IONIZING RADIATION: SOURCES AND EXPOSURES

We are constantly exposed to ionizing radiation. It is in the air we breathe and in the things around us. It reaches us from outer space. It also is used extensively in medical diagnosis and treatment. It is part of our lives.

2.1 Ionizing Radiation

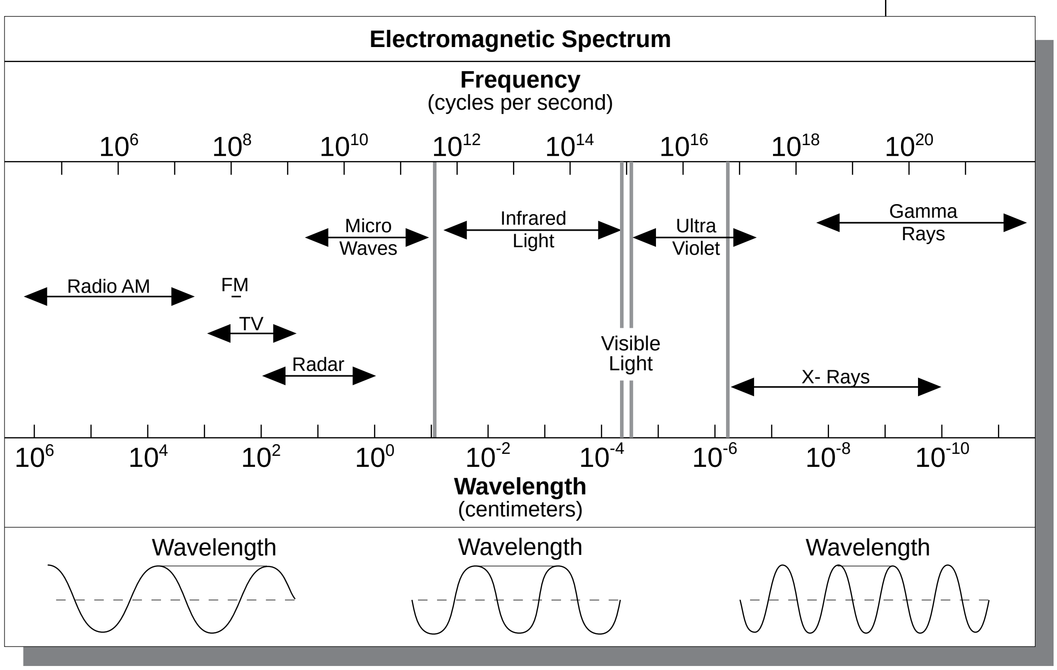
What are some forms of ionizing radiation?

Some important forms of ionizing radiation are the *alpha* and *beta particles*, *gamma rays*, and *X-rays* emitted from radioactive materials. The *cosmic radiation* that reaches the Earth from outer space is also ionizing. Ionizing radiation, in the form of X-rays, is produced by X-ray machines.

What are gamma rays and X-rays?

What is the electromagnetic spectrum?

Gamma rays and X-rays are waves of pure energy, without mass or charge. They are ionizing. They appear at the high frequency (high energy) end of what we call the *electromagnetic spectrum* shown below. The various non-ionizing radiations (radio and television waves, microwaves, light, etc.) occupy the lower frequency (lower energy) part of the electromagnetic spectrum.

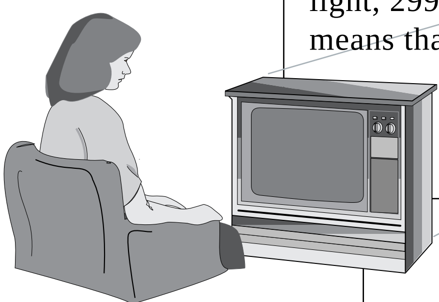


The gamma rays and X-rays emitted by radioactive materials are waves of pure energy. Like all electromagnetic waves, they travel at the speed of light and their energies are determined by their frequencies. Alpha and beta particles are not part of the electromagnetic spectrum. They travel at much less than the speed of light and their energies are functions of their velocities and masses.

How fast does electromagnetic radiation travel? What determines its energy?

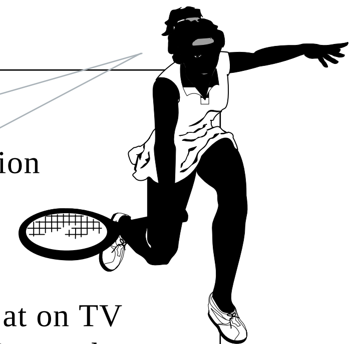
All types of electromagnetic radiation, ionizing and non-ionizing, travel at the speed of light. Their energies are not determined by their speed (the speed of light) but by their frequencies, the number of waves or cycles per second. (Alpha and beta particles are **not** part of the electromagnetic spectrum. They travel at very fast rates but slower than the speed of light.)

How is electromagnetic radiation important in your life?



The Speed of Light

It may not have occurred to you that all electromagnetic radiation travels at the speed of light and has an immediate bearing on your life. Radio and television waves travel at the speed of light, 299,274 kilometers (186,000 miles) per second. That means that a live broadcast you may be listening to or looking at on TV (from the other side of the world) is actually happening at the very second you are hearing or seeing it. If such signals had to circle the Earth, they would circle the Earth seven times every second.

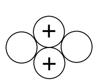


2.2 Radiation Injury

How do the types of ionizing radiation differ?

Because it can knock electrons from the atoms and molecules in its path, ionizing radiation can cause chemical and/or physical changes in human tissue. However, the various types of ionizing radiation differ widely in their abilities to penetrate tissue and deposit energy through ionization.

What are some properties of alpha particles?



Alpha particles, for instance, are relatively large and carry a double positive charge. They are not very penetrating and can be stopped by a piece of paper. They travel extremely short distances in human tissue but deposit all their energies along their short paths, doing a relatively large amount of damage.

What are some properties of beta particles?

Beta particles (electrons) are extremely small compared to alpha particles and carry a single negative charge. They are more penetrating than alpha particles, but can be stopped by thin aluminum metal. They travel much longer distances in human tissue and deposit much less energy along their paths.

What are some properties of gamma rays and X-rays?

Gamma rays and X-rays, having no mass or electrical charge, can travel extremely long distances in human tissue compared to particle radiation (alpha and beta). They deposit much less energy along their paths, but can damage internal organs.

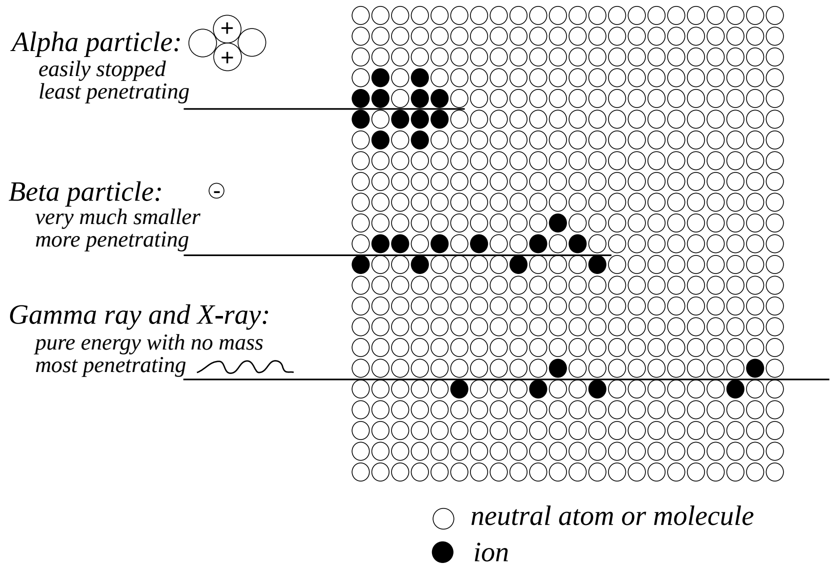
Measuring Potential Health Effects of Ionizing Radiation

The basic unit for measuring radiation received is the *rad* (radiation absorbed dose). One rad equals the absorption of 100 ergs[1] in every gram of tissue exposed to radiation.

To show biological risk, rads are converted to *rems*. The rem (radiation equivalent man) is adjusted to take into account the type of radiation absorbed and the likelihood of damage from the different types of radiation. Exposures are normally in fractions of a rem, so the commonly used unit of exposure is the *millirem* (*mrem*).

1 rem = 1000 millirem

[1]*erg—a small but measurable amount of energy (See Glossary)*



This drawing shows what the "paths" of different types of radiation might look like. Ions are formed when a particle, gamma ray, or X-ray penetrates tissue. Because alpha particles deposit all their energy along a short path, they are more likely to cause damage.

Source: Adapted from Radiation Activities for Youth Series, *copyright The Pennsylvania State University, Nuclear Engineering Department, 1988. Permission for use granted.*

How is ionizing radiation measured? What is a rad? What is a rem? What is a millirem?

Acute Exposures

The effect of radiation on the body depends mostly on how long the exposure lasted, how much energy was absorbed, and the type and number of cells that were affected. Scientists have data about high exposures received in a short time and generally agree on the effects. For instance, radiation exposures of over 100,000 millirem usually cause radiation sickness. Exposures of over 500,000 millirem received in just a few days will usually result in death. Fortunately, such *acute exposures* are extremely unusual.

What does the effect of radiation depend on?

What are some effects of acute exposures?

Low Exposures

Very little reliable information is available about the effects of human exposure to low doses of radiation. As a result, different theories predict different effects for low exposures.

Do scientists agree about the effects of radiation?

There is disagreement among scientists about the risk of harm from exposure to low levels of ionizing radiation. A minority of scientists believe that low levels of radiation have a relatively high risk of a harmful effect. However, most scientists believe that low levels of radiation have an extremely low risk of a harmful effect on health.

Can the body repair changes caused by radiation?

What is the possibility of a delayed effect?

Our bodies can usually repair cell damage that occurs naturally. Therefore, if radiation exposure is low, or the radiation is received over a long period of time, the body can usually repair itself. However, the body sometimes may repair damage incorrectly. As the incorrectly repaired cells divide and form new cells, the new cells carry the incorrect repair. There is then a possibility of a harmful effect that is delayed and does not show up for many years. It is also possible that there will be no harmful effect. Two types of possible delayed effects are cancer and genetic defects.

Why is it hard to determine the effect of exposure to low levels of ionizing radiation?

Many things can cause cancer or genetic defects. These effects cannot be distinguished from those caused by radiation. So, it is very hard to determine exactly the effects of exposure to low levels of ionizing radiation.

Minimizing Risk

Why is some risk assumed for even small exposures?

Because we cannot prove that there is no effect, some risk is assumed for even small exposures. Therefore, it is important to know the sources of ionizing radiation and to avoid unnecessary exposure.

2.3 Sources of Ionizing Radiation

Natural Background Radiation

Ionizing radiation sources include both natural and manmade sources. The main natural sources are cosmic radiation, the rocks and soils around us, radon and its decay products in the atmosphere, and the radioactive materials in our bodies. The radiation from rocks and soil is often referred to as *terrestrial* radiation. The sum of the exposures from cosmic radiation, terrestrial radiation, and the radiation from the atmosphere is called *background radiation*.

What are some natural sources?

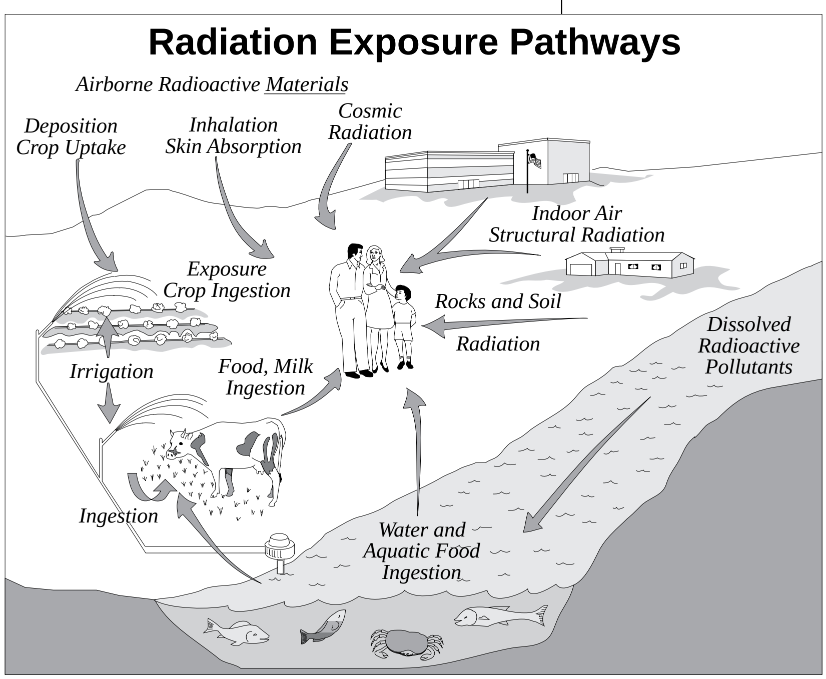
What is terrestrial radiation?

What is background radiation?

Manmade Radiation

The main sources of manmade radiation are the X-rays and the radioactive isotopes (radioisotopes) used in medical practice. Other manmade sources include nuclear industry facilities and consumer products, such as lantern mantles used for camping. Still other manmade sources are those related to technology. One example is ash from coal-fired powerplants that contains the radioactivity originally present in the coal, but in more concentrated form. Other examples are increased terrestrial radiation from disturbing earth during construction and road building, and fertilizers made from phosphates.

What are some manmade sources?



There are a variety of pathways by which people are exposed to ionizing radiation. Cosmic radiation, immersion in and inhalation of indoor and outdoor air, exposure to radiation from rocks and soil, and ingestion of food and drink are most important.

How much radiation is the average American exposed to per year from all sources?

2.4 Ionizing Radiation Exposures

The average American is exposed to about 360 millirem of ionizing radiation per year. This average exposure comes from all sources, including radon and medical exposures.

Ionizing Radiation Exposure in the United States

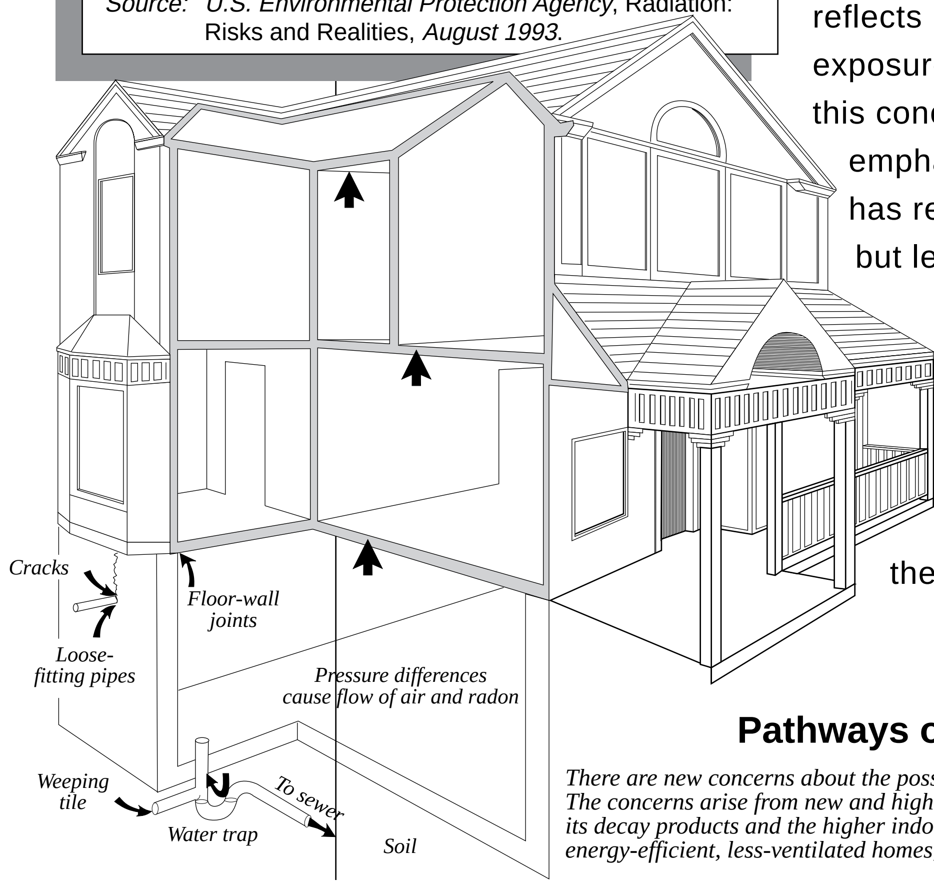
Source	**Estimated average annual whole-body exposure** (millirem)
Natural:	
Radon	200
Internal radiation	39
Cosmic radiation	31
Terrestrial radiation	28
Manmade:	
X-rays and nuclear medicine	50
Consumer products (including drinking water)	11
Miscellaneous	1
Total	**360**

Source: U.S. Environmental Protection Agency, Radiation: Risks and Realities, *August 1993*.

The table (left) shows how much each source of ionizing radiation contributes to our average annual exposure. The exposure from radon and its decay products is listed under natural sources. The category "other" under natural sources gives the sum of the exposures from cosmic radiation, terrestrial radiation, and internal radiation (radiation inside the body).

The estimated exposure from radon and its decay products reflects increased concern about exposure to radon. One reason for this concern is that today's emphasis on energy efficiency has resulted in better insulated but less well ventilated buildings. This has increased the likelihood of higher indoor radon concentrations.

In the previous table, the exposure from consumer



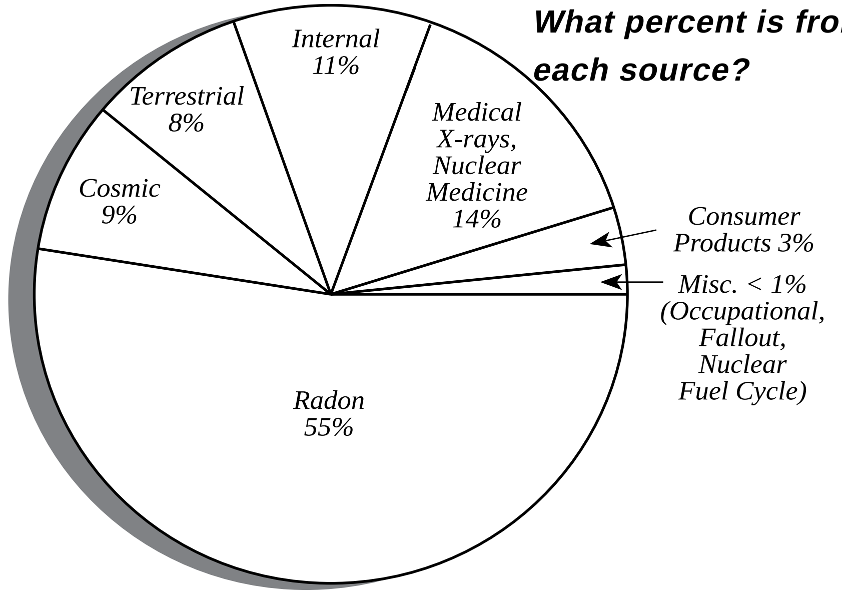
Pathways of Radon

There are new concerns about the possible health effects from radon in indoor air. The concerns arise from new and higher estimates of exposures from radon and its decay products and the higher indoor concentrations resulting from energy-efficient, less-ventilated homes, schools, and other buildings.

products does not include that received from smoking. Although scientists agree that there is radiation exposure from smoking,* current information does not permit a meaningful statistical estimate.

The pie chart at the right shows the percent each source of ionizing radiation contributes to the average individual's exposure of 360 millirem per year.

What percent is from each source?



Source: U.S. Environmental Protection Agency, Radiation: Risks and Realities, *August 1993.*

**Source: National Research Council: Committee on the Biological Effects of Ionizing Radiation (BEIR V)* The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, *1990, p. 19.*

2.5 Cosmic Radiation

Cosmic radiation originates outside the Earth's atmosphere and is composed of highly penetrating radiation of all sorts, both particles and rays. At sea level, the average annual exposure from cosmic radiation is 26 millirem. The following table shows the effect of elevation on cosmic radiation exposures.

What is the average exposure from cosmic radiation?
How does elevation affect exposure to cosmic radiation? Why?

Effect of Elevation, in Feet, on Cosmic Radiation Exposures (MREM/YR)

(Exposures reflect 10% reduction for shielding from buildings/structures)

0 (sea level)	26	4,000	39
500	27	6,000	52
1,000	28	8,000	74
2,000	31	10,000	107

Source: National Research Council: Committee on the Biological Effects of Ionizing Radiation (BEIR III) The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, 1980. *(The latest version of this report, BEIR V, does not provide additional information on the effect of elevation on exposure.)*

Jet Flight Exposure

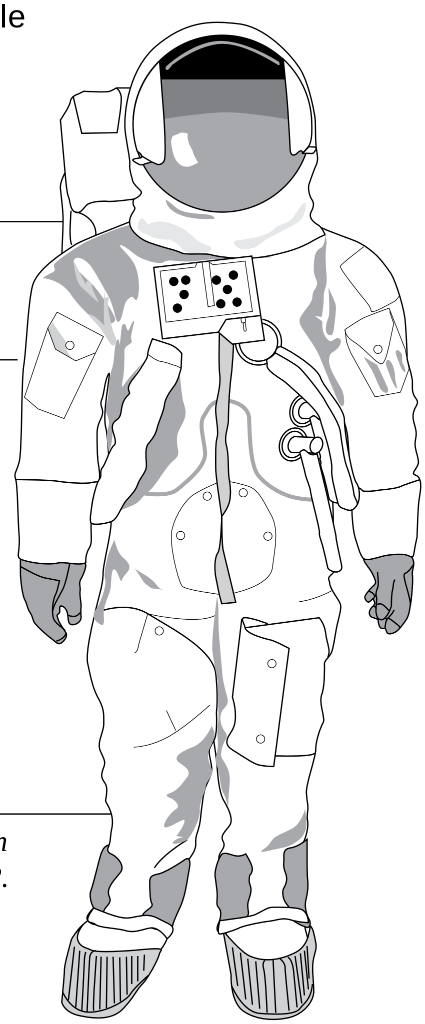
Do we get increased exposure from jet flights?

Because the atmosphere gets less dense as elevation increases, the cosmic radiation exposure rises with increasing elevation. Therefore, passengers on a jet airplane receive an additional radiation exposure from cosmic rays during the flight. According to the National Council on Radiation Protection and Measurements, cosmic exposure at 11,887 meters (39,000 feet) is 0.5 millirem per hour.

Apollo Flight Exposures

Did the astronauts receive increased exposure?

It may not have occurred to you that our astronauts in Earth orbit or on Moon missions received increased radiation exposure from cosmic rays. The table shows the estimated exposures received by our astronauts on the various Apollo missions.



Estimated Exposures Received By Astronauts On the Apollo Missions

Apollo Mission Number	Launch date	Type of orbit	Duration Mission (hours)	Exposure (mrem)
VII	Aug. 1968	Earth orbital	260	120
VIII	Dec. 1968	Circumlunar	147	185
IX	Feb. 1969	Earth orbital	241	210
X	May 1969	Circumlunar	192	470
XI	July 1969	Lunar landing	182	200
XII	Nov. 1969	Lunar landing	236	~200
XIV	Jan. 1971	Lunar landing	286	~500
XV	July 1971	Lunar landing	286	~200

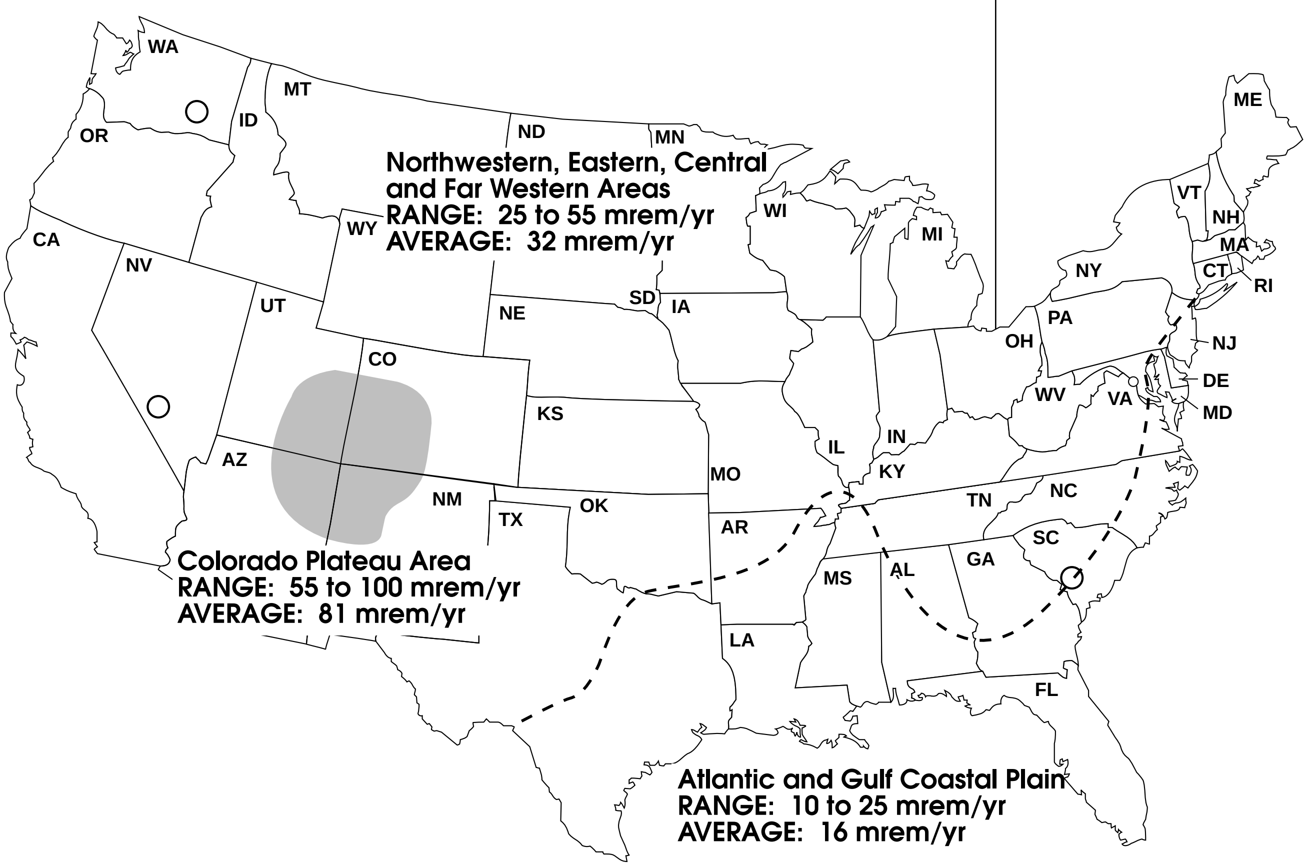
Source: United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), Ionizing Radiation: Sources and Biological Effects, *1982.*

2.6 Terrestrial Radiation

The average exposure to an individual in the United States from terrestrial radiation is about 28 millirem per year. However, terrestrial exposures do show some variations over the country, and the average annual exposure of 28 millirem takes population densities in the regions into account. On the coastal plains of the Atlantic and Gulf regions, the average exposure is 16 millirem per year. This average takes population density in the regions into account. In a region on the eastern slopes of the Rocky Mountains where Denver is located, the average terrestrial radiation exposure is 63 millirem per year. For the rest of the country, it is about 32 millirem per year, with little variation. The main contributors to terrestrial radiation are a radioactive isotope (radioisotope) of potassium and radioisotopes of the uranium and thorium series.

What is the average U.S. exposure from terrestrial radiation?

What elements contribute to terrestrial radiation?



Source: *Adapted from National Research Council: Committee on the Biological Effects of Ionizing Radiation (BEIR III),* The Effects on the Populations of Exposure to Low Levels of Ionizing Radiation, *Washington, Protection and Measurements,* NCRP Report No. 93, September 1987, p. 10. *Also from U.S. Environmental Protection Agency,* Radiation: Risks and Realities, *August 1993.*

2.7 Radioactivity in Food

How much exposure does our food contribute?

Potassium and carbon in the food we eat contribute about 19 millirem to the average annual internal exposure of 39-40 millirem. The main contributor to the exposure (about 18 millirem) is from potassium-40, a radioactive isotope of naturally occurring potassium. Slightly more than 1 millirem is contributed by radioactive carbon-14 in our food.

Like uranium and thorium, potassium-40 was present when the Earth was formed. Unlike potassium-40, radioactive carbon-14 is formed by the action of cosmic radiation on our atmosphere.

How does potassium become part of our food?

Each gram of natural potassium has a very small amount of radioactive potassium-40. Average soil contains about 1.5 percent natural potassium and is the source of potassium in our food. Carbon-14 in the atmosphere becomes incorporated in the natural carbon of growing things that are the source of carbon in our food.

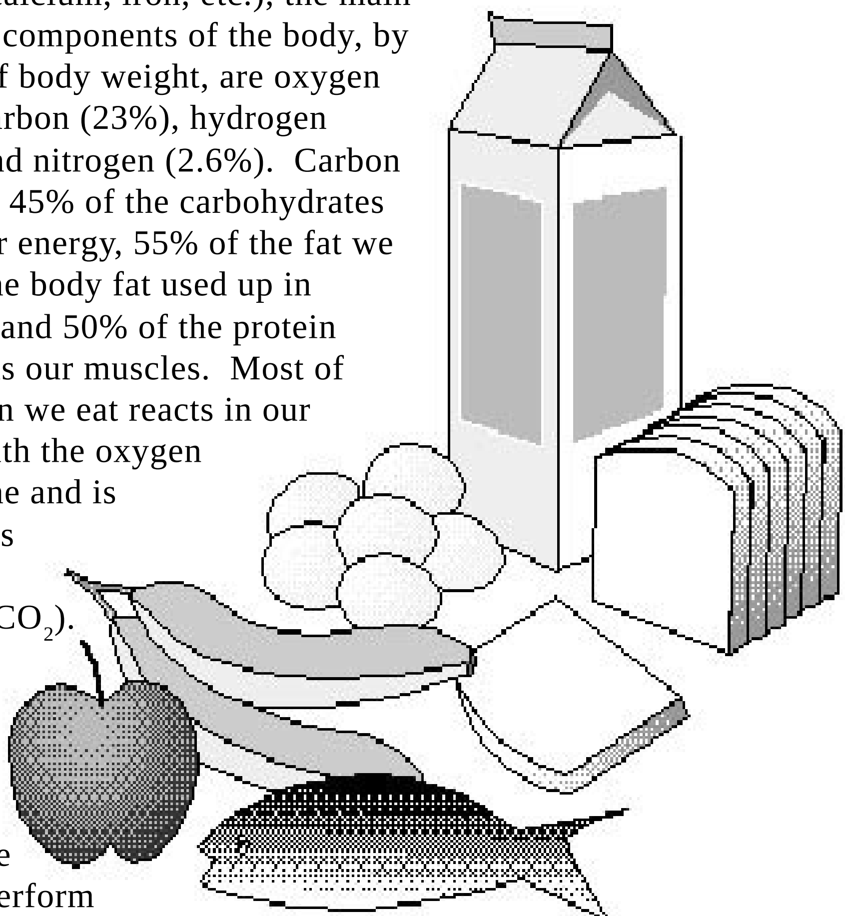
How much potassium and carbon are in our bodies?

The body maintains a natural potassium content of about 0.2 percent by weight and a carbon level of about 23 percent. Small amounts of the potassium and carbon in the food we eat are used to maintain these levels, and the rest is eliminated.

Potassium and Carbon in Our Bodies

Potassium is important for healthy body function. It helps maintain fluid pressure and balance within cells. It is also important in normal muscle and nerve response and in maintaining heart rhythm. Even a temporary potassium deficiency can result in serious upsets of body functions.

Carbon is also important. Not counting the small amounts of minerals in the body (such as potassium, sodium, calcium, iron, etc.), the main chemical components of the body, by percent of body weight, are oxygen (61%), carbon (23%), hydrogen (10%), and nitrogen (2.6%). Carbon makes up 45% of the carbohydrates we eat for energy, 55% of the fat we eat and the body fat used up in exercise, and 50% of the protein that builds our muscles. Most of the carbon we eat reacts in our bodies with the oxygen we breathe and is exhaled as carbon dioxide (CO_2).

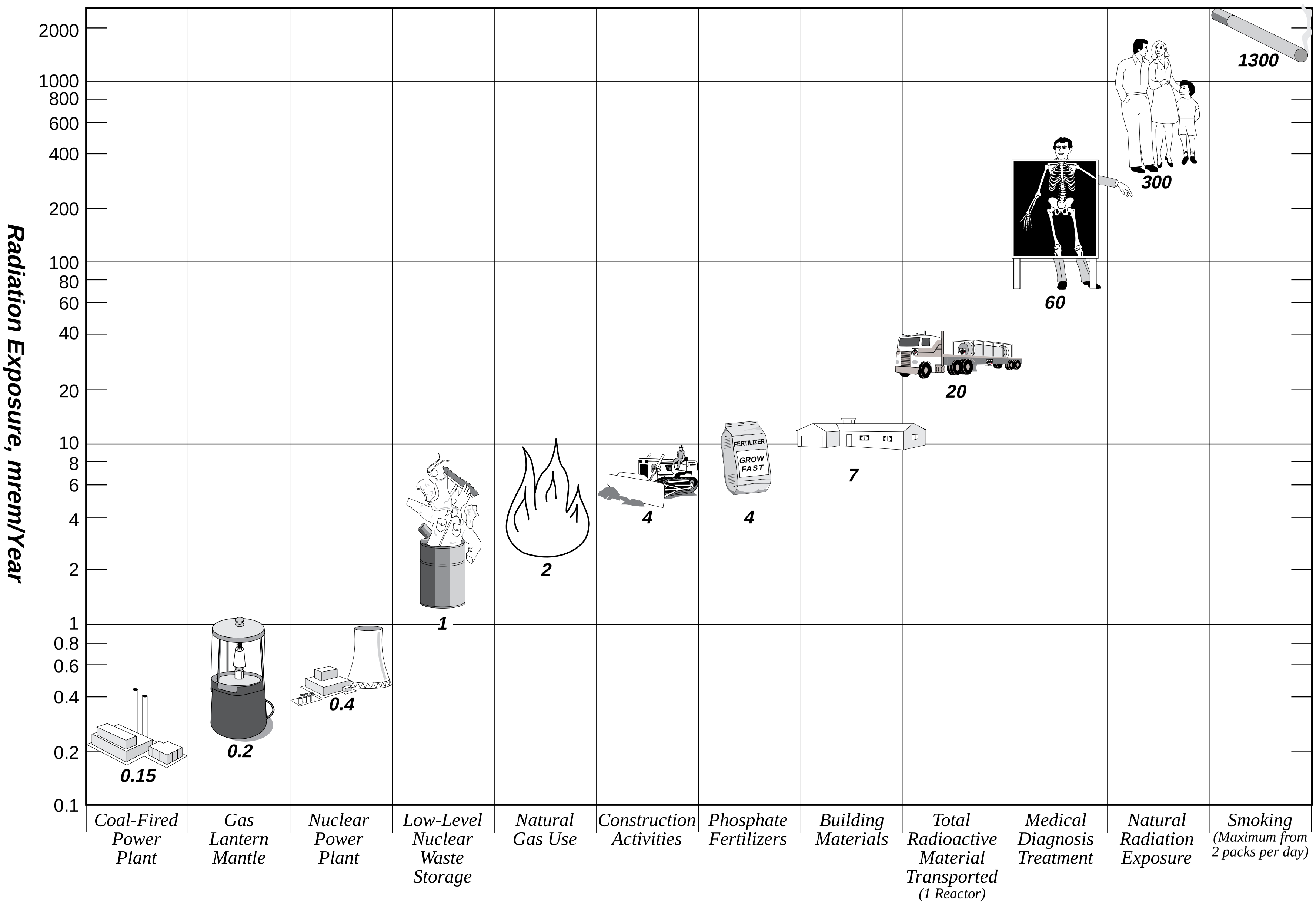


This provides the heat and energy we need to perform our daily work. That's what we mean when we say we "burn" calories during exercise.

Why is potassium important to health?

Why is carbon important?

Some Exposures from Manmade Sources Compared to the Average Natural Radiation Exposure



This chart compares the highest possible dose received from a number of activities to the average annual individual exposure to all sources of radiation. This chart was compiled in 1991 and reflects the most current numbers available at that time.

2.8 Manmade Sources

What are some exposures to manmade sources?

The figure at the left gives the annual exposures from some important manmade sources of ionizing radiation. The number given is the exposure in millirem per year to the individual receiving the highest exposure. For comparison purposes, the figure includes the average annual exposure to an individual in the United States from natural radiation sources.

The 0.1 millirem per year exposure from the transportation of all radioactive materials includes shipments to and from nuclear facilities. Shipments of waste are included.

The exposure of 1300 millirem per year from smoking deserves a special explanation. This is the maximum exposure from smoking two packs of cigarettes a day, estimated by the National Council for Radiation Protection and Measurements. It is not a statistical average individual exposure.

About the Graph

You are used to looking at graphs that use a linear scale, in which all divisions on an axis are equal. This graph uses a logarithmic scale for the y axis. The main divisions are:

100	-	1,000
10	-	100
1	-	10
0.1	-	1

The spacing represents powers of 10: 10^0, 10^1, 10^2, 10^3. The logarithmic scale allows us to represent a wide range of information in a much smaller space than would be possible with a linear scale.

The spacings within the main divisions are not equal. (They are not linear.) In a linear scale, 5 is half the distance between 1 and 10. In a log scale, 5 is 7/10 of the distance between 1 and 10; 50 is 7/10 of the distance between 10 and 100. And so forth.

2.9 Ionizing Radiation and High-Level Waste

Curie –
About 37 billion disintegrations (or counts) per second. *The number of curies is a measure of activity used to classify nuclear waste.*

A spent fuel assembly from the reactor of a nuclear powerplant will contain hundreds of thousands of *curies* of radioisotopes. When these radioisotopes undergo radioactive decay, they release both alpha and beta particles and gamma rays. While the metal in the fuel rods making up the fuel assembly will stop alpha and beta particles, it will not stop gamma rays. Therefore, we store fuel assemblies in deep pools of water at the powerplant sites to protect workers from the ionizing gamma rays coming from the fuel assemblies. Workers also use shielding when handling a spent fuel assembly outside the pool.

At a powerplant, what protects workers and the environment from exposure to radiation from spent fuel?

Shielding is the primary method of protecting workers and other people from a source of radiation. However, it is also true that the further one is from a source of radiation, the less radiation one receives. Reducing the time of exposure to a radiation source also will result in a lower exposure. Radiation workers not only use shielding to protect themselves, but they also wear radiation monitors to measure the amount of radiation they receive during their work periods.

How do shielding, distance, and time protect workers from radiation?

After 10 years of storage, the nuclear fuel will have lost 90 to 95 percent of its radioactivity. Workers would still use shielding and remote operation to handle a spent fuel assembly. To protect people and the environment, workers enclose spent fuel assemblies in a heavy shielded cask for transportation to a disposal facility. At the disposal facility, the spent fuel assemblies will be placed in disposal containers and then in the geologic repository deep underground. Radiation monitors outside the repository, above the spent fuel, will not be able to detect any of the direct gamma radiation from the fuel because of the large amount of rock shielding the fuel.

How are people and the environment protected from ionizing radiation during disposal?

Previous Section | Table of Contents | Next Section