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Science, Society, and America's Nuclear Waste

Ionizing Radiation

Unit 2 First Edition

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IONIZING RADIATION

Introduction	iii
Reading Lessons	
Ionizing Radiation: Sources and Exposures	SR-1-14
Unit Summary	SR-15-16
Enrichment Reading Lessons	
Atoms and Isotopes Review	SR-17-20
Biological Effects of Ionizing Radiation	SR-21-29
Radioactivity Review	SR-31-34
Glossary	SR-35-38
Index	SR-39-40
Bibliography	SR-41

INTRODUCTION

Radiation

Radiation is perhaps easiest to understand when you remember that it is energy moving through space in the form of waves and particles. Radiation is everywhere – in, around, and above the world we live in. We could think of it as a natural energy force that surrounds us. We are generally not very aware of it until we are reminded of it by someone or something, like a reflector on a bicycle, a full moon, or listening to a favorite radio program.

Types of Radiation

Depending on how much energy it has, radiation can be described as either *non-ionizing* (low energy) or *ionizing* (high energy).

Non-Ionizing Radiation

All our lives, perhaps without knowing it, we have reaped the benefits associated with non-ionizing radiation. For example, radio and television waves provide news and

entertainment in the home, microwaves ease some cooking tasks, the light from electric light bulbs takes away the night, and the ultraviolet light from grow lights brings an artificial sun indoors for our flowering plants. These are some forms of non-ionizing radiation.

Ionizing Radiation

High-energy, ionizing radiation is called ionizing because it can knock electrons out of atoms and molecules, creating electrically charged particles called *ions*. Material that ionizing radiation passes through absorbs energy from the radiation mainly through this process of *ionization*.

Ionizing radiation can be used for many beneficial purposes, but it also can cause serious, negative health effects. That is why it is one of the most thoroughly studied subjects in modern science. Most of our attention in this section will be focused on ionizing radiation – what it is, where it comes from, and some of its properties.

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

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.

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.

What are some forms of ionizing radiation?

What are gamma rays and X-rays?

What is 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?

How is electromagnetic radiation important in your life?

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.)

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, 186,000 miles per second. That means that a live broadcast from the other side of the world you may be listening to or looking at on TV 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?

What are some properties of alpha particles?

What are some properties of beta particles?

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

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.

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.

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.

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 ergs¹ 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

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

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.

Alpha particle:
easily stopped
least penetrating

Beta particle:
very much smaller
more penetrating

Gamma ray and X-ray:
pure energy with no mass
most penetrating

○ neutral atom or molecule

● ion

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?

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.

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.

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.

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

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.

Do scientists agree about the effects of radiation?

Can the body repair changes caused by radiation?

What is the possibility of a delayed effect?

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

Why is some risk assumed for even small exposures?

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*.

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 natural sources?

What is terrestrial radiation?

What is background radiation?

What are some manmade sources?

Radiation Exposure Pathways

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 of the U.S. population (Millirem)
Natural sources	200
Radon	100
Other	0.9
Occupational	0.05
Miscellaneous	6
Environmental sources	0.06
Medical	
Diagnostic X-rays	39
Nuclear Medicine	14
Total	360

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 products does not

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.

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.

Source: National Council on Radiation Protection and Measurements, NCRP Report No. 93, September 1987.

*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.

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.)

What is the average exposure from cosmic radiation?

How does elevation affect exposure to cosmic radiation? Why?

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 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. (The latest versions of this report, BEIR IV and BEIR V, do not provide additional information on this exposure.)

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.

How does potassium become part of 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.

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

SOURCE: Developed from data in National Council on Radiation Protection and Measurements, NCRP Report No. 93

2.8 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.

What are some exposures to manmade sources?

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.

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.

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.

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

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

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

SUMMARY

2.10 Ionizing Radiation

Radiation is energy that moves through space in the form of waves and particles. We are constantly exposed to radiation of all kinds, but the radiation of most concern is ionizing radiation. Ionizing refers to the ability of higher energy radiation to create electrically charged particles called ions in the material it penetrates, including human tissue.

Radioactive materials emit ionizing radiation in the form of alpha and beta particles and X-rays and gamma rays. An alpha particle is essentially a helium nucleus with a positive charge of 2 (2 protons) and an atomic weight of 4 (2 protons and 2 neutrons). Beta particles are negative electrons. X-rays and gamma rays are waves of pure energy.

2.11 Identification of Atoms

Because the ionizing radiation from radioactive materials comes from the nuclei of the radioactive atoms in the material, it is called "nuclear radiation." The individual radioactive atoms, which are identified by the number of protons and neutrons in their nuclei, are often called radioisotopes. The number of protons (i.e., the atomic number) determines what an atom is. For example, uranium has the highest naturally occurring atomic number, 92.

2.12 Sources of Radioisotopes

There are many naturally occurring radioisotopes in the world. With a few important exceptions, nearly all result from the uranium and thorium present when the Earth was formed. There are also many manmade radioisotopes, most created by the use of uranium in nuclear reactors.

What is radiation?

What is ionizing radiation?

What form of ionizing radiation is emitted by radioactive materials?

What is nuclear radiation?

What makes an atom what it is?

Where do radioisotopes come from?

2.13 Radioactive Decay and Half-Life

Radioactive materials become less active with time by radioactive decay. The decay of a radioisotope is measured in half-lives. The half-life of a radioisotope is the time it takes for a quantity of that radioisotope to lose half of its activity. Half-lives of radioisotopes range from a fraction of a second to more than a billion years. For example, radioisotopes in spent nuclear fuel will be hazardous for hundreds of thousands of years.

2.14 Sources of Exposure

The annual average radiation exposure of an individual in the United States, from all sources, is estimated at 360 mrem. Of this, 82% comes from natural sources: outer space, the air we breathe, the earth around us and the food we eat. Essentially, the rest results from medical X-rays, nuclear medicine, and consumer products. Nuclear power and miscellaneous sources contribute much less than 1 percent.

2.15 Radiation Protection

It is important to use caution in handling highly radioactive materials. The shielded casks used to store or transport spent nuclear fuel are examples of how we use shielding to protect workers, the public, and the environment from exposure to ionizing radiation.

Planning for the permanent disposal of our Nation's nuclear waste is a complex undertaking that presents numerous challenges in terms of radiation protection. The waste must be transported safely to the disposal site. At the disposal site, the waste must be handled safely and packaged properly. Finally, it must be permanently isolated from the public and the environment for long periods of time.

*What is the annual average individual radiation exposure?
How much from natural sources?
How much from other sources?*

ATOMS AND ISOTOPES REVIEW

Nuclear waste requires special handling and disposal because it is radioactive and emits radiation. In order to understand radioactivity and radiation, we must first learn about atoms, how atoms react with each other to form "molecules," and about special forms of atoms called isotopes.

2.16 Introduction

What do you suppose would happen if you took a lump of salt and began to break it up into smaller and smaller pieces? Sooner or later you would get pieces so small that you wouldn't be able to see them. The smallest piece that still is salt is called a *molecule*.

Everything is made of molecules—tables, chairs, sugar, salt, and even the cells of your own body. However, all molecules are **not alike**. A molecule of sugar is different from a molecule of salt.

But that is not the whole story. Molecules are made of even smaller parts, which are called atoms. Atoms are so small that it takes millions of them to make a speck of dust. We know that at least 92 different kinds of atoms occur in nature. These different kinds of atoms are known as elements. Combining atoms of different elements or atoms of the same element makes molecules.

The kind of molecule depends on which atoms combine. This combining of atoms is called a chemical reaction. In chemical reactions, atoms do not change; instead, they combine with other atoms or separate from other atoms.

For example, gold is an element, and a bar of pure gold contains only atoms of one element, gold. On the other hand, table salt is a compound. It is made of groups of atoms called molecules. A molecule of table salt has one atom of the element sodium and one atom of the element chlorine. A molecule of water has two atoms of hydrogen and one atom of oxygen. This is why chemists call water H_2O .

What are things made of?

What is an atom?

NaCl

The symbol for sodium is Na and the symbol for chlorine is Cl, so table salt is Na Cl; the symbol for hydrogen is H and the symbol for oxygen is O, so water is H_2O .

H_2O

So, atoms are basic building blocks of everything in the universe. They are the smallest particles of an element that have all the chemical properties of the element.

2.17 Atoms

What are the parts of an atom?

As small as atoms are, they are made of even smaller particles. There are three basic particles in most atoms—*protons*, *neutrons*, and *electrons*.

The Helium Atom

Protons carry a positive electrical charge. Neutrons have no electrical charge. Protons and neutrons together make a bundle at the center of an atom. This bundle is the *nucleus*.

Electrons have a negative electrical charge and move around the nucleus. Normally, an atom has the same number of protons and electrons.

What charges do the parts of the atom carry?

Does the atom have an electrical charge?

If the positively charged protons and the negatively charged electrons are equal in number, they balance each other. As a result, the atom has no electrical charge.

We use protons to identify atoms. For instance, an atom of oxygen has 8 protons in its nucleus. Carbon has 6, iron 26, gold 79, lead 82, uranium 92, and so on.

Carbon-6 protons

Iron-26 protons

Gold-79 protons

Uranium-92 protons

2.18 Isotopes

The nucleus in every atom of an element always has the same number of protons. However, the number of neutrons may vary. Atoms that contain the same number of protons, but different numbers of neutrons, are called *isotopes* of the element.

All atoms are isotopes. To show which isotope of an element we are talking about, we total the number of protons and neutrons. Then we write the sum after the chemical symbol for the element. For example, in the nucleus of one isotope of uranium there are 92 protons and 143 neutrons. We refer to it as uranium-235 or U-235 ($92 + 143 = 235$). A second uranium isotope, which contains 3 additional neutrons, is uranium-238 or U-238 ($92 + 143 + 3 = 238$). (The number may also be written in superscript before the symbol: ^{235}U or ^{238}U .)

Isotopes of a given element have the same chemical properties, but they may differ in their nuclear properties. Also, isotopes of an element have different numbers of neutrons and the same number of protons. However, some proton-neutron combinations are more stable than others.

Some unstable isotopes stabilize themselves by emitting or shooting out energy rays similar to X-rays. Others may emit particles from their nuclei and change into different elements. These rays and particles are called *radiation*, and the process of isotopes emitting them to become more stable is called *radioactive decay*.

What is an isotope?

How are isotopes identified?

Uranium-235

$$92 + 143 = 235$$

Uranium-238

$$92 + 143 + 3 = 238$$

2.19 Summary

Everything is made up of small pieces called molecules. Atoms combine to form molecules. Atoms are the smallest units of an element that have all of the chemical properties of the element. Atoms are composed of smaller particles known as protons, neutrons, and electrons.

Protons have a positive electrical charge, neutrons have no electrical charge, and electrons have a negative electrical charge. Protons and neutrons together form the nucleus or "center" of the atom, and electrons move around the nucleus.

The nucleus of each atom of an element contains the same number of protons, but the number of neutrons may vary. Isotopes of an element are identified by adding the number of protons and neutrons together and writing the sum after the chemical symbol for the element. Unstable isotopes can change from one form to another by emitting particles or energy rays in a process called radioactive decay.

BIOLOGICAL EFFECTS OF IONIZING RADIATION

Ionizing radiation can cause damage to living tissue. Scientists generally agree on the effects of high levels of exposure. But there is disagreement about the effects of low levels of exposure.

2.20 Introduction

Because ionizing radiation is high energy radiation which can knock electrons out of atoms and molecules, it can damage human tissue. The effects of ionizing radiation on the body depend on many things. First and most important, how much radiation energy was absorbed by the body? Second, what type of radiation was it? Third, what kind of cells—and how many of them—were exposed?

It was once thought that there might be a radiation exposure so low that there would be no risk associated with it. The risk of injury does decrease with decreasing exposure. But, while there may be very little likelihood of injury from exposures to low levels of radiation, some degree of risk is assumed when people are exposed to even very small amounts of radiation.

The damage done by radiation results from the way it affects *molecules* essential to the normal function of body cells. Four things may happen when radiation strikes a cell: 1) It may pass through the cell without doing any damage. 2) It may damage the cell, but the cell repairs the damage. 3) It may damage the cell so that the cell not only fails to repair itself but reproduces itself in damaged form over a period of years. 4) It may kill the cell. The death of a single cell may not be harmful, but serious problems occur if so many cells are killed in a particular organ that the organ no longer can function properly. Over time, incompletely or incorrectly repaired cells may produce delayed health effects such as cancer or genetic *mutations* or birth defects in babies exposed prior to birth.*

*Source: Primer on Radiation, FDA Consumer (HEW Publication No.) (FDA) 79-8099.

What factors determine the effects of radiation on the body?

Is there a threshold for risk?

What can happen when radiation strikes a cell?

What is the effect of exposure time?

Longer exposures to radiation increase the chance that damage will occur. However, if enough time passes between exposures, a higher total exposure may be tolerated than if the total exposure is received all at once. This effect is similar to the body's response to solar radiation — too much sun can cause a severe sunburn, but short exposures and sun block can limit the sun's burning effect on the skin.

Longer exposures to ionizing radiation allow some of the damaged cells to be repaired by the body, helping to reduce the overall effect. A damaged area may also be healed by healthy cells from an area not exposed to radiation. Radiation damage to **large** numbers of cells may be partially repaired, but some damage is permanent.

Does the amount of tissue exposed matter?

What cells are more sensitive to radiation?

The more tissue exposed to radiation, the greater the chance of injury. Exposure of the whole body, for instance, presents more risk than exposure of an arm or leg or single organ to the same radiation. Also, organs differ in how sensitive they are to radiation, so the type of cells exposed makes a difference. Rapidly dividing cells are generally more sensitive.

Tissue Sensitivity

Some cells, tissues, and organs are significantly more sensitive to radiation than others. Generally, organs with rapidly dividing cell systems, such as the bone marrow, gonads, and intestines, are more sensitive than non-dividing systems like the kidneys, liver, and brain. Cells that perform specialized functions are less sensitive than those that do not.

How do the types of radiation differ in the way they deposit energy?

What are some properties of alpha radiation?

What are some properties of beta radiation?

The type of radiation is also important. Alpha, beta, and gamma radiations differ in both their abilities to penetrate tissue and in the likelihood that they will cause biological damage. Alpha particles are large and carry a double positive charge. They travel only a short distance in living tissue, but they deposit all their energy in that short path. This increases the likelihood that they will cause damage. Beta particles carry a single negative charge and are thousands of times smaller than alpha particles. They travel longer distances in living tissue than alpha particles, but deposit their energy over a longer path. For this reason, they are less likely to cause damage. Because alpha and beta particles are not very penetrating, they mainly damage skin and surface organs. However, they can affect internal organs if substances giving off alpha and beta radiation are swallowed or inhaled.

Gamma rays and X-rays have similar properties, but gamma rays are generally more energetic. Their biological effects are similar. Their paths in living tissue are long. This means their energy is deposited over a longer path and is less likely to cause damage. But because they can penetrate the body more deeply, they can affect internal organs.

What are some properties of gamma and X-rays?

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.

2.21 Measuring Potential Health Effects

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

To show biological risk, rads are converted to *rems*. The rem is adjusted to take into account the type of radiation absorbed and the differences in likelihood of damage from the different

How do we measure radiation exposure?

How do we estimate biological risk from exposure?

*erg - a small but measurable amount of energy (See glossary)

types of radiation. But exposures are normally fractions of a rem, so the commonly used unit is the *millirem*.

$$1 \text{ millirem} = \frac{1}{1,000} \text{ of a rem}$$

2.22 Biological Effects

What are somatic effects?

There are two categories of effects from ionizing radiation: *somatic effects* and *genetic effects*. Somatic effects appear in the exposed person. They result from radiation damage to body cells that are **not** reproductive cells. They can occur soon after the exposure or they can take a number of years to become obvious. Somatic effects cannot be inherited.

What are genetic effects?

Genetic effects may appear in children conceived after a parent has been exposed to radiation if that parent's egg or sperm cells were affected. Genetic defects can be inherited.

What are the effects of acute exposures?

Large exposures in short periods of time (acute exposures) produce injuries within weeks or even hours. The severity

What is Radiation Sickness?

Acute exposure ranging from 100,000 to 400,000 millirem can result in any and/or all of the following effects.

Within hours or weeks: nausea, headache, loss of appetite, changes in blood cells.

Within succeeding weeks: loss of hair, hemorrhaging, diarrhea, effects on the central nervous system.

In most cases, prompt medical treatment gradually restores the patient's health.

Even larger exposures can destroy bone marrow cells. (This happened to some victims of the Chernobyl nuclear reactor accident in the Soviet Union in the 1980s). Bone marrow transplants have been used to treat people exposed to large amounts of radiation, but results depend upon exposure and individual variations.

depends on the amount of radiation received. For example, 100,000 to 400,000 millirem, could cause *radiation sickness*. An exposure of 400,000 to 500,000 millirem within a short period of time, if left untreated, has a 50 percent chance of causing death in a population. An exposure of 500,000 millirem is nearly 1,500 times the 360 millirem exposure the average American receives from all sources in a year.

Exposure to low amounts of radiation (1,000 millirem or less) produces no observable effect. Larger exposures received over weeks or months may not produce visible symptoms. There is a slight risk, however, that a delayed effect (such as cancer) could develop 10 to 40

years later. It's also possible (but even less likely) that damage to a reproductive cell could have occurred.

2.23 Ionizing Radiation and Cancer

Based on the cancer death rate of groups of people exposed to **large** amounts of ionizing radiation, we know that it can cause cancer. The most significant groups are 1) survivors of the atomic bombs dropped on Japan; 2) U.S. *radiologists* who used ionizing radiation from the 1920's through the 1940's to diagnose and treat medical problems; and 3) people given high X-ray exposures to treat a disease of the spine in the early days of radiation treatments.

No direct data exists to estimate the risk of death from cancer caused by low levels of ionizing radiation, such as we receive from our natural environment. Scientists agree on effects from high levels of exposure. But there is disagreement about effects of low levels of exposure. There is uncertainty about effects of low exposures because there is no direct data, and conclusions have to be made on the basis of information we have gathered about cancer deaths from high exposures.

As you can see in the graph, risk of cancer death decreases as exposure to high levels of radiation decreases. The straight line drawn through the high exposure data down to zero is assumed to show fairly well the cancer death risks from low levels of exposure to alpha radiation. The effects of low exposures to beta, gamma, and X-ray radiation are more uncertain, as shown by the gray area of the graph.

Effects of low exposures to beta particles, gamma rays, or X-rays could be 2 to 10* times less than what would be predicted by the straight line.

* Source: *United Nations Scientific Committee on the Effects of Atomic Radiation: Sources, Effects and Risks of Ionizing Radiation, 1988.*

What are the effects of low exposures?

How do we know ionizing radiation can cause cancer?

Why are we concerned about low levels of ionizing radiation?

Cancer Risk versus Radiation Exposure: A straight line drawn to zero exposure through data of high exposures is believed to estimate the effects of low exposures of alpha radiation. The effects of low exposures of beta, gamma, or X-ray radiation could be 2 to 10 times less than would be predicted by the straight line.

Many things cause cancer, including ultraviolet light, smoking tobacco, asbestos, and certain pesticides and many other chemicals. Statistics show that 17 percent of the people (170,000

Cancer Deaths Attributable to Various Sources^a

<u>Source</u>	<u>Cancer Deaths, Percent</u>
Diet	35 ^b
Tobacco	30 ^b
Infection	10 ^c
Sexual lifestyle	7 ^b
Occupation	4
Alcohol	3
Natural environment	3 ^d
Pollution	2
Medical care	1
Food additives	1
Industrial products	1
Unknown	—

^a Adapted from R. Doll and R. Peto, *Journal of the National Cancer Institute*, vol. 66, 1981.

^b Ranges of possible percentages:

Diet, 10-70; Tobacco, 25-40; Sexual lifestyle, 1-13

^c Speculative; range not estimated

^d Includes background radiation

• Sources of some common cancers unknown (e.g., prostate, bone marrow, lymph tissue); psychological contributions (such as stress) not identified

out of 1 million) in the United States die from cancer from all causes. As you already know, average annual exposure for people living in the United States is about 300 millirem from **natural** sources. It is generally accepted among scientists that from one to three percent of all cancer deaths could be the result of this yearly exposure.

2.24 Effects on the Unborn

Many genetic and environmental factors affect development of babies before birth. For this reason, it is difficult to say with certainty how radiation exposure affects an unborn child. Therefore, information gathered from animal studies is generally used to estimate these effects.

Why is it hard to estimate how radiation affects an unborn child?

Animal studies have shown that exposure can result in a very wide range of results—from no observable damage to malformations of major organs of the body, slowed growth, damage to the central nervous system, and even death. Effects vary depending on the stage of development at the time of exposure and the level of exposure. Since experimental studies are not conducted on humans, the major sources of information about effects on humans are survivors of the atomic bombs in Japan and patients exposed during medical diagnosis or treatment. The most commonly reported abnormalities are defects to the central nervous system and slowed growth.

Rapidly dividing cells are especially sensitive to radiation. So, before birth and during infancy when children grow rapidly, medical exposures to radiation carry a risk. Scientists generally agree that exposure to ordinary diagnostic X-ray is **not** likely to be harmful. Nevertheless, it is important to balance benefits of exposure to radiation against risks. It is wise for a woman of child-bearing age to determine whether or not she is pregnant before being exposed to radiation above background levels. This precaution can help avoid unnecessary risk.

2.25 Birth Defects: A Fact of Life

Approximately 10 percent of all children born (100 thousand out of a million) have some genetic defect. These defects range from those so mild they are never noticed to those that are severe and even fatal. Spontaneous defects occur when unknown factors cause cells to not work properly. Defects may also occur because cells are affected by something in the environment, including ionizing radiation.

Genetic effects are effects that are inherited by the offspring of an individual whose egg or sperm cells have been damaged. No hereditary defects caused by ionizing radiation have been observed in humans, even among Japanese survivors of the atomic bombs. However, there is enough data from laboratory studies (most often using mice) to predict such effects.

What data on humans is available?

How common are birth defects?

Have genetic defects from radiation been observed in humans?

2.26 DNA: Mighty Molecules

What is DNA?
Why are they
important?

What kinds of
damage can happen
to DNA?

Our bodies are made up entirely of cells. You were formed—and continue to grow—because cells continue to divide and reproduce themselves. Very large molecules in our cells determine what types of cells will form, making us what and who we are. These molecules are called *DNA*, which stands for *deoxyribonucleic acid*.

Take a close look at the drawing of a DNA molecule. Notice that the top section shows a normal, healthy arrangement. The second and third sections, on the other hand, show two different types of damage to DNA. The second section shows the most common type of injury, a break in the spiral. The third section contains a break in one of the crosslinks. The fourth section illustrates how the body might incorrectly repair a crosslink. An abnormality like this can be passed on to many cells.

Our bodies are composed of **billions** of cells. It's not surprising, then, to learn that damage to DNA occurs all the time. For the most part, our bodies simply go about their business of repairing damage. DNA repair does take a certain amount of time, however, and too much injury within a given time can overwhelm the ability of the body to repair the damage. If the damage is not repaired—or if it is repaired incorrectly—the results are passed along to a great many cells.

One of the many causes of damage to DNA is ionizing radiation. Low exposures usually do not affect the body's ability to repair damage. But high levels of exposure can damage such a large number of DNA molecules that repair (or proper repair) is less likely. This increases the possibility of harmful health effects.

There is some indication that radiation causes cancer by a DNA defect or incorrect repair. However, exactly how radiation or any other cancer-causing agents cause cancer is still not completely understood. It is also uncertain whether low exposures to ionizing radiation cause cancer. However, because we cannot prove that there is no effect, some small risk is assumed for any low level of exposure greater than zero.

Genetic disorders are also related to defects in DNA. But many things may cause genetic disorders, and many disorders caused by radiation can't be distinguished from those with other causes. Nevertheless, as with cancer, some small risk is assumed for any level of radiation exposure.

What is the possible effect of damage to DNA?

RADIOACTIVITY REVIEW

2.27 Introduction

Before we can understand *radioactivity*, we must first learn something about ourselves and the world around us. All matter, even our own bodies, is composed of *atoms*. There are more than you can possibly imagine. The ink dot at the end of this sentence, for instance, has more than a thousand billion atoms.

2.28 The Atom Defined

The atom is the smallest part of an element that has all the chemical properties of that element. The properties of the oxygen and carbon atoms, for example, determine the fact that when wood or coal burns in air, the principle end product is a combination of one carbon atom with two oxygen atoms called carbon dioxide. Similarly, when two hydrogen atoms combine with one oxygen atom, the result is ordinary water.

2.29 A Microscopic Universe

The inside of the atom, however, is mostly empty space, a microscopic "universe" occupied by a relatively small number of negative

electrons revolving around a central mass called the *nucleus*, millions of times smaller than the atom but accounting for nearly all its weight. The nucleus may be considered to be made up of particles called *protons*, with a positive electrical charge, and particles called *neutrons*, which are

neutral and have no electrical charge. Protons and neutrons are thousands of times more massive than electrons, which explains why the nucleus accounts for nearly all the weight of the atom.

What are atoms?

What are the parts of atoms?

2.30 The Chemistry of an Element

What is an atomic number?

What is atomic weight?

The number of protons in the nucleus determines what the element is and, therefore, the chemistry of the element. The hydrogen nucleus is a single proton, the carbon nucleus has six protons, and oxygen has eight protons, etc. The *atomic number* of an atom is equal to the number of protons in the nucleus. Its *atomic weight* is the sum of the proton and neutrons in the nucleus. For instance, carbon has six protons and six neutrons. Its atomic weight is twelve ($6 + 6 = 12$).

2.31 Isotopes

**What is an isotope?
A radioisotope?**

It is possible for atoms having the same chemistry or atomic number (the number of protons) to have different atomic weights because of differing numbers of neutrons. Atoms of the same chemical element having different atomic weights are called *isotopes* of that element. If the isotope is radioactive, it is sometimes referred to as a *radioisotope*.

In the case of atoms that are radioactive, the nucleus spontaneously emits energetic particles or electromagnetic rays that escape the bounds of the atom. This process is *radioactive decay*. Because the emitted particles and rays come from the nucleus, they are referred to as “nuclear” radiations.

2.32 Transformation of Atoms

What are alpha and beta particles?

The nuclei of some radioactive atoms, generally the heavier or larger atoms, expel a part of themselves as a particle composed of two neutrons and two protons (actually a helium nucleus) called an *alpha particle*. By expelling an alpha particle, the nucleus is changed to the nucleus of an element with an atomic number lower by 2 and an atomic weight lower by 4.

In other radioactive nuclei, one of the neutrons emits a negative electron called a *beta particle*. This increases the number of protons in the nucleus by one and converts the atom to another element with an atomic number higher by one.

For example, when the uranium-238 nucleus emits an alpha particle, it becomes the nucleus of a thorium-234 atom. In other words, the uranium atom becomes a thorium atom. It is the same nucleus but the chemistry has changed. When the strontium-90 nucleus emits a beta particle, it becomes the nucleus of yttrium-90. Again, it is the same nucleus, but the chemistry has changed.

2.33 Radioactive Decay Series

There are three naturally occurring radioactive decay series: the uranium-238 (U-238), the uranium-235 (U-235), and the thorium-232 (Th-232) series. The very long-lived uranium and thorium isotopes were present in the earth from the beginning, and the many radioactive atoms resulting from their decay are called their "daughter products."

It is important to understand these naturally occurring decay series and their daughter products and to understand that radioactivity is a fact of life on earth and not necessarily the product of a nuclear age. It is also important, therefore, to distinguish between the naturally occurring radioactive daughter products like radium-226, radon-222, and polonium-210 and those radioactive "fission products" produced by the fissioning of uranium in a nuclear reactor. The fission products, such as iodine-131, cesium-137, strontium-90, etc., result from the splitting of uranium atoms in a nuclear reaction and are not the products of the radioactive decay of uranium.

Alpha and beta decay: The boxes at right illustrate what happens during decay.

What are the three naturally occurring radioactive decay series?

Decay Transitions

ALPHA

Decay Transitions

BETA

2.34 Alpha Decay

During alpha decay, a uranium-238 nucleus (consisting of 92 protons and 146 neutrons) emits an alpha particle consisting of 2 protons and 2 neutrons. As a result, the nucleus now contains 90 protons and 144 neutrons. This means it is now the nucleus of a thorium atom. This thorium isotope has an atomic weight of 234 ($90 + 144 = 234$) so it is thorium-234.

2.35 Beta Decay

During beta decay, a neutron in a thorium-234 nucleus (that consists of 90 protons and 144 neutrons) becomes a proton. As a result, the nucleus now consists of 91 protons and 143 neutrons. This means it is an atom of protactinium. This protactinium isotope has an atomic weight of 234 ($91 + 143 = 234$) so it is protactinium-234.

2.36 Changing Chemistry**What are gamma rays?**

Some radioactive materials emit what are called *gamma rays*. Gamma rays are electromagnetic rays that are similar to X-rays but are more energetic. Gamma rays are emitted when a nucleus changes from a higher to a lower energy state, and often accompanies alpha or beta decay. For example, cesium-137, a beta emitter, and radium-236, an alpha emitter, also emit very strong gamma rays.

2.37 Detecting Radioactive Decay

In their study of radioactive materials, scientists use a variety of extremely sensitive instruments. For example, a geiger counter uses high voltages to detect small amounts of radiation, even down to a single ionizing particle. Geiger counters are used to measure radioactivity in natural sources such as rocks and soils, as well as in man-made sources, including spent nuclear fuel.

This and other instruments are helpful in cleaning up research and work facilities where radioactive materials have been present. People at these work locations often wear badges that contain a small bit of photographic film. These film badges record the amount of ionizing radiation to which a worker has been exposed.

G l o s s a r y

absorbed dose — The amount of radiation energy absorbed, especially by human tissue; measured in rads.

acceptable level of risk — A level of risk associated with a particular activity at which dangers are acceptable to the evaluator.

accessible environment — The area surrounding a nuclear waste disposal site.

acute exposure — Large exposure received over a short period of time.

alpha particle — A positively charged particle emitted in the radioactive decay of certain radioactive atoms. An alpha particle is identical to the nucleus of the helium atom.

atom — The smallest part of a chemical element that has all the chemical properties of that element.

atomic — Of or relating to an atom.

atomic number — The number of protons (or number of positive charges) in the nucleus of an atom. The number of protons determines what an atom is chemically, and, hence, identifies it as belonging to a certain chemical element.

atomic weight — The sum of the protons and neutrons in the nucleus of an atom.

axis — (geography) A straight line about which a body is symmetrical. (graphing) A reference line which distances are measured in a graph.

background radiation — The natural radioactivity in the environment. Background radiation consists of cosmic radiation from outer space, radiation from the radioactive elements in rocks and soil, and radiation from radon and its decay products in the air we breathe.

beta particle — A negatively charged particle that is emitted by certain radioactive atoms. A beta particle is identical to the electron.

cancer — An abnormal mass of new tissue growing uncontrollably on or in the body; a disease in which such growths form.

catastrophic — Disastrous.

cosmic radiation — Energetic particles and rays from space, that strike the Earth at nearly the speed of light.

decay product — The isotope produced by the decay of a radioactive isotope.

DNA (deoxyribonucleic acid) — The part of living cells that determines hereditary characteristics. It consists of two long chains of alternating phosphate and deoxyribose units twisted into a double helix and joined at the axis of the helix by hydrogen bonds between complimentary base pairs (adenine and thymine or cytosine and guanine). The linear sequences of base pairs make up the "genes" that determine hereditary characteristics.

electromagnetic spectrum — The complete range of frequencies of electromagnetic waves from the lowest to the highest, including radio infrared, visible light, ultraviolet, X-ray, gamma ray, and cosmic ray waves.

electron — A subatomic particle with a negative charge. The electron circles the nucleus of an atom.

emit — To send out.

erg — An extremely small amount of energy. Example: to raise a pound weight one foot would require about 13.6 million ergs.

exponent — A symbol above and to the right of a mathematical expression to indicate the operation of raising to a power.

factor — Any of the numbers or symbols in mathematics that yield a product when multiplied together. Any related or relevant subject considered to reach a conclusion.

fission — The splitting of a fissionable nucleus into two smaller, nearly equal, radioactive nuclei, accompanied by the emission of two or more neutrons and a significant amount of energy. Fission in a nuclear reactor is initiated by the fissionable nucleus absorbing a neutron.

frequency — The number of cycles per second of a wave.

gamma ray — Gamma radiation emitted during the radioactive decay of certain radioactive materials.

genetic effect — Effect that can be transferred from parent to offspring.

global — Of or pertaining to the whole world, worldwide.

gonad — One of the primary sex glands. For example: ovaries, testes.

half-life — The amount of time needed for half of the atoms in a quantity of a radioisotope to decay.

ion — Atom, molecule, or molecular fragment carrying a positive or negative electrical charge.

ionization — The production of ions from neutral atoms or molecules by some process. For example, exposure to ionizing radiation.

ionizing radiation — Radiation that has enough energy to remove electrons from substances that it passes through, forming ions.

isolation — Inhibiting the migration of radioactive material to the extent that the amounts entering the accessible environment will not exceed prescribed limits.

isotope — Atoms of the same element that have equal numbers of protons but differing numbers of neutrons.

kilogram — One thousand grams or 2.2046 pounds.

linear scale — Graph scale in which divisions are equal; straight line.

logarithmic scale — Graph scale in which some divisions represent powers of 10 (100,101,102,103, etc.).

millirem — A unit of radiation exposure equal to one-thousandth of a rem.

molecule — The smallest unit into which a chemical compound containing two or more atoms can be divided and still keep all of its chemical characteristics.

mutation — A permanent, transmittable change in the characteristics of an offspring that makes it different from its parents.

neutron — A subatomic particle that appears in the nucleus of all atoms except hydrogen. Neutrons have no electrical charge.

noble gas — A gaseous chemical element that does not readily enter into chemical combination with other elements.

non-ionizing — Low energy radiation such as radio and television waves.

nuclear fuel cycle — The steps necessary to use uranium to produce electricity. These include mining and milling uranium, converting the uranium to a fuel-form, using the uranium as reactor fuel, and disposing of the waste.

nuclear radiation — Ionizing radiation (alpha, beta, and gamma) originating in the nuclei of radioactive atoms.

nuclear reactor — A device in which a fission chain reaction can be initiated, maintained, and controlled.

nucleus — The central part of an atom that contains the protons and neutrons.

nuclides — General term used for radioactive atoms, referred to as radionuclides.

primate hominid — Early manlike creature.

proton — A subatomic particle in the nucleus of an atom with about the same mass as the neutron but carrying a positive charge.

rad (Radiation Absorbed Dose) — A measurement of the energy deposited in any material by ionizing radiation. One rad is equal to the absorption of 100 ergs of energy in every gram of the material exposed to the radiation.

radiation — Energy that moves through space in the form of particles or electromagnetic waves.

radiation sickness — Sickness that results from high exposure to radiation received in a short time. Common symptoms include: nausea, fatigue, vomiting, loss of teeth and hair, and in more severe cases damage to blood-forming tissue and decrease in red and white blood cells. In most cases, prompt medical treatment gradually restores patient's health.

radioactive decay — The spontaneous giving off of an alpha or beta particle or a gamma ray by a radioisotope.

radioisotope — A naturally occurring or artificially created radioactive isotope of a chemical element.

radiologist — Doctor who uses radiation to diagnose and treat medical problems.

radon — A radioactive noble gas.

rem — A unit of exposure to ionizing radiation; an estimate of the health risk that exposure to ionizing radiation could have on human tissue.

somatic effect — Effect of radiation limited to the exposed individual.

spent fuel — Fuel that has been used in a nuclear reactor and then withdrawn. Spent fuel is thermally hot and highly radioactive.

sperm — Male reproductive cell that carries genetic material of father of offspring.

terrestrial radiation — The portion of natural radiation (background) that is emitted by naturally occurring radioactive materials in the Earth.

transition — The process of changing from one state or style to another; change from one element to another due to the process of radioactive decay.

transuranic — Having an atomic number greater than 92; elements with atomic numbers higher than the atomic number for uranium (92).

ultraviolet light — Light with wavelength shorter than visible light, but longer than X—rays.

uranium — A naturally occurring radioactive element with the atomic number 92 and an atomic weight of approximately 238.

X-ray — Electromagnetic radiation used in medical diagnosis.

- Alpha particles**, 1, 2-3
 - exposure and risk of cancer, *enrichment 25*
 - penetration in human tissue, *enrichment 22*
- Apollo missions**, 8
- Atomic number**, *enrichment 19*
- Atoms**, 17-20, *figure 18*
- Background radiation**, 5
- Basic particles**, 18
- Beta particles**, 1, 2-3
 - and risk of cancer, *enrichment 25*
 - penetration in human tissue, *enrichment 22*
- Biological effects of radiation**, *enrichment 24*
 - and Chernobyl nuclear reactor accident, *enrichment 24*
 - genetic effects, *enrichment 24, enrichment 27*
 - somatic effects, *enrichment 24*
 - radiation sickness, *enrichment 24*
- Biological risk**, 3, 4
- Birth defects and radiation**, *enrichment 27*
- Cancer**, *enrichment 25-26*
 - multiple causes, *enrichment 26*
 - and potential radiation-induced DNA defects, *enrichment 29*
- Carbon**, 10, 11
- Chemical reactions**, 17
- Chernobyl nuclear reactor accident**, *enrichment 24*
- Cosmic radiation**, 5, 7-8
 - and Apollo missions, 8, *chart 8*
 - effect of elevation, 7, *chart 7*
 - and jet flights, 8
- Curie**, 14
- Decay series**, *enrichment 33-34*
- DNA**, *enrichment 28-29*
- Electromagnetic spectrum**, 1, *figure 1*
- Elevation**, 7
- Erg**, 3
- Exposure to radiation**
 - and DNA, *enrichment 29*
 - effect of exposure time, *enrichment 22*
 - effects on humans, *enrichment 24-27*
 - measurement, *enrichment 23*
 - and pregnancy, *enrichment 27*
- Gamma rays**, 1, 2-3
 - exposure and risk of cancer, *enrichment 25*
 - penetration in human tissue, *enrichment 23*
- Genetic effects of radiation**, *enrichment 21, enrichment 24, enrichment 27*
- Injury to human tissue**, 2, 3, *figure 3*
- Ionizing radiation**, 1-2, 15
 - alpha particles, 1-3, *enrichment 22, enrichment 33*
 - average exposure per year, all sources, 6, *charts 6, 7*
 - and genetic disorders, *enrichment 27*
 - and radon in indoor air, 6, *illustration 6*
 - beta particles, 1-3, *enrichment 22*
 - biological effects of radiation, *enrichment 24-27*
 - biological risk, 3, 4
 - and birth defects, *enrichment 27*
 - and Chernobyl nuclear reactor accident, *enrichment 24*
 - and decay series, *enrichment 33-34*
 - and DNA, *enrichment 28-29*
 - and electromagnetic spectrum, 1, *figure 1*
 - and exposure, *enrichment 21, enrichment 22-29*
 - in food, 10
 - gamma rays, 1-3, *enrichment 23, enrichment 25*

- genetic effects, *enrichment* 21, *enrichment* 24, *enrichment* 27
 - and high-level waste, 14
 - and injury to human tissue, 2-3, *figure* 3
 - acute exposure, 3
 - cell repair, 3-4
 - low-exposure, 4
 - manmade sources, *figure* 5
 - and pregnancy, *enrichment* 27
 - radiation sickness, *enrichment* 24
 - and radon, 6
 - risk of cancer versus radiation
 - exposure, *enrichment* 25-26
 - and smoking, 7, 13
 - and somatic effects, *enrichment* 24, *enrichment* 25-26
 - sources of, *figure* 5
 - manmade, 5
 - natural, 5
 - terrestrial radiation, 5,9
 - tissue sensitivity to, *enrichment* 22
 - X-rays, 1-3, 19, *enrichment* 23, *enrichment* 25
- Isotopes**, 5, 19, 20
- Jet flights**, 8
- Linear scale**, 13
- Logarithmic scale**, 13
- Molecules**, 17, *enrichment* 21
- Mutations**, *enrichment* 21
- National Council for Radiation Protection and Measurements**, 13
- Neutrons**, 18, 19, 20
- Potassium**, 10, 11
- Protons**, 18, 19, 20
- Radiation** (*see* ionizing radiation)
- Rad**, 3, *enrichment* 23
- Radiation sickness**, *enrichment* 24
- Radioactive decay**, 14, 19, 20
- Radioisotopes**, 5
- Radon**, 6
- Rem**, 3, *enrichment* 23
- Risk**
 - of cancer versus radiation exposure, *enrichment* 25-26
- Shielding**, 14
- Smoking**, 7, 13
- Somatic effects of radiation**, *enrichment* 24, *enrichment* 25-26
- Speed of light**, 2
- Terrestrial radiation**, 5, 9
- Tissue sensitivity to ionizing radiation**, *enrichment* 22-23, *figure* 23
- X-rays**, 1-3, *enrichment* 19, 27
 - penetration in human tissue, *enrichment* 23
 - exposure and risk of cancer, *enrichment* 25

UNIT 2

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