# Chem 481 Lecture Material
**3/11/09**

Health Physics

NRC Dose Limits

The NRC has established the following annual dose limits.

| Organ | NRC Limit (mrem/year) | Comments |
|---|---|---|
| Whole Body | 5000<br>(50 mSv/yr) | Includes dose from both internal and external sources. The Whole Body limit applies to exposure of the torso and head when the radiation is penetrating enough to irradiate tissues at a depth of 1 cm where the deeper blood-forming tissues are located. |
| Lens of the Eye | 15,000<br>(150 mSv/yr) | The Lens of the Eye limit applies to exposure of the eye to radiation penetrating enough to irradiate the lens, at a depth of 0.3 cm. |
| Extremities | 50,000<br>(500 mSv/yr) | The extremities include the arm or leg below the elbow or knee. The Extremities limit applies to exposure of the extremities when the radiation is penetrating enough to irradiate tissues at a depth of 1 cm. |
| Skin | 50,000<br>(500 mSv/yr) | The Skin limit applies to dose deposited in the skin when the radiation is penetrating enough to irradiate tissues at a depth of 0.007 cm. |
| Embryo/Fetus | 500 (for the entire pregnancy)<br>(5 mSv) | Applies only when a Declaration of Pregnancy has been submitted |
| Occupational exposure of a minor | 10% of the limits above | Applies to anyone under 18 years of age |
| Member of the general public | 100<br>(1 mSv/yr) | Applies to dose from licensed operation exclusive of background radiation dose |

Note that the limits above suggest an accumulated lifetime occupational exposure limit of (N-18) x 5 rem, where N is the age of the individual. The ICRP has also recommended limits on the quarterly dose as well as the annual dose.

## Ways to Minimize Radiation Dose

Use time distance and shielding to minimize your exposure to radiation.

Time - Reduce the time near radioactive materials. This can be accomplished by carefully planning all work in advance of manipulating radioactive substances.

Distance - Increase the distance between you and the source. Remember that radiation intensity decreases as $1/r^2$. Using tools (e.g., tongs) to handle radioactive sources can significantly reduce your exposure.

Shielding - Increase the shielding around a radioactive source. Dense absorbers such as lead are the most effective shields for gamma radiation.

Containment is another factor that can keep radioactive material from the environment and thus minimize your exposure to radiation. Working in rooms with a reduced air pressure decreases the unwanted release of radioactive substances into the environment.

## Risks of Radiation Exposure

### Mechanisms of Damage

Injury to living tissue results from the transfer of energy to atoms and molecules in the cellular structure. Ionizing radiation causes atoms and molecules to become ionized or excited. These excitations and ionizations can:

- produce free radicals.
- break chemical bonds.
- produce new chemical bonds and cross-linkage between macromolecules.
- damage molecules that regulate vital cell processes (e.g., DNA, RNA, proteins).

The cell can repair certain levels of cell damage. At low doses, such as that received every day from background radiation, cellular damage is rapidly repaired. At higher levels, cell death results. At extremely high doses, cells cannot be replaced quickly enough, and tissues fail to function.

## Tissue Sensitivity

In general, the radiation sensitivity of a tissue is:

- proportional to the rate of proliferation of its cells
- inversely proportional to the degree of cell differentiation

The following tissues and organs are listed from most radiosensitive to least radiosensitive.

| | Tissue/Organ |
|---|---|
| most sensitive | blood-forming organs |
| | reproductive organs |
| | skin |
| | bone and teeth |
| | muscle |
| least sensitive | nervous system |

This also means that a developing embryo is most sensitive to radiation during the early stages of differentiation, and an embryo/fetus is more sensitive to radiation exposure in the first trimester than in later trimesters.

## Prompt and Delayed Effects

Radiation effects can be categorized by when they appear.

Prompt effects: effects, including radiation sickness and radiation burns, seen immediately after large doses of radiation delivered over short periods of time

Delayed effects: effects such as cataract formation and cancer induction that may appear months or years after a radiation exposure

## Prompt Effects

High doses delivered to the whole body of healthy adults within short periods of time can produce effects such as blood component changes, fatigue, diarrhea, nausea and death. These effects will develop within hours, days or weeks, depending on the size of the dose. The larger the dose, the sooner a given effect will occur.

| Dose (rem) | Effect |
|---|---|
| 50 | blood count changes |
| 100 | vomiting (threshold) |
| 150 | mortality (threshold) |
| 320-360 | $LD_{50/60}$‡ (with minimal supportive care) |
| 480-540 | $LD_{50/60}$ (with supportive medical treatment) |
| 800 | 100% mortality (with best available treatment) |

‡ $LD_{50/60}$ is that dose at which 50% of the exposed population will die within 60 days.

## Partial Body Exposure

These acute effects apply only when the whole body is relatively uniformly irradiated. The effects can be significantly different when only portions of the body or an individual organ system are irradiated, such as might occur during the use of radiation for medical treatment. For example, a dose of 500 rem delivered uniformly to the whole body may cause death while a dose of 500 rem delivered to the skin will only cause hair loss and skin reddening.

## Delayed Effects of Radiation Exposure

Cataracts - Cataracts are induced when a dose exceeding approximately 200-300 rem is delivered to the lens of the eye. Radiation-induced cataracts may take many months to years to appear.

Cancer - Studies of people exposed to high doses of radiation have shown that there is a risk of cancer induction associated with high doses. The specific types of cancers associated with radiation exposure include leukemia, multiple myeloma, breast cancer, lung cancer, and skin cancer. Radiation-induced cancers may take 10 - 15 years or more to appear. There may be a risk of cancer at low doses as well.

It has been difficult to estimate cancer induction risks because most of the radiation exposures that humans receive are very close to background levels. At low dose levels of millirems to tens of rems, the risk of radiation-induced cancers is so low, that if the risk exists, it is not readily distinguishable from normal levels of cancer occurrence. In addition, leukemia or solid tumors induced by radiation are indistinguishable from those that result from other causes.

Using the linear no-threshold risk model (see figure below), the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (the BEIR Committee) in 2006 estimated that approximately 1 person in a hundred would be expected to develop cancer from a whole-body dose of 0.1 Sv (10 rem) above background, while approximately 42 persons out of 100 would be expected to develop cancer from other causes.

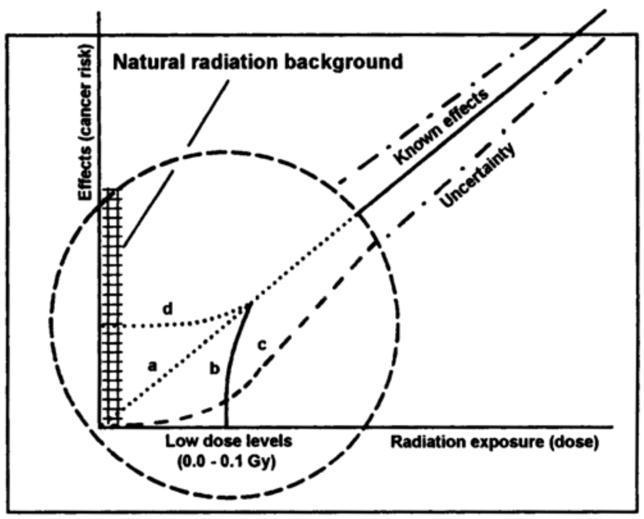


FIG. 18.10. Dose−effect relations in the known (with spread) and in the unknown (within circle) range, and some hypotheses.

Another way of stating the risk of radiation exposure is to note that a dose of 10 mrem creates a risk of death from cancer of approximately 1 in 1,000,000. You can put this into perspective by considering other ‘1 in a million chance of death’ activities.

- smoking 1.4 cigarettes in a lifetime (lung cancer)
- eating 40 tablespoons of peanut butter (aflatoxin)
- spending two days in New York City (air pollution)
- driving 40 miles in a car (accident)
- flying 2500 miles in a jet (accident)
- canoeing for 6 minutes (drowning)
- receiving a dose of 10 mrem of radiation (cancer)

## Genetic Effects

There is no direct evidence of radiation-induced genetic effects in humans, even at high doses. Various analyses indicate that the rate of genetic disorders produced in humans is expected to be extremely low, on the order of a few disorders per million live born per rem of parental exposure.

## Prenatal Radiation Exposure

Rapidly proliferating and differentiating tissues are most sensitive to radiation damage. Consequently, radiation exposure can produce developmental problems, particularly in the developing brain, when an embryo/fetus is exposed prenatally.

The developmental conditions most commonly associated with prenatal radiation exposure include low birth weight, microcephaly, mental retardation, and other neurological problems. These effects are related to the developmental stage at which the exposure occurs. The threshold dose for developmental effects is approximately 10 rem.

The evidence that the developing embryo/fetus is more sensitive to radiation-induced cancer is inconclusive, but it is prudent to assume that there is some increased sensitivity.

## External and Internal Radiation Hazards

Because gamma radiation is much more penetrating than alpha or beta radiation it poses the greatest threat when the source is external to the body. However, for radioactive material that has been ingested, alpha radiation can be the worst. In the table below, several commonly used radionuclides are listed along with the tissue/organ where they do the most damage (critical organ). The effective half life [$t_{½}$ (eff)] reflects both the decay process [$t_{½}$ (rad)] and elimination from the body [biological half life, $t_{½}$ (biol)]. The maximum permissible body burden (MPBB) is the quantity of a specific radionuclide that delivers the maximum permissible dose to the critical organ. Note that many alpha emitters concentrate in the bone and have very long effective half lives.

| Nuclide | Critical organ | $t_{1/2}$(eff) (days) | MPBB ($\mu$Ci) |
|---|---|---|---|
| $^{3}$H | Body tissue | 12 | $10^3$ |
| $^{14}$C | Fat | 12 | 300 |
| $^{24}$Na | GI (SI) | 0.17 | 7 |
| $^{32}$P | Bone | 14 | 6 |
| $^{35}$S | Testis | 76 | 90 |
| $^{42}$K | GI (S) | 0.04 | 10 |
| $^{51}$Cr | GI (LLI) | 0.75 | 800 |
| $^{55}$Fe | Spleen | 390 | $10^3$ |
| $^{59}$Fe | GI (LLI) | 0.75 | 20 |
| $^{60}$Co | GI (LLI) | 0.75 | 10 |
| $^{64}$Cu | GI (LLI) | 0.75 | 10 |
| $^{65}$Zn | Total | 190 | 60 |
| $^{85}$Kr | Total | | |
| $^{90}$Sr | Bone | $6.4 \times 10^3$ | 2 |
| $^{95}$Zr | GI (LLI) | 0.75 | 20 |
| $^{99}$Tc | GI (LLI) | 0.75 | 10 |
| $^{106}$Ru | GI (LLI) | 0.75 | 3 |
| $^{129}$I | Thyroid | 140 | 3 |
| $^{131}$I | Thyroid | 7.6 | 0.7 |
| $^{135}$Xe | Total | | |
| $^{137}$Cs | Total | 70 | 30 |
| $^{140}$Ba | GI (LLI) | 0.75 | 4 |
| $^{144}$Ce | GI (LLI) | 0.75 | 5 |
| $^{198}$Au | GI (LLI) | 0.75 | 20 |
| $^{210}$Po | Spleen | 42 | 0.03 |
| $^{222}$Rn* | Lung | (3.8) | (0.01) |
| $^{226}$Ra* | Bone | $1.6 \times 10^4$ | 0.1 |
| $^{230}$Th | Bone | $7.3 \times 10^4$ | 0.05 |
| $^{232}$Th* | Bone | $7.3 \times 10^4$ | 0.04 |
| $^{233}$U | Bone | 300 | 0.05 |
| $^{238}$U | Kidneys | 15 | $5 \times 10^{-3}$ |
| $^{238}$Pu | Bone | $2.3 \times 10^4$ | 0.04 |
| $^{239}$Pu | Bone | $7.2 \times 10^4$ | 0.04 |
| $^{241}$Am | Kidneys | $2.3 \times 10^4$ | 0.1 |

## Dose Estimates

The calculation of radiation dose from a particular source is rather complicated, however, there are useful rules of thumb for estimating the dose rate from gamma and beta sources.

For gamma radiation

$$exposure\ rate\ (mR/hr) \simeq \frac{6(mCi)\,n\,E_\gamma}{d^2}$$

where mCi is the millicurie activity of the source;

n is the number of gamma rays emitted per decay;

$E_\gamma$ is the average energy of the emitted gamma rays (MeV);

d is the distance to the source (ft).

Since exposure rate ~ dose rate = equivalent dose rate for gamma radiation, this rule provides an estimate of the dose rate (mrad/hr) and the equivalent dose rate (mrem/hr).

For higher-energy beta sources

$$dose\ rate\ (mrad/hr) \simeq \frac{338{,}000\,(mCi)}{d^2}$$

where mCi is the millicurie activity of the source;

d is the distance to the source (cm).

<u>Dosimetry</u>

Individual radiation exposure can be monitored by using a personal dosimeter when working with radioactive sources. Such dosimeters can determine doses from energetic beta, x-ray, gamma and neutron radiation. The sensitivity depends on the type of dosimeter and type of radiation. Common dosimeters (see figures below) are quartz fiber, film badges, thermoluminescence dosimeters (TLD), optically stimulated luminescence dosimeters (OSL).