Chapter 7: External Radiation Protection
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Basic Principle for Radiation Protection

Basic Principles

- Maximizing distance
- Minimizing exposure time
- Shielding the radiation source
So How Much Shielding is Needed?

To determine the shielding requirement, we need to compute the dose equivalent and effective dose equivalent.
Dose Equivalent (or Equivalent Dose)

The concept of the effective dose equivalent was introduced by ICRP in 1977. To discuss this concept, we would need to start from the equivalent dose.

Equivalent Dose is the product of the dose and a modifying factor called the quality factor (Q), which reflects the relative biological effectiveness (RBE) of the radiation:

\[ H (Sv) = D (Gy) \times Q \]

- Q are indices of the “relative biological effectiveness” (RBE) of a radiation. RBE is a complicated function of type of radiation, energy and the biological system under consideration.
- The values of Q are not measured. They are determined by a committee based on the relatively RBE derived in health physics practice.
- The unit for dose equivalent is Sv, or Rem (1 Rem = 0.01 Sv)
Dose Equivalent (or Equivalent Dose)

TABLE 12.1. Dependence of Quality Factor $Q$ on LET of Radiation as Formerly Recommended by ICRP, NCRP, and ICRU

<table>
<thead>
<tr>
<th>LET (keV μm$^{-1}$ in Water)</th>
<th>$Q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 or less</td>
<td>1</td>
</tr>
<tr>
<td>3.5–7.0</td>
<td>1–2</td>
</tr>
<tr>
<td>7.0–23</td>
<td>2–5</td>
</tr>
<tr>
<td>23–53</td>
<td>5–10</td>
</tr>
<tr>
<td>53–175</td>
<td>10–20</td>
</tr>
<tr>
<td>Gamma rays, X rays, electrons, positrons of any LET</td>
<td>1</td>
</tr>
</tbody>
</table>

TABLE 12.2. Dependence of Quality Factor $Q$ on LET as Currently Recommended by ICRP, NCRP, and ICRU

<table>
<thead>
<tr>
<th>LET, $L$ (keV μm$^{-1}$ in Water)</th>
<th>$Q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
<td>1</td>
</tr>
<tr>
<td>10–100</td>
<td>$0.32L - 2.2$</td>
</tr>
<tr>
<td>&gt; 100</td>
<td>$\frac{300}{\sqrt{L}}$</td>
</tr>
</tbody>
</table>
Equivalent Dose

\[ H_T(Sv) = \sum_R Q_R \cdot D_{T,R}(Gy) \]

- T is tissue (organ)
- R is radiation type R – there are multiple types of radiation contribute to the dose to the organ
- \( D_{T,R} \) is absorbed dose in tissue (T) from radiation (R)
- \( Q_R \) is radiation weighting factor
- \( H_T \) is the dose equivalent, expressed
Committed Equivalent Dose

Committed Equivalent Dose

- That dose averaged throughout tissue T over the 50 years after intake of the radioactive material

\[
H_{50,T} = \int_{t}^{t+50} \dot{H}(t) \, dt
\]

- \( T = \) tissue T
- \( t = \) time
- \( H_{50,T} = \) Committed Equivalent Dose
Different tissues respond differently to same radiation dose, such as differences in susceptibility, ability of recover, essentialness etc.

Tissue weighting factors used to provide a common scale:

$$H_E = \sum_T w_T H_T$$

$H_E$ is the effective dose equivalent
$W_T$ is the tissue weighting factor
Effective Dose Equivalent

<table>
<thead>
<tr>
<th>Tissue or Organ</th>
<th>$W_T$, ICRP 26</th>
<th>$W_T$, ICRP 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Bone marrow (red)</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Colon</td>
<td>Not given</td>
<td>0.12</td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Stomach</td>
<td>Not given</td>
<td>0.12</td>
</tr>
<tr>
<td>Bladder</td>
<td>Not given</td>
<td>0.05</td>
</tr>
<tr>
<td>Breast</td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>Liver</td>
<td>Not given</td>
<td>0.05</td>
</tr>
<tr>
<td>Esophagus</td>
<td>Not given</td>
<td>0.05</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Skin</td>
<td>Not given</td>
<td>0.01</td>
</tr>
<tr>
<td>Bone surface</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>Remainder$^{b,c}$</td>
<td>0.30</td>
<td>0.05</td>
</tr>
</tbody>
</table>

$^a$The values are based on a reference population of equal numbers of both sexes and a wide range of ages. In the definition of effective dose, they apply to workers, to the whole population, and to either sex.

$^b$For purposes of calculation, the remainder is composed of the following additional tissues and organs: adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus, and uterus. The list includes organs which are likely to be selectively irradiated. Some organs in the list are known to be susceptible to cancer induction. If other tissues and organs subsequently become identified as having a significant risk of induced cancer, they will be included either with a specific $W_T$, or in this additional list constituting the remainder. The latter may also include other tissues or organs selectively irradiated.

$^c$In those exceptional cases in which a single one of the remainder tissues or organs receives an equivalent dose in excess of the highest dose in any of the 12 organs for which a weighting factor is specified, a weighting factor of 0.025 should be applied to that tissue or organ and a weighting factor of 0.025 to the average dose in the rest of the remainder as defined above.
Effective Dose Equivalent (Restated)

$H_E = \sum_{T} w_T \cdot H_T$

- $H_E$ applies only to stochastic effects.
- $w_T$ is the tissue weighting factor -- the fraction of the total stochastic risk associated with the irradiation of tissue $T$. 
Effective Dose Equivalent

- EDE is a concept, not a measurable quantity.
- Applies to situation where irradiation of organs and tissues is non-uniform.
- EDE yields the same “radiation detriment” as a numerically-equivalent whole-body dose.
- $W_T$ values are assigned based on ICRP Report 26.
- EDE is the index of dose to be used for purposes of regulatory compliance in the United States (10 CFR 20).
Committed Equivalent Dose

\[ H_{50,T} = \int_{t}^{t+50} \dot{H}(t) \, dt \]

- That dose averaged throughout tissue T over the 50 years after intake of the radioactive material
- \( T \) = tissue T
- \( t \) = time
- \( H_{50,T} \) = Committed Equivalent Dose
ICRP 26/30 Philosophy (borrowed from Chapter 8)

- **Stochastic effects**
  - were defined as those effects for which the probability of the effect occurring, rather than its severity, is a function of dose without a threshold.
  - cancer (fatal)
  - hereditary (next two generations)

- **Non-stochastic (deterministic) effects**
  - were those effects for which the severity is a function of dose and a threshold may exist.
  - cataract of lens of the eye (0.15 Sv/y)
  - almost any organ in the body can have a nonstochastic effect, but typically the doses are quite large
Basic Limits (borrowed from Chapter 8)

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

\[ \sum_{T} w_{T} H_{T,50} \leq 0.05 \text{ Sv} \]

and

\[ H_{T,50} \leq 0.5 \text{ Sv} \]

\[ H_{T,rem} = \sum_{R} Q_{R} D_{T,R,rad} \]

\[ H_{50,T} = \int_{t}^{t+50} \dot{H}(t) \, dt \]