CHAPTER 3

BIOLOGICAL EFFECTS OF IONIZING RADIATION
When radiation splits a chemical bond in this way, it is known as **DIRECT DAMAGE**.

The H and OH components of the fractured water molecule can give a variety of reactions. Three important ones are shown below:

\[ H + OH \rightarrow H_2O \]  
no problem, water is formed again.

\[ H + H \rightarrow H_2 \]  
no damage, a few hydrogen "gas" molecules can be tolerated.

\[ OH + OH \rightarrow H_2O_2 \]  
hydrogen peroxide is formed; this is poisonous. In fact, chemical poisoning by \( H_2O_2 \) resembles radiation sickness in many ways.

The damage produced by the charged H and OH bits drifting around before combining to form \( H_2O \), or combining with other biologically important molecules is known as **INDIRECT DAMAGE**.
An absorbed radiation dose of 1 GRAY corresponds to the deposition of 1 joule of energy in 1 kg of material.

1 Gy = $10^3$ mGy = $10^6$ μGy
The QUALITY FACTOR of a particular kind of radiation is defined as the ratio of the biological damage produced by the absorption of 1 gray of that radiation to 1 gray of X- or gamma radiation.

**QUALITY FACTORS**

<table>
<thead>
<tr>
<th>Radiation</th>
<th>Energy</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>gamma</td>
<td>all</td>
<td>1</td>
</tr>
<tr>
<td>beta</td>
<td>all</td>
<td>1</td>
</tr>
<tr>
<td>neutrons</td>
<td>slow</td>
<td>5</td>
</tr>
<tr>
<td>neutrons</td>
<td>fast</td>
<td>20</td>
</tr>
<tr>
<td>alpha</td>
<td>all</td>
<td>20</td>
</tr>
</tbody>
</table>
An equivalent dose of one SIEVERT represents that quantity of radiation dose that is equivalent, in terms of specified biological damage, to one gray of X- or gamma rays.

\[ H(\text{Sv}) = D(\text{Gy}) \times Q \]
Dose Rate, uGy/h

Maximum at 8800 m

About 0.7 uGy Extra Dose From This Flight

Fig. 3.1. Exposure Rate vs. Time on a Commercial Flight
Fig. 3.2. Annual Variation in Background Radiation near Point Lepreau (including Cosmic Rays)

Fig. 3.3. Seasonal Variation in Natural Background Radiation
### Average Population Equivalent Dose from Natural and Man-Made Sources (μSv / Year)

<table>
<thead>
<tr>
<th>Category</th>
<th>Cause</th>
<th>Dose (μSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Background</td>
<td>Cosmic Rays</td>
<td>330</td>
</tr>
<tr>
<td></td>
<td>Radon Daughters</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>External Terrestrial</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>Internal Sources</td>
<td>200 / 1570</td>
</tr>
<tr>
<td>Medical Exposure (gonad dose)</td>
<td>Diagnostic X-Rays</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Radiotherapy</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Nuclear Medicine</td>
<td>5 / 355</td>
</tr>
<tr>
<td>Fall-out</td>
<td>Weapons Testing</td>
<td>10 / 10</td>
</tr>
<tr>
<td>Occupational Doses (non-nuclear)</td>
<td>Medical</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Dental</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Research &amp; Education</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Industry (non-nuclear)</td>
<td>0.3 / 3</td>
</tr>
<tr>
<td>Miscellaneous Sources</td>
<td>Colour TV, Air Travel, etc.</td>
<td>3 / 3</td>
</tr>
<tr>
<td>Nuclear Power Generation (projected)</td>
<td>Uranium Mining</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Reactor Operation</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Other Fuel Processes</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Transportation</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Accidents</td>
<td>0.5 / 20</td>
</tr>
</tbody>
</table>

![Pie chart](image)

**Fig. 3.4. Background Radiation in Canada**
<table>
<thead>
<tr>
<th>mSv</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>100,000</td>
<td>Typical dose to the thyroid in radiation therapy</td>
</tr>
<tr>
<td>10,000</td>
<td>Hospital leukaemia treatment — 50% successful</td>
</tr>
<tr>
<td>1,000</td>
<td>Highest annual radon dose in a UK home (equivalent to 5,000 mSv whole-body)</td>
</tr>
<tr>
<td>100</td>
<td>Dose giving an extra 1% risk of cancer (250 mSv)</td>
</tr>
<tr>
<td></td>
<td>Annual radon dose to Health Spa Workers (200 mSv)</td>
</tr>
<tr>
<td>10</td>
<td>Environmental radiation dose in some parts of the world</td>
</tr>
<tr>
<td>1</td>
<td>Estimated maximum CAT scan dose (40 mSv)</td>
</tr>
<tr>
<td></td>
<td>Annual dose limit for Radiation Workers (20 mSv)</td>
</tr>
<tr>
<td>1.0</td>
<td>Typical annual background radiation dose in NB (2 mSv)</td>
</tr>
<tr>
<td></td>
<td>Average annual occupational dose Point Lepreau workers (1.3 mSv)</td>
</tr>
<tr>
<td>0.1</td>
<td>Annual dose limit for members of the general public (1 mSv)</td>
</tr>
<tr>
<td></td>
<td>Maximum dose to members of the public from Three Mile Island accident (0.8 mSv)</td>
</tr>
<tr>
<td>0.01</td>
<td>Typical chest X-ray dose (0.1 mSv)</td>
</tr>
<tr>
<td></td>
<td>NB Power target for dose to the public from Point Lepreau emissions (50 μSv)</td>
</tr>
<tr>
<td></td>
<td>Dose from one return flight from NB to BC (40 μSv)</td>
</tr>
<tr>
<td>0.01</td>
<td>Annual dose from fall-out from past bomb tests (10 μSv)</td>
</tr>
<tr>
<td></td>
<td>Expected annual dose from Point Lepreau at maturity (5 μSv)</td>
</tr>
<tr>
<td>0.001</td>
<td>Annual dose from luminous signs, TV, smoke detectors</td>
</tr>
<tr>
<td></td>
<td>1990 dose to local residents from Point Lepreau emissions (1 μSv)</td>
</tr>
</tbody>
</table>

**A Log Scale of Radiation Doses in Society**

**SOMATIC EFFECTS** are those experienced by the exposed individual.
SOMATIC EFFECTS are those experienced by the exposed individual.

Cancer, Radiation Injury

HEREDITARY EFFECTS do not appear until subsequent generations are born.

Natural Mutations

Experimental Results with Mice

Hereditary Risk from Radiation
= 1% per Sv to either parent
Fig. 3.6. Cell Division
Long-Term Somatic Effects

Cell Mutation and Cancer

Radiation Induced Cancer in Humans:
Radium Dial Painters
Ankylosing Spondilitis
Japanese A-Bomb Survivors

Fatal Cancer Risk for Radiation Workers = 4%/Sv.

Fig. 3.7. Cancer Cases in Radium Dial Painters
An ACUTE exposure is one that is delivered in a short period of time, i.e., within a day.

A CHRONIC exposure is one that continues over long periods of time, i.e., months and years.

Short-term somatic effects:

1. the effects of radiation on living cells,
2. the self-renewal tissues in the body,
3. the functions of these tissues,
4. the effects of damage to these tissues, and
5. how we can treat injuries to these tissues.

Fig. 3.8. Dose Response Curve
The tissues in our bodies most affected by an acute radiation dose are those in which the cells are reproducing most rapidly. These are the skin, the blood-forming tissues, the gonads and the digestive system lining (called the GI tract).

<table>
<thead>
<tr>
<th>SKIN</th>
<th>Contains body fluids, protects underlying tissues, prevents bacterial invasion</th>
</tr>
</thead>
<tbody>
<tr>
<td>GONADS</td>
<td>Procreation, recreation</td>
</tr>
<tr>
<td>BLOOD:</td>
<td></td>
</tr>
<tr>
<td>Red Blood Cells</td>
<td>Transport oxygen</td>
</tr>
<tr>
<td>White Blood Cells</td>
<td>Gobble up bacteria and germs</td>
</tr>
<tr>
<td>Antibodies</td>
<td>Destroy or immobilize foreign molecules and bacteria</td>
</tr>
<tr>
<td>Platelets</td>
<td>Assist in blood-clotting mechanism</td>
</tr>
<tr>
<td>GI TRACT LINING</td>
<td>Secretes digestive enzymes, absorbs nourishment from food, prevents bacterial invasion</td>
</tr>
</tbody>
</table>
Rapidly Dividing Cells

Skin Infection

Skin Surface

Capillary Drainage

As bacteria drain into the lymph node, they are filtered out and destroyed

To Lymphatic System

Fig. 3.9. Cross-Section of Lymph Node

Piece of Small Intestine

Villi

Single Villus

The villi greatly increase the internal surface area of the intestine. They secrete digestive enzymes and aid food absorption

Fig. 3.10. Cross-Section of GI Tract
<table>
<thead>
<tr>
<th>Dose Range</th>
<th>Probable Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-250</td>
<td>No detectable clinical effects. Delayed effects may occur, but are highly unlikely.</td>
</tr>
<tr>
<td>250-1000</td>
<td>Slight blood changes with later recovery. Possible nausea. Serious delayed effects are possible but unlikely.</td>
</tr>
<tr>
<td>1000-2000</td>
<td>Nausea and fatigue, possible vomiting. Reduction in certain blood cells with delayed recovery.</td>
</tr>
<tr>
<td>2000-3000</td>
<td>Nausea and vomiting probable on first day. Two week latent period followed by general malaise, loss of appetite, diarrhoea, moderate loss of weight. Possible death in 2-6 weeks but for most healthy individuals recovery likely.</td>
</tr>
<tr>
<td>3000-6000</td>
<td>Nausea, vomiting and diarrhoea probable in first few hours. Short latent period followed by loss of appetite, general malaise, then haemorrhage, loss of weight, skin blotchiness, diarrhoea, inflammation of throat. Some deaths in first weeks, possible eventual death to 50% of individuals receiving about 3500 mGy without medical treatment.</td>
</tr>
<tr>
<td>over 6000</td>
<td>Nausea, vomiting and diarrhoea in first hours. Short latent period followed by diarrhoea, haemorrhage, skin blotchiness, inflammation of throat, fever by end of first week. Rapid weight loss and death as early as second week with possible eventual death of 100% of exposed individuals.</td>
</tr>
</tbody>
</table>
# Effects of Acute Radiation Dose of 4 - 6 Gy

<table>
<thead>
<tr>
<th>Time from Exposure</th>
<th>Biological Effects</th>
<th>Symptoms Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage I 0-48 hours</td>
<td>Body cells killed by the radiation disintegrate, releasing irritants into the blood system. The body senses this and assumes the last meal to be at fault.</td>
<td>Vomiting, nausea, loss of appetite, fatigue.</td>
</tr>
<tr>
<td>Stage II 2 days - 3 weeks</td>
<td>Following the removal of the irritants, there is a period during which the concentrations of all blood constituents are falling.</td>
<td>Symptoms disappear, and patient feels well.</td>
</tr>
<tr>
<td>Stage III after 2 weeks</td>
<td>There is now a severe shortage of blood constituents. Shortage of red cells: - poor oxygen transport. Lack of white cells: - open to infection. Lack of platelets: - no clotting of damaged blood vessels.</td>
<td>Severe lethargy, fever, bleeding, and blotchy skin. Fatalities occur here.</td>
</tr>
<tr>
<td>Stage IV after 8 weeks</td>
<td>For the radiation victim to survive Stage III, he must have sufficient blood-forming tissue to sustain life, perhaps aided by medical treatment consisting of massive doses of antibiotics, massive blood transfusions and possibly bone marrow transplants. The patient's condition will improve but up to six months are required before full recovery.</td>
<td></td>
</tr>
<tr>
<td><strong>TREATMENT</strong></td>
<td><strong>REASON</strong></td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>----------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Complete rest</td>
<td>Conservation of the blood constituents</td>
<td></td>
</tr>
<tr>
<td>Strict environmental sterility</td>
<td>Reduction of bacteria contact</td>
<td></td>
</tr>
<tr>
<td>Antibiotics</td>
<td>To aid body's bug-fighting equipment</td>
<td></td>
</tr>
<tr>
<td>Blood transfusions</td>
<td>Restoration of blood constituents</td>
<td></td>
</tr>
<tr>
<td>Intravenous feeding</td>
<td>To aid or replace normal digestive processes</td>
<td></td>
</tr>
</tbody>
</table>
Localised Doses to Specific Organs or Tissues

Skin

Blood-Forming System

GI Tract

Reproductive System

Thyroid

Eye

Central Nervous System

Developing Embryo and Foetus

Mortality
Malformations
Mental Retardation
Reduced Intelligence
Childhood Cancer
Lethal Acute Doses

3 - 5 Gy $LD_{50}$

$> 5$ Gy  Severe GI Damage = Death

$> 10$ Gy  Inflammation of Lungs: Death

$> 15$ Gy  Nervous System Damage
Death within few days

$> 100$ Gy  Death within few hours
Fig. 3.4. Background Radiation in Canada