Pearson

# 20.11: The Effects of Radiation on Life

As we discussed in Section 20.3, the energy associated with radioactivity can ionize molecules. When radiation ionizes important molecules in living cells, problems can develop. The ingestion of radioactive materials—especially alpha and beta emitters—is particularly dangerous because the radioactivity, once inside the body, can do even more damage. We divide the effects of radiation into three different types: acute radiation damage, increased cancer risk, and genetic defects.

## Acute Radiation Damage

Acute radiation damage results from exposure to large amounts of radiation in a short period of time. The main sources of this kind of exposure are nuclear bombs and exposed nuclear reactor cores. These high levels of radiation kill large numbers of cells. Rapidly dividing cells, such as those in the immune system and the intestinal lining, are most susceptible. Consequently, people exposed to high levels of radiation have weakened immune systems and a lowered ability to absorb nutrients from food. In milder cases, recovery is possible with time. In more extreme cases, death results, often from infection.

## Increased Cancer Risk

Lower doses of radiation over extended periods of time can increase cancer risk. Radiation increases cancer risk because it can damage DNA, the molecules in cells that carry instructions for cell growth and replication. When the DNA within a cell is damaged, the cell normally dies. Occasionally, however, changes in DNA cause cells to grow abnormally and to become cancerous. These cancerous cells grow into tumors that can spread and, in some cases, cause death. Cancer risk increases with increasing radiation exposure. However, cancer is so prevalent and has so many convoluted causes that determining an exact exposure level for increased cancer risk from radiation exposure is difficult.



## Genetic Defects

Another possible effect of radiation exposure is genetic defects in future generations. If radiation damages the DNA of reproductive cells—such as eggs or sperm—then the offspring that develop from those cells may have genetic abnormalities. Genetic defects of this type have been observed in laboratory animals exposed to high levels of radiation. However, such genetic defects—with a clear causal connection to radiation exposure—have yet to be verified in humans, even in studies of Hiroshima survivors.

## Measuring Radiation Exposure and Dose

We measure radiation exposure in a number of different ways. One method is to measure **exposure**, the number of decay events to which a person is exposed. The unit used for this type of exposure measurement is the *curie* (Ci), defined as $3.7 \times 10^{10}$ decay events per second. A person exposed to a curie of radiation from an alpha emitter is bombarded by $3.7 \times 10^{10}$ alpha particles per second. However, recall that different kinds of radiation produce different effects. For example, we know that alpha radiation has much greater ionizing power than beta radiation. Consequently, a certain number of alpha decays occurring within a person's body (due to the ingestion of an alpha emitter) would do more damage than the same number of beta decays. If the alpha emitter and beta emitter were external to the body, however, the radiation from the alpha emitter would largely be stopped by clothing or the skin (due to the low penetrating power of alpha radiation), while the radiation from the beta emitter could penetrate the skin and cause more damage. Consequently, the curie is not an effective measure of how much biological tissue damage the radiation actually does.

A better way to assess radiation exposure is to measure radiation **dose**, the amount of energy actually absorbed by body tissue. The units used for this type of exposure measurement are the *gray* (Gy), which corresponds to 1 J of energy absorbed per kilogram of body tissue, and the *rad* (for *r*adiation *a*bsorbed *d*ose), which corresponds to 0.01 Gy.

$$\begin{aligned} 1 \text{ gray (Gy)} &= 1 \text{ J/kg body tissue} \\ 1 \text{ rad} &= 0.01 \text{ J/kg body tissue} \end{aligned}$$

Although the gray and the rad measure the actual energy absorbed by bodily tissues, they still do not account for the amount of damage to biological molecules caused by that energy absorption, which differs from one type of radiation to another and from one type of biological tissue to another. For example, when a gamma ray passes through biological tissue, the energy absorbed is spread out over the long distance that the radiation travels through the body, resulting in a low ionization density within the tissue. When an alpha particle passes through biological tissue, in contrast, the energy is absorbed over a much shorter distance, resulting in a much higher ionization density. The higher ionization density results in greater damage, even though the amount of energy absorbed by the tissue might be the same.

Consequently, a correction factor, called the **biological effectiveness factor**, or **RBE** (for *R*elative *B*iological *E*ffectiveness), is usually multiplied by the dose in rads to obtain the dose in a unit called the **rem** for *r*oentgen *e*quivalent *m*an.

$$\text{dose in rads} \times \text{biological effectiveness factor} = \text{dose in rems}$$

> A *roentgen* is the amount of radiation that produces $2.58 \times 10^{-1}$ C of charge per kg of air.

The biological effectiveness factor for alpha radiation, for example, is much higher than that for gamma radiation.

> The SI unit that corresponds to the rem is the sievert (Sv). However, the rem is still commonly used in the United States. The conversion factor is $1 \text{ rem} = 0.01 \text{ Sv}$.

On average, each of us is exposed to approximately 310 mrem of radiation per year from the natural sources listed in Table 20.4. The majority of this exposure comes from radon, one of the products in the uranium decay series. As you can see from Table 20.4, however, some medical procedures also involve exposure levels similar to those received from natural sources. The increased use of computed tomography (CT) scans over the last decade—which have associated exposures of 200–1600 mrem—has raised some concerns about the overuse of that technology in medicine.



Table 20.4 **Radiation Dose by Source for Persons Living in the United States**

| Source | Dose |
|---|---|
| **Natural Radiation** | |
| A 5-hour jet airplane ride | 2.5 mrem/trip (0.5 mrem/hr at 39,000 f |
| Cosmic radiation from outer space | 27 mrem/yr (whole body dose) |
| Terrestrial radiation | 28 mrem/yr (whole body dose) |
| Natural radionuclides in the body | 35 mrem/yr (whole body dose) |
| Radon gas | 200 mrem/yr (lung dose) |
| **Diagnostic Medical Procedures** | |
| Chest X-ray | 8 mrem (whole body dose) |
| Dental X-rays (panoramic) | 30 mrem (skin dose) |
| Dental X-rays (two bitewings) | 80 mrem (skin dose) |
| Mammogram | 138 mrem per image |
| Barium enema (X-ray portion only) | 406 mrem (bone marrow dose) |
| Upper gastrointestinal tract test (X-ray portion only) | 244 mrem (bone marrow dose) |

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|---|---|
| Upper gastrointestinal tract test (X-ray portion only) | 244 mrem (bone marrow dose) |
| Thallium heart scan | 500 mrem (whole body dose) |
| **Consumer Products** | |
| Building materials | 3.5 mrem/yr (whole body dose) |
| Luminous watches (H-3 and Pm-147) | 0.04–0.1 mrem/yr (whole body dose) |
| Tobacco products (to smokers of 30 cigarettes per day) | 16,000 mrem/yr (bronchial epithelial do |

Source: Department of Health and Human Services, National Institutes of Health.

It takes much more than the average natural radiation dose or the dose from a medical diagnostic procedure to produce significant health effects in humans. The first measurable effect, a decreased white blood cell count, occurs at instantaneous exposures of approximately 20 rem (Table 20.5). Exposures of 100 rem produce a definite increase in cancer risk, and exposures of over 500 rem often result in death.

Table 20.5 **Effects of Radiation Exposure**

| Approximate Dose (rem) | Probable Outcome |
|---|---|
| 20–100 | Decreased white blood cell count; possible increase in cancer risk |
| 100–400 | Radiation sickness including vomiting and diarrhea; skin lesions; incr |
| 500 | Death (often within 2 months) |
| 1000 | Death (often within 2 weeks) |
| 2000 | Death (within hours) |

Conceptual Connection 20.5 **Radiation Dose**

Interactive