuclide \( j \)

\( E_i \) (in MeV) is the average or unique energy of radiation \( i \) as appropriate

\( AF(T \leftarrow S)_i \) is the fraction of energy absorbed in \( T \) per emission of \( i \) in \( S \)

- Alphas and electrons are almost completely absorbed in \( S \)
- Exceptions are mineral bone and GI
- Photon absorptions are given in ICRP 23

\( M_T \) is the mass of the target organs.
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

- Total dose equivalent to the lung (cont’d)

- To proceed, we would need to know the SEE for Cs-137

---

**Figure 8.2.** Transformation scheme and input and output data for $^{137}$Cs dosimetry. (From L. T. Dillman: Radionuclide Decay Schemes and Nuclear Parameters for Use in Radiation Dose Estimation. *J. Nuclear Medicine, Vol. 10*, Supplement No. 2, MIRD Pamphlet No. 4, 1969.)
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

\( \sum_i SEE(\text{lung} \leftarrow \text{lung})_i = 0.280 \frac{\text{MeV}}{\text{t}} / \text{kg} \)

\( \sum_i SEE(\text{lung} \leftarrow \text{total body})_i = 6.47 \times 10^{-3} \frac{\text{MeV}}{\text{t}} / \text{kg} \)
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

Total dose equivalent to the lung (Continued)

We would also need to know the cumulated activity due to the deposition of Cs-137 in the lung and the rest of the body. For this, we use

$$\tilde{A}(t) = \frac{A_s(0)}{\lambda_E} \left(1 - e^{-\lambda_E t}\right),$$

Since we are interested in a very long time scale, the cumulated activity after time $t$ is given by

$$\tilde{A}(t) = \frac{A_s(0)}{\lambda_E}.$$
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

- Total dose equivalent to the lung (cont’d)

- Considering the contribution from transformations in each compartment, the cumulated activity due to the 1Bq of Cs-137 in the lung is

$$\tilde{A} = 8.64 \times 10^4 \times \frac{s}{\text{day}} \left[ \left( \frac{0.076 \frac{t}{s}}{69.3 \text{ day}^{-1}} \right) + \left( \frac{0.004 \frac{t}{s}}{3.47 \text{ day}^{-1}} \right) + \left( \frac{0.200 \frac{t}{s}}{1.39 \text{ day}^{-1}} \right) + \left( \frac{0.050 \frac{t}{s}}{1.39 \text{ day}^{-1}} \right) + \left( \frac{0.050 \frac{t}{s}}{1.39 \text{ day}^{-1}} \right) \right],$$

$$\tilde{A} = 1.9 \times 10^4 \text{ transformations.}$$

**Table 8.7. Activity Deposited in the Several Compartments of the Lung after an Inhalation of 1 Bq $^{137}$Cs, and the Clearance Rates for Each Compartment**

<table>
<thead>
<tr>
<th>Compartment</th>
<th>$A_s(0)$, t/s</th>
<th>$T_{1/2}$, day</th>
<th>$\lambda_E$, per day</th>
</tr>
</thead>
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<td>0.5</td>
<td>1.39</td>
</tr>
<tr>
<td>f (P→LN)</td>
<td>0.050</td>
<td>0.5</td>
<td>1.39</td>
</tr>
<tr>
<td>LN</td>
<td>0.050</td>
<td>0.5</td>
<td>1.39</td>
</tr>
</tbody>
</table>

NPRE 441, Principles of Radiation Protection, Spring 2021
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

Total committed dose equivalent to the lung

The committed dose to the lung due to the activity accumulated in the same organ after deposition of 1Bq.

\[
H_{50,T} = 1.6 \times 10^{-13} \frac{J}{\text{MeV}} \times \sum_i \tilde{A}_{si} \times \frac{SEE(T \leftarrow S)_i}{\text{Bq} \cdot \text{s}} \times 1 \frac{\text{transf.}}{\text{Bq} \cdot \text{s}} \times W_{Ri} \times \frac{1}{\text{Gy}}.
\]

\[i: \text{going through all source organs that could contribute to the dose in the target organ.}\]

where \( \tilde{A}_{si} = \text{cumulated activity, Bq} \cdot \text{s, in the various source organs;} \)

\[SEE_i = \text{specific effective energy, MeV per transformation per kilogram; and} \]

\( W_R = \text{quality factor of the radiation, Sv/Gy.} \)
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

Total dose equivalent to the lung (cont’ed)

Considering the contribution from transformations in each compartment, the committed equivalent dose in the lung from 1Bq of Cs-137 in the lung is

$$H_{50} = 8.6 \times 10^{-10} \text{ Sv.}$$

$$H_{50} = \frac{1.6 \times 10^{-13} \frac{J}{\text{MeV}} \times 1.9 \times 10^4 \text{ t} \times 0.280 \frac{\text{MeV}}{\text{kg}} / \text{t} \times 1 \frac{\text{Sv}}{\text{Gy}}}{1 \frac{\text{J}}{\text{Bq}/\text{Gy}}},$$

$$\text{SEE (lung-lung)}$$

$$\text{quality factor}$$
Step 2:
Dose to the lung from the radioactivity deposited in the rest of the body
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

- Total dose equivalent to the lung (cont’d)
  - Calculating the committed dose to the lung due to the activity accumulated in the rest of the body after deposition of 1 Bq.
  - Note: the activity deposited in the NP (nasopharyngeal) region does not directly contribute to the intrapulmonary dose. Therefore, for each Bq deposited, there should be 0.25 Bq deposited in the rest of the body.
  - The retention of Cs-137 in body is given by (6.59 in Cember)

$$ q(t) = 0.1 \, q_0 \, e^{-(0.693t/2 \text{ days})} + 0.9 \, q_0 \, e^{-(0.693t/110 \text{ days})} $$

Therefore, the total accumulated activity in the rest of the body from 1 Bq of inhaled Cs-137 activity is

$$ \tilde{A}(t) = \frac{A_S(0)}{\lambda_E} $$

$$ \tilde{A} = 8.64 \times 10^4 \, \frac{S}{d} \left[ \frac{0.25 \, \frac{t}{S} \cdot 10\%}{0.347 \, d^{-1}} + \frac{0.25 \, \frac{t}{S} \cdot 90\%}{0.0063 \, d^{-1}} \right] = 3.1 \times 10^6 \, (t) $$
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

- Total dose equivalent to the lung (cont’d)

  Therefore, the total committed dose in the lung due to the contribution from the rest of the body after the intake of 1 Bq is

  \[
  H_{50} = 1.6 \times 10^{-13} \frac{\text{J}}{\text{MeV}} \times 3.1 \times 10^6 \times 6.74 \times 10^{-3} \frac{\text{MeV}}{\text{kg}} \frac{1}{t} \times 1 \frac{\text{Sv}}{\text{Gy}},
  \]

  \[
  H_{50} = 8.4 \times 10^{-9} \text{ Sv}.
  \]

- The total committed dose to the lung, due to the 1 Bq intake, is then

  \[
  H_{50,L} = 8.6 \times 10^{-10} \frac{\text{Sv}}{\text{Bq}} + 8.4 \times 10^{-9} \frac{\text{Sv}}{\text{Bq}} = 9.3 \times 10^{-9} \frac{\text{Sv}}{\text{Bq}}.
  \]
Step 3:
Effective Dose to the Whole Body
Inhalation ALI for $^{137}\text{Cs}$ according to ICRP 30 Criteria

- Determine the committed equivalent dose to the body by a unit uniform distribution of activity.

- From a previous calculation, we found that the committed dose equivalent to the body by a unit activity uniformly distributed throughout the body is

$$1.3 \times 10^{-8} \frac{\text{Sv}}{\text{Bq}}.$$

- Note that within every Bq intake, 0.63 Bq will be absorbed in the body, so the committed dose equivalent to the rest of the body by a unit active intake is

$$0.63 \times 1.3 \times 10^{-8} = 8.19 \times 10^{-9} \text{ Sv/Bq}.$$
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

- Determine the ALI for Cs-137 intake.

Treating the body as a two-organ (lung and the rest of the body) configuration and using the weighting factor of 0.12 for the lung and 0.88 for the body, the dose equivalent to the lung is

$$Tissue\text{ }weighting\text{ }factor$$

$$0.12 \times 9.3 \times 10^{-9} = 1.16 \times 10^{-9} Sv/Bq$$

The effective dose equivalent (EDE) to the body is

$$\sum W_T \cdot H_{50,T} = 0.12 \times 9.3 \times 10^{-9} + 0.88(0.63 \times 1.1 \times 10^{-8}) = 7.17 \times 10^{-9} \frac{Sv}{Bq}$$

Only 63% of intake activity is absorbed in the body.
Step 4: Evaluate the ALI
Calculating ALI (stochastic and nonstochastic)

\[
ALI_s \equiv I_s (Bq \, y^{-1}) = \frac{0.05 \, Sv \, y^{-1}}{\sum_T w_T H_{50,T} (p.i.u.a.)}
\]

\[
ALI_N \equiv I_N (Bq \, y^{-1}) = \frac{0.5 \, Sv \, y^{-1}}{H_{50,T} (p.i.u.a.)}
\]

ALI can be determined with the following steps:

- Calculate the dose to the lung from Cs-137 deposited in the lung and from Cs-137 distributed in the rest of the body.
- Calculate the total body effective dose equivalent from the inhaled activity.
- Derive the radiation limits using the above equations.
Inhalation ALI for $^{137}$Cs according to ICRP 30 Criteria

**Step 3:** Determine the ALI for Cs-137 intake.

\[ ALI_{non-stoch} = \frac{0.5Sv}{0.12 \times 9.3 \times 10^{-9}Sv/Bq} \]
\[ = 4.48 \times 10^8 Bq \]

and

\[ ALI_{stoch} = \frac{0.05Sv}{7.17 \times 10^{-9}Sv/Bq} \]
\[ = 6.97 \times 10^6 Bq \]

So

\[ ALI_{cs-137} = 6.97 \times 10^6 Bq \]
How to Derive ALI?

Analyze the dose distribution and clearance model

- for each target organ, derive the committed dose equivalent due to a unit intake radioactivity, \( H_{T,50} (\text{p.i.u.a.}) \)
  
  (need to consider all types of radiations and all organs that could contribute to the dose to the target organ)

\[
\text{ALI}_{\text{non-stochastic}} = \frac{\text{Dose Limit}}{H_{T,50} (\text{p.i.u.a.})}
\]

- derive the committed dose equivalent for all the organs involved, \( [H_{T,50} (\text{p.i.u.a.})] \)

- derive the committed effective dose equivalent (CEDE)

\[
H_{E,50} (\text{p.i.u.a.}) = \sum_{T} w_T H_{T,50} (\text{p.i.u.a.})
\]

\[
\text{ALI}_{\text{stochastic}} = \frac{\text{Dose Limit}}{H_{E,50} (\text{p.i.u.a.})}
\]

- \( \text{ALI} = \min(\text{ALI}_{\text{stochastic}}, \text{ALI}_{\text{non-stochastic}}) \)