Radiation Biological Effects
http://www.jlab.org/div_dept/train/rad_guide/effects.html

The human body is made up of many organs, and each organ of the body is made up of specialized cells. Ionizing radiation can potentially affect the normal operation of these cells. In this unit, we will discuss the potential for biological effects and risks due to ionizing radiation and put these potential risks into perspective when compared to other occupations and daily activities.

4.1 EFFECTS OF RADIATION ON CELLS

Biological effect begins with the ionization of atoms. The mechanism by which radiation causes damage to human tissue, or any other material, is by ionization of atoms in the material. Ionizing radiation absorbed by human tissue has enough energy to remove electrons from the atoms that make up molecules of the tissue. When the electron that was shared by the two atoms to form a molecular bond is dislodged by ionizing radiation, the bond is broken and thus, the molecule falls apart. This is a basic model for understanding radiation damage. When ionizing radiation interacts with cells, it may or may not strike a critical part of the cell. We consider the chromosomes to be the most critical part of the cell since they contain the genetic information and instructions required for the cell to perform its function and to make copies of itself for reproduction purposes. Also, there are very effective repair mechanisms at work constantly which repair cellular damage - including chromosome damage.

The following are possible effects of radiation on cells:

Cells are undamaged by the dose

Ionization may form chemically active substances which in some cases alter the structure of the cells. These alterations may be the same as those changes that occur naturally in the cell and may have no negative effect.

Cells are damaged, repair the damage and operate normally

Some ionizing events produce substances not normally found in the cell. These can lead to a breakdown of the cell structure and its components. Cells can repair the damage if it is limited. Even damage to the chromosomes is usually repaired. Many thousands of chromosome aberrations (changes) occur constantly in our bodies. We have effective mechanisms to repair these changes.
Cells are damaged, repair the damage and operate abnormally

If a damaged cell needs to perform a function before it has had time to repair itself, it will either be unable to perform the repair function or perform the function incorrectly or incompletely. The result may be cells that cannot perform their normal functions or that now are damaging to other cells. These altered cells may be unable to reproduce themselves or may reproduce at an uncontrolled rate. Such cells can be the underlying causes of cancers.

Cells die as a result of the damage

If a cell is extensively damaged by radiation, or damaged in such a way that reproduction is affected, the cell may die. Radiation damage to cells may depend on how sensitive the cells are to radiation.

All cells are not equally sensitive to radiation damage. In general, cells which divide rapidly and/or are relatively non-specialized tend to show effects at lower doses of radiation than those which are less rapidly dividing and more specialized. Examples of the more sensitive cells are those which produce blood. This system (called the hemopoietic system) is the most sensitive biological indicator of radiation exposure. The relative sensitivity of different human tissues to radiation can be seen by examining the progression of the Acute Radiation Syndrome on the following pages.

Review:

1) When a cell is damaged by radiation: □
   a. it always causes death to the cell
   b. it may repair the damage and operate normally
   c. it induces radiation poisoning
   d. there is a high probability of cancer

2) If radiation causes damage to a cell, and the cell is not effectively repaired: □
   e. the outcome is always cancer
   f. any future offspring of the person will carry the mutation
   g. the cell may be removed by the immune system
   h. the cell will die

3) The mechanism that causes damage to cells from radiation exposure is □.

The most radiosensitive cells in the body are those that divide □, and
4.2 ACUTE AND CHRONIC RADIATION DOSE

Potential biological effects depend on how much and how fast a radiation dose is received. Radiation doses can be grouped into two categories, acute and chronic dose.

4.2.1 Acute dose

An acute radiation dose is defined as a large dose (10 rad or greater, to the whole body) delivered during a short period of time (on the order of a few days at the most). If large enough, it may result in effects which are observable within a period of hours to weeks.

Acute doses can cause a pattern of clearly identifiable symptoms (syndromes). These conditions are referred to in general as Acute Radiation Syndrome. Radiation sickness symptoms are apparent following acute doses $>100$ rad. Acute whole body doses of $>450$ rad may result in a statistical expectation that 50% of the population exposed will die within 60 days without medical attention.

As in most illnesses, the specific symptoms, the therapy that a doctor might prescribe, and the prospects for recovery vary from one person to another and are generally dependent on the age and general health of the individual.

Blood-forming organ (Bone marrow) syndrome ($>100$ rad) is characterized by damage to cells that divide at the most rapid pace (such as bone marrow, the spleen and lymphatic tissue). Symptoms include internal bleeding, fatigue, bacterial infections, and fever.

Gastrointestinal tract syndrome ($>1000$ rad) is characterized by damage to cells that divide less rapidly (such as the linings of the stomach and intestines). Symptoms include nausea, vomiting, diarrhea, dehydration, electrolytic imbalance, loss of digestion ability, bleeding ulcers, and the symptoms of blood-forming organ syndrome.

Central nervous system syndrome ($>5000$ rad) is characterized by damage to cells that do not reproduce such as nerve cells. Symptoms include loss of coordination, confusion, coma, convulsions, shock, and the symptoms of the blood forming organ and gastrointestinal tract syndromes. Scientists now have evidence that death under these conditions is not caused by actual radiation damage to the nervous system, but rather from complications caused by internal bleeding, and fluid and pressure build-
up on the brain

Other effects from an acute dose include:

- 200 to 300 rad to the skin can result in the reddening of the skin (erythema), similar to a mild sunburn and may result in hair loss due to damage to hair follicles.
- 125 to 200 rad to the ovaries can result in prolonged or permanent suppression of menstruation in about fifty percent (50%) of women.
- 600 rad to the ovaries or testicles can result in permanent sterilization.
- 50 rad to the thyroid gland can result in benign (non cancerous) tumors.

As a group, the effects caused by acute doses are called *deterministic*. Broadly speaking, this means that severity of the effect is determined by the amount of dose received. Deterministic effects usually have some threshold level - below which, the effect will probably not occur, but above which the effect is expected. When the dose is above the threshold, *the severity of the effect increases as the dose increases.*

**4.2.2 Chronic dose**

A chronic dose is a relatively small amount of radiation received over a long period of time. The body is better equipped to tolerate a chronic dose than an acute dose. The body has time to repair damage because a smaller percentage of the cells need repair at any given time. The body also has time to replace dead or non-functioning cells with new, healthy cells. *This is the type of dose received as occupational exposure.*

The biological effects of high levels of radiation exposure are fairly well known, but the effects of low levels of radiation are more difficult to determine because the deterministic effects described above do not occur at these levels.

Since deterministic effects do not generally occur with chronic dose, in order to assess the risk of this exposure, we must look to other types of effects. Studies of people who have received high doses have shown a link between radiation dose and some delayed, or *latent* effects. These effects include some forms of cancer and genetic effects.

The risks for these effects are not directly measurable in populations of exposed workers, therefore the risk values at occupational levels are *estimates* based on risk factors measured at high doses.

To make these estimates, we must use a relationship between the occurrence of
cancer at high doses and the potential for cancer at low doses. Since the probability for cancer at high doses increases with increasing dose, this relationship is assumed to hold true with low doses. This type of risk model is called \textit{stochastic}.

Using this model and knowledge of high-dose cancer risks, we can calculate the \textit{probability} of cancer occurrence at a given dose. In this way, the rem can be used as a unit of \textit{potential harm}. For instance, the relatively well known cancer risk from doses in the range of hundreds of rem can be 'scaled down' to assess the potential risk from a dose of 100 mrem (0.1 rem). This scaling, or extrapolation is generally considered to be a conservative approach (may over-estimate the risk) to estimating low-dose risks.

We will use such estimates in a moment to help put the risks from exposure into perspective.

\section*{4.3 SOMATIC VS GENETIC EFFECTS}

\textbf{Somatic effects appear in the exposed person.} Somatic effects may be divided into two classes based on the rate at which the dose was received.

- \textbf{Prompt somatic effects} are those that occur soon after an acute dose (typically 10 rad or greater to the whole body in a short period of time). One example of a prompt effect is the temporary hair loss which occurs about three weeks after a dose of 400 rad to the scalp. New hair is expected to grow within two months after the dose, although the color and texture may be different.

- \textbf{Delayed somatic effects} are those that may occur years after radiation doses are received. Among the delayed effects thus far observed have been an increased potential for the development of cancer and cataracts. Since some forms of cancer are among the most probable delayed effects, the established dose limits were formulated with this risk in mind. These limits are set such that the calculated risk of cancer in radiation workers is an increase of a very small fraction of the normal cancer risk. (More on risk in a moment)

\textbf{Genetic, or heritable effects appear in the future generations of the exposed person as a result of radiation damage to the reproductive cells.} Genetic effects are abnormalities that may occur in the future generations of exposed individuals. They have been extensively studied in plants and animals, but risks for genetic effects in humans are seen to be considerably smaller than the risks for somatic effects. Therefore, the limits used to protect the exposed person from harm are equally effective to protect future generations from harm.

\textit{Did you know?} If you don't smoke, your overall risk for death from cancer - not
counting occupational radiation exposure - is about 20% - that is, about one in five Americans die from cancer.

**4.4 POSSIBLE CONSEQUENCES OF RADIATION DOSE**

The table below places the possible effects from acute and chronic dose into risk categories. We will look at a comparison of the amount of risk involved in a moment.

<table>
<thead>
<tr>
<th>Can acute dose cause -</th>
<th>Risk for deterministic effects?</th>
<th>Risk for stochastic effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes - Thresholds appear at various levels for different effects. Classified as &quot;early&quot; somatic effects.</td>
<td>Yes - Probability of occurrence varies in linear manner with dose. Classified as &quot;latent&quot; effects.</td>
</tr>
</tbody>
</table>

| Can chronic dose cause - | Some - A few deterministic effects can occur with long term exposure IF dose exceeds the threshold for the effect. Example- cataracts. (Dose limits are set such that these thresholds are not expected to be reached in a normal working lifetime.) | "Assumed" Yes - Probability for occurrence is extrapolation from dose effect curve for high doses. At occupational levels, epidemiological data cannot confirm or refute the calculated magnitude of risk. |

**4.5 PRENATAL RADIATION EXPOSURE**

Since an embryo/fetus is especially sensitive to radiation, (embryo/fetus cells are rapidly dividing) special considerations are given to pregnant workers. Protection of the embryo/fetus is important because the embryo/fetus is considered to be at the most radiosensitive stage of human development, particularly in the first 20 weeks of pregnancy.

Limits are established to protect the embryo/fetus from any potential effects which may occur from a significant amount of radiation. This radiation exposure may be the result of exposure to external sources of radiation or internal sources of radioactive material.

Potential effects associated with prenatal radiation doses include:
- Growth retardation
- Small head/brain size
- Mental retardation
- Childhood cancer

At present occupation dose limits, the actual probability of any of these effects occurring in the embryo/fetus from occupational exposure of the mother is small.

**Review:**

A large dose of radiation in a short period of time is called a(n) 6) [ ] dose.

7) If a person receives a rapid dose of 10 rads, what prompt effects are expected to be seen? [ ]

A relatively small dose over a long period (i.e. 2 rem/yr for 25 years), is known as 8) [ ] dose.

9) Prenatal exposure refers to radiation dose received: [ ]
   - o. during childhood
   - p. by an embryo/fetus during pregnancy
   - q. by an adult female prior to her becoming pregnant

**4.6 COMPARISON OF RISKS**

Acceptance of a risk is a highly personal matter. It requires a good deal of informed judgment. The risks associated with occupational radiation doses are considered acceptable as compared to other occupational risks by virtually all the scientific groups who have studied them. The following chart may help you put the potential risk of radiation into perspective when compared to other occupations and daily activities.

<table>
<thead>
<tr>
<th>Industry Type or Activity</th>
<th>Estimated Days of Life Expectancy Lost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity</td>
<td>Lost</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Smoking 20 cigarettes a day</td>
<td>2370 (6.5 years)</td>
</tr>
<tr>
<td>Overweight by 20%</td>
<td>985 (2.7 years)</td>
</tr>
<tr>
<td>Mining and Quarrying</td>
<td>328</td>
</tr>
<tr>
<td>Construction</td>
<td>302</td>
</tr>
<tr>
<td>Agriculture</td>
<td>277</td>
</tr>
<tr>
<td>Government</td>
<td>55</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>43</td>
</tr>
<tr>
<td>Radiation - 340 mrem/yr for 30 years</td>
<td>49</td>
</tr>
<tr>
<td>Radiation - 100 mrem/yr for 70 years</td>
<td>34</td>
</tr>
</tbody>
</table>

*Note:* The "life expectancy lost" value is determined from data on percentage of deaths due to the risk factor weighted by the average age at death. Since radiation related deaths are calculated values, they are based on the assumption of cancer as the cause of death, with the associated average age of death from cancer victims. All radiation risk values are based on the latest report from the National Academy of Sciences' *Biological Effects of Ionizing Radiation* (BEIR) series - BEIR V.

The table below presents another way of looking at health risks. This table lists activities calculated to have a one-in-a-million chance of causing death.

<table>
<thead>
<tr>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking 1.4 cigarettes (lung cancer)</td>
</tr>
<tr>
<td>Radiation dose of 10 mrem (cancer)</td>
</tr>
<tr>
<td>Eating 40 tablespoons of peanut butter (liver cancer)</td>
</tr>
<tr>
<td>Eating 100 charcoal broiled steaks (cancer)</td>
</tr>
<tr>
<td>Spending 2 days in New York City (air pollution)</td>
</tr>
<tr>
<td>Driving 40 miles in a car (accident)</td>
</tr>
<tr>
<td>Flying 2,500 miles in a jet (accident)</td>
</tr>
<tr>
<td>Canoeing for 6 minutes (accident)</td>
</tr>
</tbody>
</table>

*A Comparison:* Remember the 20% cancer risk mentioned earlier? If you receive
400 mrem/yr for 30 years, your calculated cancer risk is 20.5%. Smokers have a 25% cancer risk.

**Conclusions Regarding Health Risk**

We assume that any radiation exposure, no matter how small, carries with it some risk. However, we know that on average these risks are comparable to or smaller than risks we encounter in other activities or occupations that we consider safe. Since we have extensive control over how much radiation exposure we receive on the job, we can control and minimize this risk. The best approach is to keep our dose As Low As Reasonably Achievable, or ALARA - a term we will discuss in detail later. Minimizing the dose minimizes the risk.

**Review:**

10) If a person received a dose of 1 rem/yr for 50 years, what effects are expected to be seen?

11) A radiation dose of 5 rem/year for 50 years is thought to involve more risk than cigarette smoking. (Hint: this dose is about 20 times higher than the example of 340/year for 30 years.)

12) A burn to the skin is an example of a [ ] effect.

13) Induction of cancer due to radiation exposure is an example of a [ ] effect.

14) The risks of heritable genetic effects occurring from radiation are estimated to be [ ] than the risk for cancer induction.

15) The risk to a developing embryo/fetus from radiation exposure is greater than for an adult because its cells are [ ] and rapidly dividing.
ANSWERS TO UNIT 4 REVIEW QUESTIONS

1. b
2. c
3. ionization
4. rapidly
5. unspecialized
6. acute
7. none
8. chroniv
9. b
10. none
11. less
12. prompt somatic
13. delayed somatic
14. less
15. unspecialized