Dose → how much ionizing energy is incident on the patient's tissues.

- Some cases calculated as if the source is internal to the body
  - Committed Dose

Effective Dose → tissue-weighted sum of equivalent doses & considers both the type of radiation AND the nature of each exposed tissue
Effective Dose = \( \sum \frac{W_T}{H_T} \) (tissue)

\[ = \sum W_T \sum \frac{W_R}{D_{T,R}} \]

\( W_R \) (Q...radiation quality factor)
- X-rays, gamma ray, \( \beta \) particle, muon ... \( W_R = 1 \)
- protons \( \rightarrow W_R = 2 \)
- alpha particle, heavy nuclei, fission products ... \( W_R = 20 \)
- neutrons (energy dependent) ... \( W_R = 5 - 20 \)
$W_T \rightarrow \text{tissue weighting factor}$

Gonads $\rightarrow 0.08$
Marrow $\rightarrow 0.12$
Bladder $\rightarrow 0.04$
Skin $\rightarrow 0.01$
"Rest of the body" $\rightarrow 0.12$

Sum for the body is 1 $\left[ \sum_T W_T = 1 \right]$
If (over a short period) you are exposed to 1-10 Gy

- Lymphopenia
  - $TD_{50} = 5$ Gy

- Aplasia
  - $TD_{50} = 10$ Gy

- Cataracts
  - $8$ Gy

- Sterility
  - $6$ Gy

- Pneumonitis
  - $10$ Gy

- Enteritis
  - $10$ Gy
**Rem** — non-SI unit, common in USA

\[
1 \text{ rem} = 100 \text{ erg/g} \quad \cdots \quad 1 \text{ rem} = 0.01 \text{ Sv}
\]

\[
1 \text{ mrem} = 10^{-5} \text{ Sv} = 10 \mu \text{Sv} = 0.01 \text{ mSv}
\]

Avg annual dose from **natural** background

\[
\sim 300 - 350 \text{ mrem}
\]

- Cosmic rays \( \sim 30 \text{ mrem} \)
- Transoceanic flight \( \Rightarrow 2 \text{ mrem} \)
- Chest x-ray \( \Rightarrow 5 \text{ mrem} \)

Concern arises \( \sim 10 \text{ rem} \)
- Whole-body CT → 1000 mrem ... 10 mSv
- Nuclear brain scan → ~450 mrem
- Ba swallows → ~300 mrem

Nuclear Regulatory Commission...

- For the Public, limit is 100 mrem/year
- Dose limit for the whole body: 5000 mrem/year
- Dose limit for any organ: 50000 mrem/year
Typical (non-SI) measure of exposure is Roentgen (R)

\[ R = 2.58 \times 10^{-4} \text{ Gy} \]

Exposure to 1 R is 1 rad of dose (0.96)

Dose \( D = \int X \) exposure

\[ f = \frac{Z_{eff, \text{tissue}}}{Z_{eff, \text{air}}} \]

\[ Z_{eff} : \quad \text{Air} \rightarrow 7.8 \]

\[ \text{Heo} \rightarrow 7.5 \quad \text{for most tissue} \]

\[ \text{Muscle} \rightarrow 7.6 \]

\[ \text{Bone} \rightarrow 12 - 20 \quad f_{\text{bone}} \]

Higher atomic number of the tissue taken relative to \( Z_{eff} \) by air.
Cancer risks

\( \approx \) Assuming a single dose of 1 Sv

Supers out... fatal cancers in 8-15% of population
<table>
<thead>
<tr>
<th>Procedure</th>
<th>Eff Dose (mSv)</th>
<th>Cancer Risk</th>
<th>Cigs</th>
<th>Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest X-ray</td>
<td>0.032</td>
<td>$1.3 \times 10^{-6}$</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>Head CT</td>
<td>2</td>
<td>$1.2 \times 10^{-4}$</td>
<td>830</td>
<td>2120</td>
</tr>
<tr>
<td>Bone scan</td>
<td>4.6</td>
<td>$1.8 \times 10^{-5}$</td>
<td>1300</td>
<td>3280</td>
</tr>
</tbody>
</table>

- Cigs $\rightarrow$ 10/day = moderate ($1:200$) risk of death in a year
- Car Travel $\rightarrow$ accident on the road ($1:5000$)