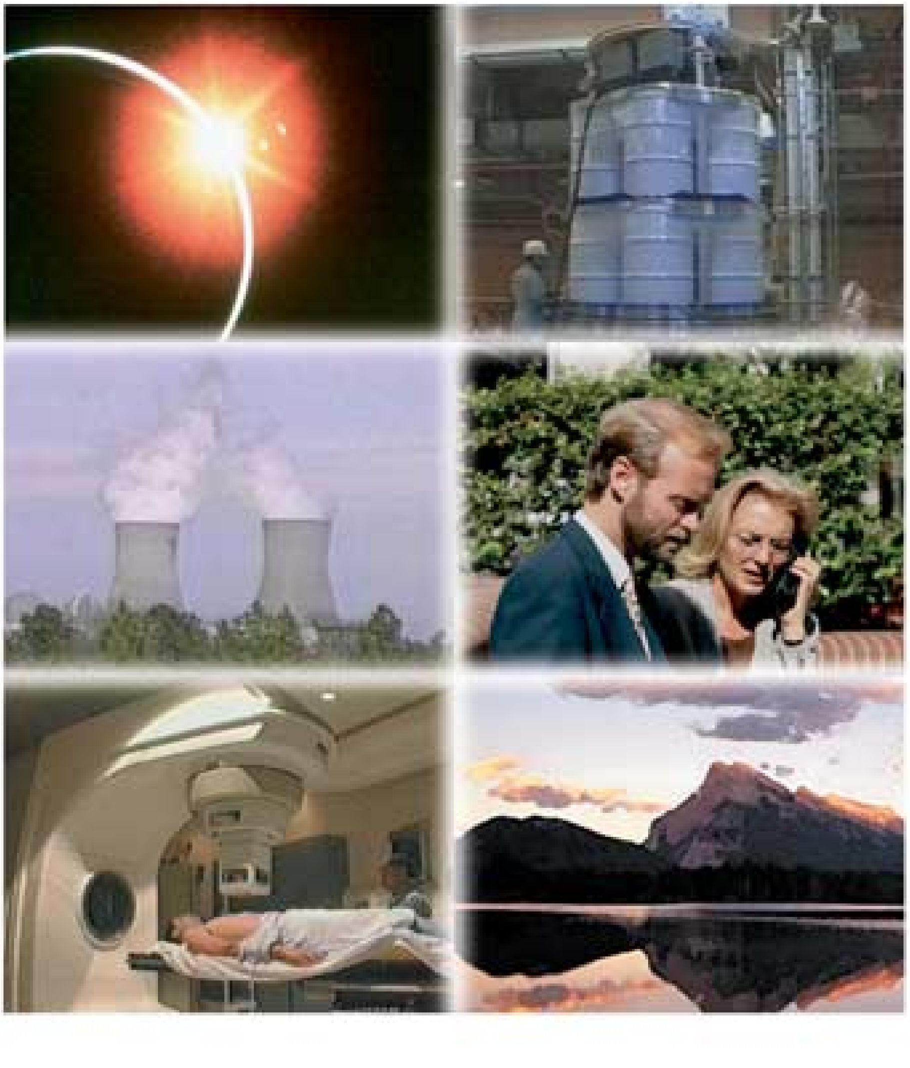
UNDERSTANDING RADIATION IN OUR WORLD



COVER 2

UNDERSTANDING RADIATION IN OUR WORLD

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Preface

"Radiation." What images come to our minds?

- ✔ "Duck and cover" drills in schools in the 1950s, and orders to scurry under our desks.
- ✔ Waste drums and protests over waste disposal sites.
- ✔ Radon, the naturally-occurring radioactive gas present in many homes across the country.
- ✔ Medical X-rays or radiation therapy for cancer.
- ✔ Ultraviolet radiation from the sun.

These are just a few examples of radiation, its sources, and uses.

Radiation is part of our lives. Natural radiation is all around us and manmade radiation benefits our daily lives in many ways.

Yet radiation is complex and often not well understood. Understanding radiation and its risks and benefits can help us—as individuals and as a society—to make informed decisions about the use of radiation and actions to protect ourselves from possible harm.

Understanding Radiation in Our World attempts to explain the basics of radiation and some of its potential complexities and nuances, and to provide some perspective on its potential risks and benefits. The Guide has a companion set of videos: "A Look at Radiation" and "Managing Radiation."

This guide is one of the continuing series of "plain talk" guides produced by the National Safety Council's Environmental Health Center (EHC). The goal of the series is to help the public better understand, and therefore better manage, some of the leading environmental risks we face day in and day out.

Bud Ward
Executive Director, Environmental Health Center
National Safety Council

March 2001

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I

Introduction

Introduction

Dangers of Radiation

Radiation as a Part of Our Everyday Lives

Radiation is all around us, every minute of every day. Some radiation is essential to life, such as heat and light from the sun. We could not exist without it. Some radiation informs and entertains us, through video signals and sounds from television sets and radios. As used in medicine, radiation helps us diagnose and treat diseases and save lives. Yet it can also pose serious risks.

Radiation is energy that comes from both *natural* sources, and *manmade* sources that provide many of the conveniences and necessities of modern living.

Natural Radiation

We are exposed to radiation from numerous natural background sources: the atmosphere, soil and water, food, and even our own bodies. On average, much more of our exposure to radiation comes from these natural sources than from manmade sources.

Manmade Radiation

A smaller but increasing amount of the radiation we are exposed to is manmade. Modern technologies, for example, use radiation to:

- Diagnose and treat medical problems
- Communicate over long distances
- Generate electricity for our domestic and industrial needs
- Eliminate harmful bacteria from food
- Conduct basic and applied research

Dangers of Radiation

Managing exposure to radiation is a major concern to citizens and government officials in the United States and around the world.

- Excessive exposure to high-energy (ionizing) radiation can trigger changes in body cells leading to cancer, birth defects, and—in extreme cases—catastrophic illness and death.
- Too much exposure to the sun's rays can damage eyes and burn skin, causing cataracts or cancer.

Several events and circumstances continue to influence public perceptions about radiation dangers.

- Pictures and stories of the terrible effects of massive radiation doses to the people of Hiroshima and Nagasaki have created a lasting fear of radiation.
- Development and testing of nuclear weapons have left a legacy of pollution that in the United States alone will take decades and billions of dollars to clean up.
- Accidents at two nuclear power plants—Three Mile Island in Pennsylvania and Chernobyl in the former Soviet Union—introduced the term "meltdown" to popular culture and raised continuing questions about the safety of nuclear power.

In addition, uncertainties remain about the safe disposal of spent fuel from nuclear power plants and other high-level radioactive waste.

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Introduction

About this Guidebook

About this Guidebook

This guidebook provides information on:

- The nature and sources of radiation
- Benefits and risks involved in use of radiation
- Management of radioactive waste
- Actions by state, federal, and international agencies and by individuals to ensure that public health is protected from radiation hazards

The goal of *Understanding Radiation in Our World* is to help you make informed judgments on important radiation issues that affect your health, your lifestyle, and the well-being of your family and community:

- How big a risk does radiation pose to us, our families, children, future generations and the environment?
- How much and what kinds of risk should we tolerate?
- What should we do, as individuals and as a society, to ensure that the benefits of radiation are not outweighed by the risks?

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What is the Nature of Radiation?

What is the Nature of Radiation?

Types of Radiation

Energy

Radiation is energy—the primal energy of the universe, originally created billions of years ago. Ionizing radiation is emitted as the unstable atoms of radioactive materials constantly emit alpha, beta, gamma, or other forms of radiation as they "decay" to a stable state. This process can take from a fraction of a second to billions of years, depending on the material. Radioactive materials (called *radioisotopes* or *radionuclides*) and the radiation they produce are everywhere—in the soil, in our food and water, and in our bodies.

There is an important difference between radiation and radioactivity (although the terms are often mistakenly used interchangeably):

- *Radiation* is energy in the form of waves or particles sent out over a distance. (A simple example is the ripples of water radiating outward in a pond after a pebble is dropped into the water.) There are many different types of radiation.
- *Radioactivity* is a property of a substance, such as uranium or plutonium, which emits high-energy (ionizing) radiation.

Radiation travels over distances ranging from fractions of a millimeter to billions of light-years. This energetic quality of radiation makes life possible but also presents threats of danger and destruction.

To better understand radiation it is important to remember that:

- Not all radiation is the same.
- Different kinds of radiation affect living things in different ways.

Types of Radiation

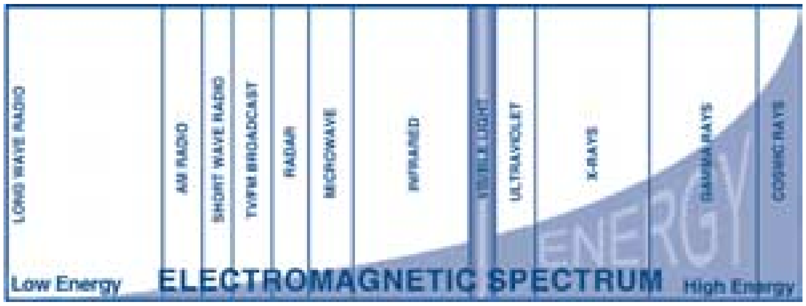
The most basic distinction scientists make between types of radiation is the amount of energy involved (Figure 1). Radiation with lower energy levels is called *nonionizing*; radiation with higher energy levels is called *ionizing*.

This guidebook sometimes uses the generic term "radiation" to refer to ionizing radiation. Keep the differences between the two types in mind as you consider the benefits and risks of the various types of radiation.

Nonionizing Radiation

Nonionizing radiation has lower energy levels and longer wavelengths. Examples

Figure 1. The electromagnetic spectrum



Source:
The Ohio State University Extension

Table 1: Basic Types of Radiation

Type	Examples
Non-Ionizing Electromagnetic Radiation	Radio waves, Microwaves, Infra red (heat), Visible Light (color)
Ionizing Electromagnetic Radiation	X-rays, Gamma rays, Cosmic rays
Ionizing Atomic Particle Radiation	Beta radiation, Alpha radiation, Neutrons

include radio waves, microwaves, visible light, and infrared rays from a heat lamp.

Our senses can detect some types of non-ionizing radiation: we can see visible light, and feel the burning effects of infrared radiation.

Nonionizing radiation is strong enough to influence the atoms it contacts, but not strong enough to affect their structure. For example, microwave radiation is used to heat the water in food by causing water molecules to vibrate.

Living tissue can generally be protected from harmful nonionizing radiation by devices such as goggles, protective clothing, and shielding around radiation-generating equipment. However, concern has been raised about possible health effects from nonionizing radiation produced by such things as cell phones and electric power lines. (See Electric and Magnetic Fields, Chapter 2, page 22)

Ionizing Radiation

Ionizing radiation has higher energy levels. Examples include X-rays and cosmic rays.

Ionizing radiation has enough energy to directly affect the structure of atoms of the materials, including human tissue, which it passes through. A description of the structure of atoms will help in understanding the effects of ionizing radiation. (Table 1)

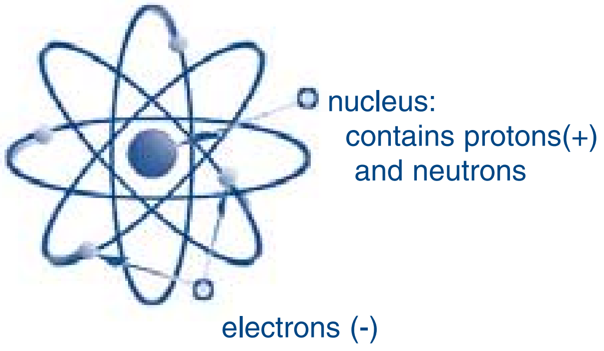
Structure of Atoms

All substances are composed of atoms that are made up of three subatomic particles: *protons*, *neutrons*, and *electrons* except hydrogen (which may have no neutrons). The protons and neutrons are tightly bound together in the positively charged nucleus at the center of the atom, while a cloud of negatively charged electrons orbits the nucleus. (Figure 2)

The number of protons in the nucleus determines its atomic element. The simplest element, hydrogen, has only one proton in its nucleus. Oxygen has eight protons. Heavier elements, such as uranium and plutonium, have more than 90 protons.

Elements may have various *isotopes*. An

Figure 2.
Structure of an Atom



Source: U.S. Environmental Protection Agency isotope is one of two or more atoms that have the same number of protons but different numbers of neutrons in their nuclei.

Most atoms are *stable* because the nuclear forces holding the protons and neutrons together are strong enough to overcome the electrical energy that tries to push the protons apart. (The energy pushing protons apart is like two magnets with the same charge that push each other apart.)

When the number of neutrons in the nucleus is above a certain level, however, the atom becomes *unstable* or *radioactive*, and some of its excess energy begins to escape. This energy is ionizing radiation.

Effects of Ionizing Radiation on Atoms

When ionizing radiation passes through material, such as human tissue, it may "knock" one or more negatively charged electrons out of orbit around the nuclei of atoms of the material. If this happens, this causes the atoms to become positively charged (ionized). When this occurs in our bodies, molecules and cells may be damaged. The health effects of this damage may be immediate or appear gradually over many years.

Forms of Ionizing Radiation

Ionizing radiation can take two different forms:

- *Electromagnetic waves* which spread out in all directions through space at the speed of light.
- *High-energy particles* which travel through space at various rates.

Examples of ionizing radiation include:

- X-rays (used in medicine and for scientific research) and
- Gamma rays (emitted by some materials, including the sun and stars and soil).

Detection of Ionizing Radiation

Ionizing radiation is generally not detectable by our senses: we cannot see, smell, hear, or feel it. This, together with its unpredictable health effects, may explain why it causes so much anxiety.

However, ionizing radiation is relatively easy to detect and measure using electronic equipment. Instruments such as Geiger counters can detect radiation and help us track the amount of radiation exposure. These instruments can tell us if we are too close to a source that can harm us and warn us of a release of radiation.

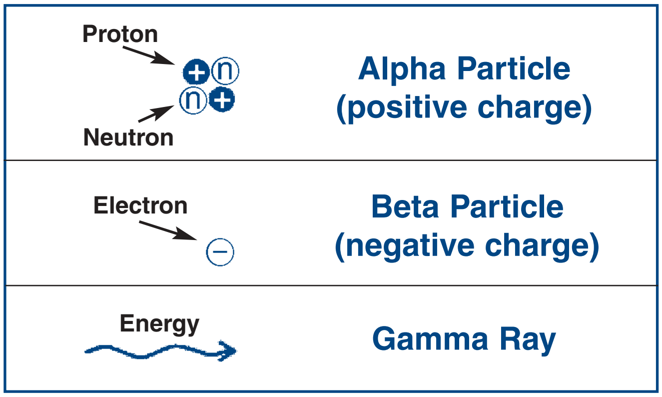
Radioactive Decay

When the nucleus of a radioactive isotope decays, emitting ionizing radiation, the nucleus is transformed into a different isotope, called a *decay product*. The new isotope may be stable or unstable. If it is unstable, it will continue to decay, changing its nucleus and emitting more ionizing radiation. Several decays may occur before a stable isotope is produced. (Figure 3)

Figure 3.
Radioactive Decay

Source: The Ohio State University Extension

Figure 4. Types of Ionizing Radiation



Source: The Ohio State University Extension

Half-life

The *half-life* is the time it takes for one-half of a radioactive isotope's atoms to decay.

For example, suppose that several atoms of a radioactive isotope with a half-life of three hours were isolated and observed. After three hours, one-half of those radioactive atoms would remain. The other half would have decayed into different isotopes. After three more hours, only half of the remaining radioactive atoms (one-fourth of the original number) would remain unchanged.

The half-life can vary substantially from one isotope to another, ranging from a fraction of a second for plutonium-214, to 8 days for Iodine-131, to 24 thousand years for plutonium-239, to billions of years for uranium-238.

The half-life of an isotope determines the longevity of its radioactivity. The longer the half-life, the more atoms it takes to give a certain amount of radioactivity. However, the half-life of a radioactive material is *not* a direct measure of the risk associated with the material. (See Determining Levels of Risk, Chapter 3, page 41.)

Types and Sources of Ionizing Radiation

The major types of ionizing radiation emitted as a result of radioactive decay are alpha and beta particles and gamma rays. (Figure 4) X-rays, another important type of radiation, arise from processes outside of the nucleus.

Alpha Radiation

An alpha particle is composed of two neutrons and two protons in a tight positively-charged bundle that has escaped from the nucleus of a heavy radioactive element, such as uranium or radium, during radioactive decay.

Alpha radiation is relatively slow-moving, has little penetrating power and can be stopped by a single sheet of notebook paper or the dead outer layer of skin tissue. (Figure 5) Therefore, alpha-emitting radioisotopes are not usually a hazard outside the body.

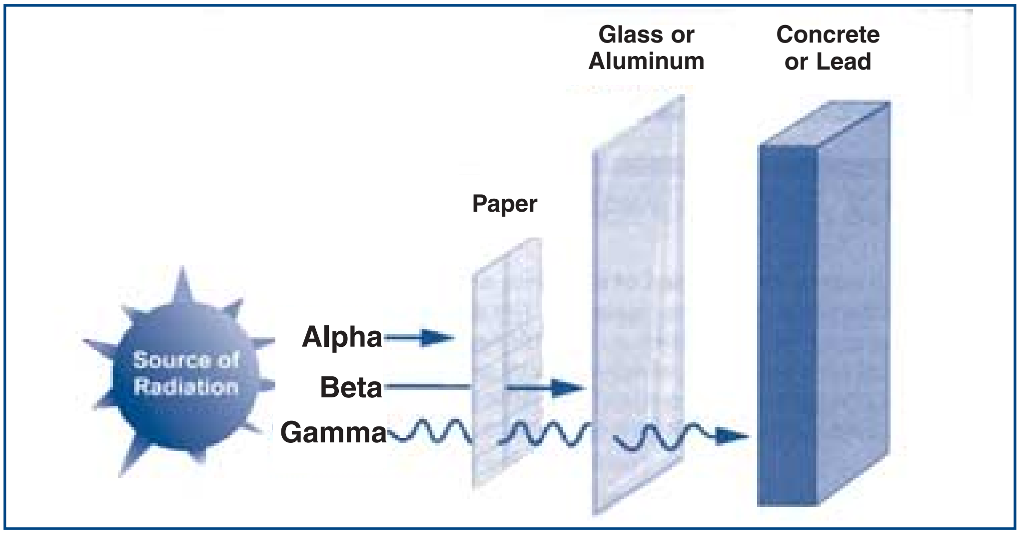
However, when alpha-emitting materials are *ingested* or *inhaled*, energy from the alpha particles is deposited in internal tissues such as the lungs and can be harmful. (See The Health Effects of Radon, Chapter 3, page 37.)

Beta Radiation

Beta particles are fast-moving free electrons emitted during radioactive decay. They can be either negatively or positively charged. A positively charged beta particle is called a positron.

A beta particle is small—less than 1/7000 of the weight of an alpha particle—and it travels farther through solid material than

Figure 5. Penetrating Power of Different Types of Radiation



alpha particles. Beta particles can travel significant distances in air. However, most beta particles can be reduced or stopped by a layer of clothing, eyeglasses, or a few millimeters of a substance such as aluminum. (See Figure 5)

Although more penetrating than alpha particles, beta particles are less damaging over the same distance. Some beta particles can penetrate the skin and cause tissue damage especially to the eyes. However, both alpha and beta emitters are generally more hazardous when they are *inhaled* or *ingested*.

Humans can be exposed to beta particles from both manmade and natural sources. Tritium, carbon-14, and strontium-90 are examples of radionuclides that emit beta particles upon decay.

Gamma Radiation

Like visible light and X-rays, gamma rays are *photons*—weightless packets of energy. Gamma rays often are emitted from a radioactive nucleus along with alpha or beta particles. They have neither a charge nor mass and are very penetrating.

Most gamma rays can pass completely through the human body. This may cause ionization and possible health effects in any organ of the body. Most gamma rays lose almost all their energy in a few feet of soil, three feet of concrete, or six inches of lead.

A naturally-occurring source of gamma rays in the environment is potassium-40. Manmade sources include iodine-131 (produced in nuclear reactors, accelerators, and nuclear explosions) and cobalt-60 (also created in nuclear reactors) which is used in food irradiation. (See Food Irradiation, Chapter 3, page 29.)

X-Rays

X-rays are emitted from processes occurring outside the nucleus. They have essentially the same properties as gamma rays, but are generally lower in energy and therefore less penetrating than gamma rays. A few millimeters of lead can stop X-rays.

X-ray machines are widely used in medicine for diagnosis and treatment, and in industry for examinations, inspections, and process controls. Because of this heavy use, X-rays are the largest source of manmade radiation exposure. Due to their very short wavelength, X-rays can pass through materials, such as wood, water, and flesh. They can be most effectively stopped by heavy materials like lead or by substantial thickness of concrete.

Neutrons

One source of ionizing radiation results from the release of neutrons during nuclear fission. Neutrons are released during nuclear fission, which may occur spontaneously or during a nuclear reaction, when a free neutron collides with a nucleus.

Neutrons have a neutral electrical charge, so they may be readily absorbed by the nuclei of other atoms, creating new radioactive isotopes. Fission fragments and neutron-activated material are responsible for the intense radioactivity on the inside surfaces of nuclear reactors.

(Material for this chapter is adapted from *What Is Radioactive Material and How Does It Decay?* (RER-20) and *What Is Ionizing Radiation?* (RER-21), Ohio State University Extension.)

Where Does Radiation Come From? 2

Sources of Ionizing Radiation

When energy particles and rays are expelled from the forces that bind them together in atoms, ionizing radiation is emitted (see Ionizing Radiation, Chapter 1, page 12). This process has been going on since the birth of the universe. Radiation has always been commonplace in our world.

Natural radioactive materials were discovered in the 1890s. It was not until 1942 that physicist Enrico Fermi and his team created the first *manmade* radioactive materials in the world's first nuclear reactor at the University of Chicago.

Manmade Radiation

In the years since these discoveries, the manmade sources and uses of radiation have multiplied so that manmade radiation is now commonplace. We use radiation to:

- Generate electricity,
- Diagnose and treat medical problems,
- Create and improve consumer products,
- Breed more productive and disease resistant crops, and
- Conduct a wide range of scientific research.

Natural Radiation

However, most of the ionizing radiation we are exposed to consists of natural, or background, radiation:

- Radon gas
- Other terrestrial sources (radioactive elements in rocks, soil, water, and plants)
- Cosmic radiation
- Internal radiation from natural elements in our bodies (such as radioactive potassium) and some foods that contain small quantities of radioactive elements (such as radium -226 in eggs, and potassium-40 in bananas and some vegetables)

Measuring Radiation Exposure

In the United States, we commonly measure human exposure to potentially harmful radiation in units called millirem (one one-thousandth of a rem). (See Measuring Human Exposure, Chapter 3, page 32.)

On average, each of us receives about 360 millirem of radiation each year. About 300 millirem, or 82 percent of the total, is natural background radiation (from radon and other natural sources).

The remaining 18 percent of our radiation exposure is from manmade sources (Figure 6):

- X-rays and other medical and dental procedures
- Consumer products (such as cigarettes, smoke detectors, color televisions)
- Operation of nuclear power plants
- Manufacture of nuclear weapons
- Fallout from past atmospheric nuclear weapons testing

Where Does Radiation Come From?

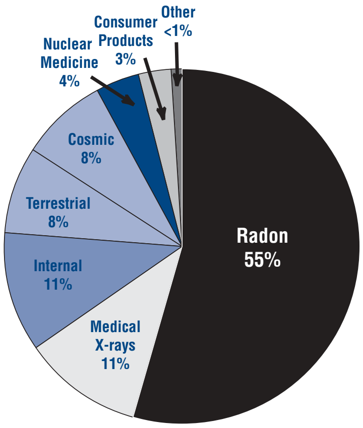
Measuring Radiation Exposure

2

Where Does Radiation Come From?

Natural Sources

Figure 6. Sources of radiation exposure



Source: National Council on Radiation Protection and Measurements

Natural Sources

Everything on Earth is exposed to a constant barrage of naturally occurring ionizing radiation from the sun, cosmic rays, and radioactive elements in the Earth's crust. The primary radioactive elements in the Earth's crust are uranium, thorium, potassium, radium, and their radioactive decay products or derivatives.

Radon

Radon is a naturally occurring gas formed from the radioactive decay of uranium-238 in rock and soil. Radon is colorless, odorless, tasteless, chemically inert, and radioactive. Radon also decays, emitting ionizing radiation in the form of alpha particles, and transforms into decay products, or "progeny" radioisotopes. The half-life of radon is about four days. Unlike radon, the progeny are not gases, and can easily attach to and be transported by dust and other particles in air. The decay of progeny continues until stable, non-radioactive progeny are formed. At each step in the decay process, radiation is released. Radon accounts for more than half (an average of 55 percent) of the radiation dose we receive each year and is the second leading cause of lung cancer, after cigarette smoking, in the U.S.

Radon moves through air or water-filled pores in the soil to the soil surface and enters the air, while some remains below the surface and dissolves in ground water (water that collects and flows under the ground's surface). Radon has been found in drinking water from public ground water supplies in many states across the country. In the outside open air, most radon dilutes into relatively low concentrations (about 0.4 picocuries per liter of air, abbreviated pCi/L).

Radon becomes a serious public health problem when high levels are found in indoor air where people can breathe it – in homes, schools, and other buildings. Radon in the soil can seep through the basement or ground floor through cracks in a foundation or construction joints and build up indoors to levels substantially higher than outdoor air levels. (Figure 7) Indoor radon has become more of a problem in recent years because new homes are built more airtight and Americans now spend an average of about 90 percent of their time indoors.

Similar homes in the same neighborhood may have very different radon readings because they are not all built on exactly the same piece of ground and construction is not identical. High levels of indoor radon (above EPA action level of 4 pCi/L for radon in indoor air) have been found in all kinds of homes throughout the U.S. In some parts of the country, indoor radon levels have been measured at *hundreds* of picocuries per liter and higher.

EPA and the Office of the U.S. Surgeon General recommend that citizens take steps to reduce indoor radon levels to below 4 pCi/L. EPA's National Residential Radon Survey completed in 1991 indicates that more than six percent of all homes nationwide have elevated radon levels, approximately one in every 15 homes (or six million homes) nationwide.

Radon can also be a problem in schools and other buildings. EPA's National School Radon Survey found that 20 percent of the schools nation-wide (about 15,000 institutions) have at least one school room with a radon level greater than 4 pCi/L.

Although most of radon exposure indoors comes from soil, radon dissolved in tap water can be released into indoor air when it is used for showering, washing or other domestic uses, or when heated before being ingested. This adds to the airborne radon indoors. It is estimated that this source accounts for less than five percent of the total indoor air concentration in houses served by ground water sources. Because it takes about 10,000 pCi/L of radon dissolved in water to produce about one pCi/L of radon in household air, the levels of radon in drinking water need to be significantly elevated to substantially contribute to the level of radon in the indoor air.

Other Terrestrial Sources

Other naturally occurring radioactive materials in the Earth's crust, such as thorium, potassium, and radium, contribute about eight percent of our annual exposure to radiation. Radiation levels from these sources also vary in different parts of the country.

Cosmic Radiation

Cosmic radiation from outside the Earth's atmosphere includes high-energy protons, electrons, gamma rays, and X- rays that hit the Earth as it moves through space. Fortunately, the Earth's atmosphere absorbs much of the energy from cosmic radiation.

About eight percent of our annual exposure comes from cosmic radiation. However, cosmic radiation increases at higher altitudes, roughly doubling every 6,000 feet. For example, the exposure to cosmic radiation is about twice as high in Denver as it is in Chicago.

Internal Radiation

About 11 percent of the average person's total annual exposure comes from radioactivity within our own bodies. Radioactive materials in the air, water, and soil are absorbed in food and then by the body's own tissues.

Potassium and carbon are two of the main sources of internal radiation exposures.

Figure 7. Radon Routes into a Home

Source: US Environmental Protection Agency

They enter our bodies through the food we eat and the air we breathe.

- Potassium, essential to life, is distributed throughout our bodies. A small portion (about one one-hundredth of a percent) of natural potassium consists of a naturally radioactive isotope called potassium-40. This isotope is the chief radioactive component in normal food and human tissue.
- Carbon-14, a radioactive isotope of carbon created by cosmic radiation, makes up a small fraction of all carbon in our bodies.

Manmade Sources

As our use of radiation increases, so does our exposure to ionizing radiation from manmade sources. Lifestyle choices, including house construction, air travel, and smoking, also affect the level of our exposure. Airline crews experience greater exposures than people who live at sea level where they are protected by a thicker blanket of atmosphere.

Medical and dental X-rays account for most of the exposure from manmade sources, an average of about 11 percent of our total annual exposure.

Consumer products such as color television sets, video displays, and smoke detectors account for another three percent of annual exposure.

Other potential sources of small amounts of radiation are:

- Mining and agricultural products, and ash from burned coal,
- Nuclear reactors and their supporting facilities (uranium mills and fuel preparation plants),
- Federal facilities involved in nuclear weapons production, and
- Fallout from past atmospheric weapons testing, which peaked in the mid-1960s.

Medicine

About 15 percent of our total average exposure to ionizing radiation is from medical X-rays (11 percent) and nuclear medicine (4 percent).

Americans receive about 200 million medical X-rays every year. (Figure 8) X-rays are an important tool in medical diagnoses.

Figure 8. X-rays Used in Medicine

Nuclear medicine involves diagnostic procedures such as nuclear *tracers*, small amounts of radioactive materials that are injected into the blood stream to allow monitoring of their progress through the body with a radiation detector. Tracers can help locate blocked or restricted blood vessels and developing tumors.

Nuclear medicine also uses radiation to treat diseases. Precisely targeted cobalt radiation, for example, can destroy diseased cells without damaging healthy cells nearby. Injections into the bloodstream of radioactive iodine, which then concentrates in the thyroid, is an effective treatment for hyperthyroidism or Graves' disease, as well as thyroid cancer. (See Medical Uses, Chapter 3, page 25).

Average annual doses from medical applications are about one-sixth the average annual dose from background radiation. However, patients undergoing *radiation therapy*, where radiation is narrowly targeted to affected tissues, can be exposed to levels many times higher than background radiation. While medical uses of radiation offer important benefits, they can also pose risks.

Consumer Products

On average, we receive about three percent of our total radiation exposure from consumer products, about 11 millirem per year.

These products include:

- Smoke detectors that use americium-241 (Figure 9)
- Lawn fertilizer containing potassium-40
- Cigarettes
- Gas lanterns
- Exit signs
- Natural gas appliances
- Brick or stone houses
- Color television sets

Radiation is also used in the manufacturing process for many consumer products. For example, cosmetics and medical supplies are sterilized by radiation. Radiation is also used to help determine the thickness of materials, how full cans are before they are sealed, and the quality of the welds in bridges and buildings. (See Industry and Consumer Products, Chapter 3, page 31.)

Nuclear Power

Nuclear power reactors, which use uranium, supply about 20 percent of the electricity used in the United States. (Figure 10)

Nuclear power plant operations account for less than one one-hundredth of a percent (less than one millirem per year) of the average American's total radiation exposure. However, workers at nuclear power plants can receive much higher doses and those who live near power plants may receive slightly higher doses.

Figure 9. Smoke detector

Nuclear Weapons

For most people, nuclear weapons production and testing are responsible for only very small amounts of radiation exposure. However, past accidental and planned releases have exposed some employees and neighbors of weapons facilities to higher radiation doses.

Fallout from atmospheric testing of nuclear weapons reached its peak in the mid-1960s. While the effect on background radiation in the vicinity of these tests was significant in the days and weeks following an explosion, the effect on world-wide background radiation levels has been minor, although measurable. The longer half-life fission products from these tests, including cesium-137 and strontium-90, caused background levels of radiation around the world to increase slightly.

Sources of Nonionizing Radiation

Nonionizing radiation is electromagnetic radiation that includes:

- Radio waves
- Microwaves
- Infrared light
- Visible light

Figure 10. Map of U.S. Nuclear Power Facilities

Source: U.S. Department of Energy

Hazards of Nonionizing Radiation

Unlike ionizing radiation, nonionizing radiation does *not* have enough photon energy to remove an electron from an atom. However, it can still be hazardous. For example:

- Powerful industrial lasers, which emit tightly focused or coherent beams of visible light, can burn through human tissue and even metal.
- Some nonionizing radiation can interfere with the operation of heart pacemakers and other medical devices, as well as critical equipment in aircraft.
- High levels of radio frequency and microwave radiation can heat tissue and if the temperature increase is high enough, can adversely affect health.

Figure 11. Power Lines

Electric and Magnetic Fields

Extremely low-frequency *electric and magnetic fields* (EMFs) surround electrical machinery, home appliances, electric wiring, and high-voltage electrical transmission lines and transformers. (Figure 11)

A good deal of public and government attention has been focused in recent years on the possible health effects of EMFs. The public is exposed to these fields through the generation, transmission, and use of electric power. The National Institute of Environmental Health Sciences (NIEHS), a branch of the National Institutes of Health (NIH), has compiled information on this issue. (You can get more information on this and other issues from the NIEHS Web site http://www.niehs.nih.gov/emfrapid)

High-voltage power transmission and distribution lines have been a major focus of concern. *Alternating-current (AC) electricity*, with a frequency of 60 cycles per second, falls into the extremely low frequency range on the electromagnetic spectrum (Chapter 1, Figure 1) and thus has far too little energy to cause ionization.

However, AC electric and magnetic fields can induce electric currents in conducting materials, including human and animal tissue. (Direct-current fields, such as the Earth's magnetic field, do not have this effect). The electric current induced in our bodies may have potential biological and health effects.

Evidence of health effects from EMF is inconclusive, although some studies have indicated a possible link between EMFs and childhood leukemia and other forms of cancer. The information available however, is not sufficient to establish a cause-effect relationship.

Some studies have reported the possibility of increased cancer risks, especially leukemia and brain cancer, for electrical workers and others whose jobs require them to be around electrical equipment. Additional risk factors, however, such as exposure to cancer-initiating agents, may also be involved.

Some researchers have looked at possible associations between EMF exposure and breast cancer, miscarriages, depression, suicides, Alzheimer's disease, and Amyotrophic Lateral Sclerosis (ALS, or Lou Gehrig's Disease), but the general scientific consensus is that the evidence is not yet conclusive.

In June of 1998, a special review panel convened by the NIEHS reviewed EMF health studies. A majority of the panel found "limited evidence that residential exposure to extremely low frequency magnetic fields may increase the risk of childhood leukemia." A majority also found limited evidence that workplace exposure to EMFs may cause chronic lymphocytic leukemia in adults.

According to NIEHS, "the probability that EMF exposure is truly a health hazard is currently small. The weak epidemiological associations and lack of any laboratory support for these associations provide only marginal scientific support that exposure to this agent is causing any degree of harm." The NIEHS did conclude, however, in its 1999 Report to Congress, that extremely-low-frequency EMF exposure cannot be recognized as entirely safe because of weak scientific evidence that exposure may pose a leukemia hazard; the associations reported for childhood leukemia and adult chronic lymphocytic leukemia cannot be dismissed easily as random or negative findings.

On the positive side, the NIEHS panel found "strong evidence" that exposure to electric and magnetic fields can speed the healing of broken bones.

How can individuals reduce exposure? People concerned about their own exposure can take several steps to reduce it. Except in certain cases, most people's greatest exposure to EMFs may come from sources inside the home, rather than from power lines outside it. The NIEHS suggests avoiding standing too close to computers, microwave ovens, televisions, or other devices that may emit EMFs. People can reduce exposure to EMFs by turning off devices such as electric blankets when they are not in use and by not keeping devices such as electric alarm clocks too close to the bed. Adults can discourage children from playing near high power lines or electrical transformers.

The distance from a source of EMFs is important because the intensity of EMFs decreases proportionally to the square of the distance to their source. So doubling your distance from a source will reduce exposure to one-quarter of its previous level.

There are no federal health standards governing public exposure to EMFs. A few states however, have set standards for transmission line electric and magnetic fields.

Radio-Frequency (RF) and Cellular Phones

As hand-held cellular telephones become increasingly popular, people are understandably concerned about potential health effects from exposure to high-frequency radio waves. (Figure 12)

The radio waves used by analog and digital cellular phones are much higher frequency than the electric and magnetic fields produced by power lines, so their biological effects are different from the possible effects of EMFs.

Studies have shown that intense exposure to this type of nonionizing radiation can cause heat-related effects such as cataracts, skin burns, deep burns, heat exhaustion, and heat stroke, as well as electrical shock.

As a result of the studies, the United States and other countries have established standards to protect workers and the public from the known effects of excess exposure to the radio waves used in telecommunications. The antennas of cell-phone base stations and personal cell phones must comply with these standards.

Figure 12.
Use of Cellular Phones Has Become Part of Many People's Daily Lives

Most epidemiological studies have found no significant correlation between exposure to radio frequency (RF) radiation and an increased risk of cancer. One animal study at the University of Adelaide in Australia, showed that mice genetically predisposed to a type of cancer developed twice as many cancers when exposed to cell phone radiation. This study is being repeated at the University of Adelaid and other research laboratories to verify the finding.

The Food and Drug Administration (FDA), responsible for protecting the public from radiation exposure from consumer products, said that "the available science does not allow us to conclude that mobile phones are absolutely safe, or that they are unsafe. However, the available evidence does not demonstrate any adverse health effects associated with the use of mobile phones."

What Are the Benefits and Risks of Ionizing Radiation?

3

Since German physicist Wilhelm Konrad Roentgen discovered X-rays in 1895, people have invented thousands of new practical and beneficial uses for ionizing radiation. These uses have improved our quality of life and increased our life span.

Ionizing radiation is widely used in:

- Medicine and research
- Industry and manufacturing consumer products
- Nuclear power
- Agriculture and food processing
- Development and testing a wide variety of materials
- National defense (nuclear weapons)

However, our use of radioactive materials and creation of new sources of ionizing radiation add to our total annual exposure and increase the risks to our health and environment. Weighing the *benefits* of ionizing radiation against its *risks*, and deciding what level of risk is acceptable, is a constant challenge for scientists, government regulators, and each of us as individuals.

This chapter includes the following topics:

- The Benefits of Ionizing Radiation
- The Risks of Ionizing Radiation
- Determining Your Exposure
- Determining Levels of Risk
- Balancing the Benefits and Risks of Radiation

Benefits of Ionizing Radiation

Ionizing radiation lets us do many things that are impossible without it, such as identifying broken bones and healing tumors in the human body, checking for flaws in jet engines, and testing the thickness of eggshells. Life for many of us would be more difficult if we were suddenly to stop creating and using radiation.

Medical Uses

The most common, and one of the earliest uses of radiation, is to diagnose injury and disease. Roentgen's discovery of the X-ray allowed physicians to look inside the human body without operating. (Figure 13)

Figure 13.
Use of X-ray machine in medicine

3

What Are the Benefits and Risks of Ionizing Radiation?

Medical Uses

Today, doctors also use radiation in many ways to treat disease. One of every three Americans hospitalized each year is diagnosed or treated using nuclear medicine, totaling more than 11 million procedures a year. Radiation is also used in 100 million laboratory tests each year on body fluids and tissue specimens to aid in diagnosing disease.

Ionizing radiation is widely used to diagnose and treat cancer, increasing survival rates and improving patients' quality of life. Radiotherapy has helped to cure various types of cancer in tens of thousands of people and temporarily to halt the disease in many others. About 500,000 cancer patients in the United States—half of all people with cancer—are treated with radiation at some point in their therapy.

For example, a promising treatment for leukemia involves arming monoclonal antibodies with radioisotopes. The antibodies are produced in the laboratory and engineered to bind to a specific protein in tumor cells. When injected into a patient, these armed antibodies bind to the tumor cells, which are then killed by the attached radioactivity. Normal cells nearby are not affected.

Other applications of radiation in cancer diagnosis and treatment include:

- Mammography to detect breast cancer at an early stage when it may be curable
- X-rays or other imaging techniques that make needle biopsies safer and more accurate and informative
- Monitoring the response of tumors to treatment, and distinguishing malignant from benign tumors
- Bone and liver scans to detect the spread of cancers
- Alleviating or eliminating pain associated with prostate or breast cancer that has spread to the bones

The National Institutes of Health (NIH) lists more advanced medical uses of radiation:

- Newer X-ray technologies such as computerized tomography (CT, or CAT) scans have revolutionized the diagnosis and treatment of diseases affecting almost every part of the body. (Figure 14)
- Another scanning technology, positron emission tomography (PET) scanning, involves injecting a small amount of a radioisotope into a patient to show the metabolic activity and circulation in the brain. PET studies enable scientists to pinpoint the site of brain tumors or the source of epileptic activity and to better understand many neurological diseases.

Figure 14. CAT scan

- Radioisotopes are used to diagnose and monitor many diseases effectively and safely. To show how the disease process alters the normal function of an organ, a patient swallows, inhales, or receives an injection of a tiny amount of a radioisotope. Special cameras reveal where the isotope accumulates in the body (for example, showing an image of the heart with both normal and malfunctioning tissue).
- Laboratory tests use radioisotopes to measure important substances in the body, such as thyroid hormones.
- Radiation treatments for thyroid diseases, including thyroid cancer and Graves disease (one of the most common forms of hyperthyroidism), are so effective they have almost totally replaced thyroid surgery.
- Radioisotopes are used in animal studies to learn how the body metabolizes a new drug before it is approved by the Food and Drug Administration (FDA).
- Radioisotopes are used to sterilize hospital items to help prevent the spread of diseases. Radiation is especially useful for sterilizing such items as sutures, syringes, catheters, and hospital clothing that would otherwise be destroyed by heat sterilization. Sterilization using radioisotopes is particularly valuable because it can be performed while the items remain in their sealed packages, thus preserving their sterility indefinitely.
- Radioisotopes are a technological backbone of biomedical research. They are used to identify how genes work, and in much of the research on AIDS. Between 70 and 80 percent of all research at NIH is performed using radiation and radioactive materials.

(Adapted from: *What We Know About Radiation*, Office of Communications, National Institutes of Health, April 11, 1994.)

Industry

Numerous businesses and industries have found uses for radiation to improve products or services. The Nuclear Regulatory Commission (NRC) and the 32 states that participate in the NRC Agreement States program issue and administer more than 20,000 licenses for medical, academic, and industrial uses of nuclear materials.

Manmade radioisotopes are used by industry to:

- **Explore for oil and natural gas.** Geologists use a technique called nuclear well logging to determine whether a well drilled deep in the ground has the potential to produce oil. Radiation from a radioisotope inside the well can detect the presence of different materials.
- **Test pipes and welds**, including structural cracks and stresses in aircraft (Figure 15) and test for flaws in jet engines. Using a process called radiography, the object tested is exposed to radiation from a sealed radiation source and a piece of photographic or radiographic film on the opposite side of the object captures an image which can help to pinpoint flaws such as cracks or breaks.

Figure 15. Airplane

- **Control the thickness of sheet products,** such as steel, aluminum foil, paper, photographic film, and plastics, during manufacture. Detectors measure, highly accurately, the amount of radiation passing through the materials and compare it to the amount that should pass through the desired thickness.

- **Cold-sterilize plastics, pharmaceuticals, cosmetics, and other heat-sensitive products.** Exposing the materials to radiation, usually gamma radiation from Cobalt-60, kills bacteria and germs and is particularly effective when other methods such as boiling or chemical treatment are not practical.
- **Conduct security checks** of airline carry-on luggage.
- **Improve the quality of manufactured goods** in thousands of industrial plants by using radiation in sensitive gauges and imaging devices (for example, ensuring that beverage cans are correctly filled using a process similar to that of measuring the thickness of sheet products).
- **Pinpoint fluid leaks, monitor engine wear and corrosion,** and measure the flow of materials through pipes, using radioactive tracers similar to those used in medicine.
- **Identify trace quantities of materials.** Criminal investigators use radiation to identify trace amounts of materials like glass, tape, gunpowder, lead, and poisons. Called activation analysis, the procedure involves placing a sample of materials in a nuclear reactor and bombarding it with neutrons, which produces a “fingerprint” of the elements in the sample.
- **Prove the authenticity of old paintings.** Museums also use activation analysis to detect whether certain modern materials are present and use other techniques with radioisotopes to spot forgeries.
- **Detect pollution.** Scientists use radioisotopes to trace and identify the sources of pollution, such as acid rain and greenhouse gases, in air, water, and soil.

Nuclear Power

One-sixth of the world’s electricity, and nearly one-fifth of the electricity in the United States, comes from nuclear power plants. (Figure 16) These plants use nuclear fission (neutrons splitting uranium atoms) to produce tremendous heat that generates electricity. Americans get more of their electricity from nuclear power than from any other source except coal.

Figure 16. Nuclear Power Plant

But nuclear power plants also have a number of drawbacks. U.S. nuclear power plants generate about 2,000 metric tons of high-level radioactive waste each year, causing significant disposal problems. (See Nuclear Reactor Waste, Chapter 4, page 52).

Environmental and antinuclear groups oppose nuclear power because of concerns about safety, the potential for nuclear weapons proliferation and terrorism, and because of the unresolved problem of nuclear waste disposal. They argue that renewable energy sources such as solar and wind power are preferable to nuclear power as long-term alternatives to fossil fuel energy. (For more on the pros and cons of nuclear power, see Balancing the Benefits and Risks, Chapter 3, page 43.)

Some people consider nuclear power plants more environmentally friendly than coal or oil-burning plants. As a byproduct of combustion, fossil-fuel plants emit air pollutants such as nitrogen oxide, sulfur dioxide, and carbon dioxide, a principal “greenhouse gas” believed to contribute to global warming. Because nuclear plants use fission instead of combustion, they produce no combustion byproducts. Without nuclear power, U.S.

carbon emissions from electric generation would be about 30 percent higher.

Also, because they are so closely regulated and monitored, nuclear power plants release *less* ionizing radioactivity (an average dose of 0.009 mrem per year) into the environment than comparable coal-fired plants (an average dose of 0.03 mrem per year). New limits on fly-ash emissions from fossil-fuel plants, however, are helping to reduce radioactive emissions from these sources as well.

According to the Nuclear Energy Institute, the industry's trade association, the annual economic impact of the nuclear power industry is $90 billion in total sales of goods and services; 442,000 jobs; and $17.8 billion in federal, state, and local government tax revenues. The Institute estimates that nuclear power reduces U.S. reliance on foreign sources of oil by nearly 100 million barrels a year, enhancing the nation's energy security, and cutting the U.S. trade deficit by billions of dollars each year.

Agriculture

Radiation has become an increasingly important tool in agricultural research and practice. Some uses and their benefits are:

- Radioisotopes as a research tool help develop new strains of food crops that are more nutritious, resist disease, and produce higher yields.

  For example, radiation has been used in producing peanuts, tomatoes, onions, soybeans, barley, and the "miracle" rice that has boosted rice production in Asia.
- Radioisotope tracers in plant nutrients aid in reducing soil and water pollution by helping researchers to learn how plants absorb fertilizer and how to calculate the optimum amount and frequency of fertilizer applications.
- Insect sterilization with radiation results in mating without offspring, thus limiting insect population growth. This has eliminated screwworm infestation in the southeastern United States and Mexico, and has helped control the Mediterranean fruit fly in California. With fewer pests, food crop productivity increases.
- Moisture monitoring with nuclear density gauges can measure the moisture content of soil, helping make the most efficient use of limited water sources for successful crop production.

Food Irradiation

Irradiation Process

One of the more controversial uses of radiation today is food irradiation. High doses of radiation do *not* make food radioactive. Irradiation kills bacteria, insects, and parasites, and retards spoilage in some foods. Irradiated foods are regularly eaten by astronauts on space missions, as well as by hospitalized patients with weak immune systems who need extra protection from microorganisms in food.

The irradiation process involves exposing food to intense controlled amounts of ionizing radiation—gamma rays from cobalt-60 or cesium-137, X-rays, or electron beams from particle accelerators. The process has about the same effect on food as canning, cooking, or freezing. It kills pests and extends shelf life, but also reduces the food's nutritional value somewhat by destroying vitamins A, B1 (thiamin), C, and E. No radiation remains in the food after treatment.

Exposing materials, including foods, to radiation from an irradiator is very different from exposing them to radiation from a reactor. The gamma radiation from cobalt-60 in an irradiator kills bacterial and germs, but does not leave any radioactive residue or cause any of the exposed materials to become radioactive. The cobalt-60 in an irradiator is contained in stainless steel capsules and does not commingle with the material being irradiated. On the other hand, material exposed to neutrons from a reactor or linear accelerator can become radioactive.

Approvals and Bans

Irradiation has been approved by:

- The FDA - for a number of foods including, herbs and spices, fresh fruits and vegetables, wheat, flour, pork, poultry, and red meat
- The World Health Organization
- The United Nations Food and Agricultural Organization
- Approximately 40 countries besides the United States

Three states—Maine, New Jersey, and New York—have banned the sale, however, of irradiated foods and food ingredients (except for spices). Many U.S. food producers have been reluctant to adopt food irradiation because of protests by food-safety groups and because of uncertainties about consumer acceptance.

Benefits

Irradiation advocates, including the FDA and the U.S. Department of Agriculture (USDA), point to a number of benefits of food irradiation:

- The process is better for the environment than treating foods with toxic chemicals, such as methyl bromide or ethylene oxide.
- Irradiation, coupled with proper handling, cooking, and storage of food, can help reduce the incidence of food-borne disease. Some six million cases a year in the United States result in more than 9,000 deaths.
- By retarding spoilage and extending the shelf life of food, irradiation also helps humanitarian groups deliver food to starving people.

Concerns

However, critics point to a number of concerns with food irradiation:

- Irradiated foods could pose a botulism hazard because the process kills bacteria that cause spoiled food to smell or look bad, thereby eliminating the traditional signals of inedible food.
- Irradiation can accelerate spoilage in several fruits, including pears, apples, citrus fruits, and pineapples.
- The irradiation process may expose workers and the environment to radiation hazards.
- Irradiation reduces the food’s nutritional value by destroying some vitamins.

While extensive studies have found no evidence that irradiated foods or compounds cause adverse health effects, some consumers may find them unacceptable because they prefer natural or organic foods.

How do you know if the food in your grocery store has been irradiated?

The FDA requires irradiated foods to be labeled with the green radiation logo, called the radura (Figure 17) and the words “treated by irradiation,” “treated with irradiation,” or “irradiated.”

However, processed foods containing irradiated ingredients and irradiated food sold in restaurants *do not* have to be labeled. Consumer groups are working to expand the labeling requirement.

Figure 17.
Radura label required on irradiated food

Should you avoid irradiated food?

If your only concern is possible adverse health effects, the government says no.

- The FDA has found no evidence that irradiation of food is less safe than other preservation methods.
- Irradiation does a good job of killing bacteria that cause food-borne diseases such as, salmonella in poultry and seafood, E. coli in beef, trichinosis in pork, and cholera in fish.

But if it is more important to you that your foods are grown and packaged naturally without artificial treatments and with their vitamins and minerals intact, then irradiated foods may not be prime candidates for your shopping list.

Consumer Products

Radiation is used in, or to produce many consumer products. For example, many smoke detectors—now installed in nearly 90 percent of American homes—use the radioactive isotope americium-241, which emits alpha radiation. By ionizing the air sealed inside the detector, the radiation produces an electric current that sets off the alarm if interrupted by smoke in the detector.

Radioactive materials are also used to:

- Eliminate dust from computer disks and audio and video tapes
- Sterilize baby powder, bandages, cosmetics, hair products, and contact lens solutions (Exposing these materials to radiation, usually gamma radiation from cobalt-60 kills bacteria and germs.)
- Control the thickness of many sheet products, such as paper, sandpaper, or aluminum foil and the amount of liquid in beverage can (Detectors measure, highly accurately, the amount of radiation passing through the materials and compare it to the amount that should pass through the desired thickness.)
- Attach a non-stick surface to a frying pan
- Brighten the porcelain in false teeth to make them look more real

None of the radiation remains in these consumer products after they are treated or sterilized.

Radioactive materials also create the glow in luminous watches and in instrument panel dials and are used in some gas camping lanterns. Radiation is also used in production of some clothing, eyeglass lenses, lightning rods, tires, ceramic glazes on some china and decorative glassware, enameled jewelry, and cellophane dispensers.

Only a small fraction of our total annual exposure to radiation, about 11 millirem a year, comes from consumer products.

The Space Program

The U.S. Space program has used radioisotope thermoelectric generators (RTGs) to power 24 of its space probes over the last 25 years. The natural decay of plutonium dioxide produces heat, which is converted to electricity by a thermocouple device. Compact and relatively light, RTGs typically produce about 300 watts of electricity and can operate unattended for years.

Among the space research probes powered-by RTGs were:

- The Apollo Lunar Surface Experiment Packages (1969–1971)
- Pioneer 10 and 11 (1972 and 1973)
- Two Viking Mars spacecraft (1978)
- Two Voyager spacecraft (1977)
- The Galileo (1989), Ulysses (1990), and Cassini (1997) spacecraft.

Sea Power

The U.S. Navy was an early user of nuclear power, launching the USS NAUTILUS, the first nuclear-powered submarine, in 1954. Since 1954, the Navy has built more than 200 submarines and surface ships powered by nuclear reactors. These vessels have traveled more than 100 million miles of ocean on nuclear power.

Nuclear submarines have two major advantages: speed and underwater range without surfacing. A modern nuclear powered Navy submarine can cruise up to one million miles, or more than 25 years, without refueling.

Research

Radioactive materials are valuable tools for research in nearly all fields of modern science: physics, mineralogy, metallurgy, biology, medicine, agriculture, environmental science, geology, chemistry, and many others.

- Many scientists use X-rays and neutrons to study the properties of a wide variety of materials, develop new plastics, and strengthen materials, such as those used in aircraft.

- *Chemists* and *biologists* use *X-ray diffraction techniques* to study the crystalline structure of proteins, the basic building blocks of life, and also to study viruses that cause diseases ranging from the common cold to AIDS.
- *Environmental scientists* use *radioisotopes* to track chemical contaminants as they move through water or the ground and to study the global movement of wind and water.
- *Geologists* read radioactive materials that occur naturally in the earth to determine the age of rocks and to study plate tectonics.
- *Archaeologists* determine the age of prehistoric artifacts through *carbon dating*, a process that measures radioactive carbon-14. When an organism is alive, its ratio of carbon-14 to carbon-12 is the same as in the atmosphere. When the organism dies, the carbon-14 begins to decay and the ratio changes. This ratio is used to determine how long ago the organism died.
- *Criminologists* use *neutron activation analysis* to detect the presence of toxic substances such as arsenic in the body.
- *Investigators* detect forgeries by measuring *radioactive decay*; and use *"ultrasoft" X-rays* to determine the authenticity of paintings and to aid in their restoration.

The Risks of Ionizing Radiation

Ionizing radiation is intricately woven into the fabric of modern life. But living and working with radiation can be hazardous. If we want to continue enjoying the benefits that radiation brings, we may have to accept some additional risk to our health and environment.

How much risk is acceptable to us as a society? This is a subject of constant and often heated debate. To participate constructively in that debate, we must:

- Understand the risks—how and to what extent the different kinds and sources of radiation can affect our health and environment.
- Learn what the producers and users of radiation, the government, and each of us as individuals, can do to minimize those risks.

Measuring Human Exposure

Several factors are involved in determining the potential health effects of exposure to radiation. These include:

- The size of the dose (amount of energy deposited in the body)
- The ability of the radiation to harm human tissue (See Ionizing Radiation, Chapter 1, page 12.)
- Which organs are affected

Amount of the Dose. The most important factor is the amount of the dose—the amount of energy actually deposited in your body. The more energy absorbed by cells, the greater the biological damage. Health physicists refer to the amount of energy absorbed by the body as the *radiation dose*. The absorbed dose, the amount of energy absorbed per gram of body tissue, is usually measured in units called *rads*.

The amount of the dose depends on such factors as:

- The number and energy level of the radiation particles emitted by the source (the source's activity, measured in units called curies)
- The distance from the source (Distance is especially important with alpha radiation; more than a few centimeters from the source, the amount of the dose approaches zero.)
- The amount of exposure time
- The degree to which radiation dissipates in the air or in other substances between the source and the recipient
- The penetrating power of the radiation

Ability to Harm Tissue. Health physicists also must take into account the ability of the type of radiation involved to harm human tissue. To do this, they multiply the absorbed dose by a biological effectiveness factor, the Q *factor*, to come up with a measurement of harm called the dose-equivalent. (Table 2) The Q factor is a "consensus factor" agreed upon by experts and used for regulatory purposes.

Table 2: Biological Effectiveness Factor by Radiation Type

Type of Radiation	Q Factor
Alpha particles	20
Beta particles	1
Gamma radiation	1
Protons, fast neutrons	10
Slow (thermal) neutrons	2

In the United States, dose-equivalent is commonly expressed in *rem*, which stands for radiation equivalent man. Small doses are measured in thousandths of a rem or *millirem*. The United States and international scientific communities also use units called *Sieverts*, which are each equal to 100 rem.

Which Organs are Affected. The potential health effects of radiation also depend on which organs of the body are most likely to absorb radiation.

- When ingested, radiation from some sources tends to accumulate in certain organs. For example, iodine-131 concentrates in the thyroid gland, where its beta radiation, at high doses, can be effective in destroying hyperactive thyroid cells.
- Radiation from other sources is distributed more widely in the body. For example, water containing tritium (a radioactive isotope of hydrogen) distributes beta-emitting radioactivity throughout the body.

(Adapted from *Ionizing Radiation—It's Everywhere!* Los Alamos Science, Los Alamos National Laboratory, Number 23, 1995.)

Studying Radiation's Effects on Humans

There are a number of studies of the effects of radiation on humans:

- The Radiation Effects Research Foundation (RERF) has been studying the long-term effects of radiation on the survivors of the Hiroshima and Nagasaki bombings in Japan since 1947. RERF is an international organization jointly funded by the Japanese Ministry of Health and Welfare, the U.S. Department of Energy (DOE), and the National Cancer Institute (NCI), part of National Institutes of Health.
- RERF researchers learn more about the effects of ionizing radiation by monitoring uranium miners and people who lived near the Nevada nuclear weapons test sites used from 1951 through 1963.
- NCI is studying the people most affected by the 1987 Chernobyl nuclear power plant accident in Ukraine, especially children who lived nearby and workers who cleaned up the plant after the accident.

After rigorous peer review, the information from the studies is published in medical and scientific journals and made available to the public. Because of these and other studies, more is known about the health effects of ionizing radiation than of any other carcinogen.

Human Health Effects of Ionizing Radiation

Ionization

Most atoms are electrically neutral; they have the same number of positively charged protons in their nucleus as negatively charged electrons orbiting the nucleus. However, when ionizing radiation passes through a material, it can transfer some of its energy to an electron; this "knocks" the electron out of its orbit. The free negative

What Are the Benefits and Risks of Ionizing Radiation?

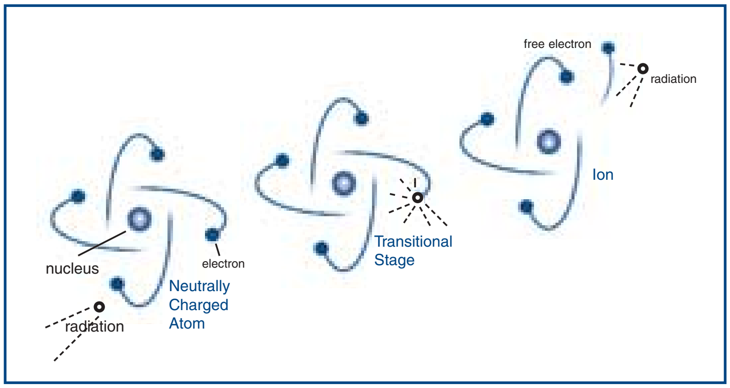
Human Health Effects of Ionizing Radiation

electron leaves behind a positively charged ion (see Figure 18). This process is called *ionization*.

Knowing about ionization is important for two reasons.

- First, ions formed in living tissue, such as the human body, can cause both short-term and long-term damage.
- Second, because ions have an electrical charge, they are easy to detect. This makes it possible to measure the amount of radiation present—even at extremely low levels.

Figure 18.
Ionization of an atom



Source: The Ohio State University Extension

Exposure to Ionizing Radiation

Exposure to high levels of ionizing radiation is dangerous, even deadly. Acute exposure to radiation in the range of 300,000 to 500,000 millirems can destroy cell tissue almost immediately, causing death within a few days or weeks for more than half of the exposed population. Fortunately, the chance of the average citizen receiving such a large dose of radiation is extremely small.

Doses above 5,000 millirem are known to substantially increase the risk of infection and cancer and potentially cause genetic damage to the exposed person and his or her offspring, Cataracts, premature aging, hair loss, skin burns, and a shortened life span are other known consequences of high-level exposure. Since a radiation-induced cancer cannot be distinguished from cancer caused by other factors, however, it is difficult to single out radiation as the cause of any particular cancer.

The average person in the United States receives an exposure of approximately 360 millirems per year. While exposure above 5,000 millirem can cause observable biological effects (and at higher doses can be fatal), there is little evidence of health or safety effects at exposure levels below 1,000 millirem. Any exposure to radiation, however, may pose some risk.

Many scientific studies have demonstrated a relationship between the amount of radiation and the likelihood of adverse health effects. To minimize human health effects, regulators assume that there is some risk associated with any level of radiation, and set exposure standards accordingly.

High-Dose Effects

In the first decades after the discovery of radioactivity and X-rays in the 1890s, the health effects of ionizing radiation were not recognized. Scientists and others who worked with radioactive materials took no special precautions to protect themselves.

Skin cancers in scientists who were studying radioactivity were first reported in 1902. By 1912, researchers found leukemia in humans and animals exposed to radiation, and by 1930 genetic effects were identified.

In the 1930s, the occupational hazards of working with radiation became apparent. A 1931 report described cases of bone cancer in women who licked the brushes (to get a better brush point) they used to paint radioactive radium on watch dials. In 1944, the first cases of leukemia were reported in physicians and radiologists who used radiation in their work. By 1951, thyroid cancer was reported in persons exposed to radiation as children.

In 1945, Japanese citizens were exposed to high doses of radiation (up to 500,000 millirem or more) during the bombings of Hiroshima and Nagasaki. (Figure 19) Studies of the atomic bomb survivors and other people exposed to high levels of radiation have shown that acute exposure to ionizing radiation can cause cancer, sterility, and genetic damage; and damage to bone marrow, the central nervous system, and the gastrointestinal system.

In the years since the bombing on Hiroshima and Nagasaki, scientists have tracked the health histories of more than 75,000 survivors. (See Studying Radiation's Effects on Humans, page 33.) The studies indicate that radiation was a factor in approximately 12 percent of *all* the cancers (including leukemia, breast cancer, thyroid cancer, and skin cancer), and approximately 9 percent of the 6,000 *fatal* cancers that developed among the atomic bomb survivors. In sum, this means approximately 500 more cancer deaths occurred among the exposed population than an unexposed population of the same size.

Other effects that appeared in the exposed population include the suppression of the immune system and cataracts. An increased rate of mental retardation has been found in atomic bomb survivors whose mothers were between 8 and 25 weeks pregnant at the time of exposure. (The brain tissues of a fetus are especially sensitive to radiation at certain stages of development.) So far, however, the children and grandchildren of exposed survivors have shown no greater incidence of genetic problems than unexposed populations. More than 56 percent of the exposed survivors were still alive in 1990, when the most recent cycle of mortality information was completed.

These studies have made it possible for scientists to record the long-term effects of a wide range of radiation doses, including doses comparable to an average person's lifetime dose from naturally occurring background radiation, about 20,000 millirem (300 millirem a year for 70 years).

Figure 19.
Atomic bomb explosion

Among the most important findings from the human health studies are:

- The larger the radiation dose a person receives, the greater the risk of developing cancer.
- The chance of cancer occurring (but not the kind or severity of cancer) increases as the dose increases.
- Most cancers do not appear until many years after exposure (typically 10 to 40 years).

Low-Dose Effects

Determining the health effects of exposure to low levels of radiation has been much more difficult than determining the effects of high-level exposure, for two reasons.

- Cells can repair some damage caused by low levels of radiation absorbed over long periods of time.
- It is difficult to tell whether a particular cancer was caused by radiation, by one of the more than 300 other known carcinogens in the environment, or by other unknown factors.

Dr. Arthur C. Upton, former chairman of the New York University Medical Center, Department of Environmental Medicine, has compared efforts to detect the effects of low-level radiation with "trying to listen to one violin when the whole orchestra is playing. You can't hear it."

The numerous studies of potential health effects in people exposed to low-level radiation (that is, below about 10,000 to 40,000 millirem) have yielded inconclusive results. For example, studies have been conducted in populations living with background radiation several times higher than the United States. These studies have not found any statistically significant evidence of a correlation between cancer mortality and levels of background radiation.

Many scientists and policy makers take the position that any amount of radiation exposure, even at background levels, poses some increased risk of adverse health effects. Just how much risk, however, is still unknown and is the subject of continuing debate.

Although no health effects have been observed at very low doses, regulators assume that any amount of radiation may pose an increased risk for causing cancer and hereditary effects. They also assume that there is a one-to-one, or linear relationship between a radiation dose and its effect. That is, small doses have a small risk in direct proportion to the known effects of large doses.

This technique, known as the *linear no-threshold hypothesis*, uses mathematical models to estimate the risks of very low exposures based on the known risks of high-level exposures. Some scientists question the linear hypothesis because of the lack of evidence of health effects from low radiation doses, as well as the fact that many other hazardous substances harmful at high doses have little or no effect at low doses. The U.S. Committee on the Biological Effects of Ionizing Radiation (BEIR), convened by the National Academy of Sciences (NAS), acknowledged in 1990, that there is no data showing that low doses of radiation cause cancer.

The BEIR Committee, however, recommended the use of the linear no-threshold hypothesis because it is consistent with other approaches to public health policy. The United States and other countries use linear estimates to set limits on all potential exposures to radiation, both for the public and for workers in jobs that expose them to ionizing radiation. (See National Academy of Sciences, Chapter 5, page 67.)

In 1998, the BEIR Committee reported that recent epidemiological studies of radiation and cancer warrant a reevaluation of the health risks associated with low-level doses of radiation. The committee will review all relevant data and develop new risk models to try to determine more definitively the health risks, if any, from low-level doses of radiation.

Lifetime Risk of Cancer from Increased Radiation Exposure

The BEIR Committee estimated the lifetime risk of cancer to individuals from high-level and low-level exposures to radiation. (Table 3) These estimates used the linear no-threshold hypothesis to develop average cancer estimates over all possible ages at which a person might be exposed, weighted by population and age distribution. The calculation compares the estimated increase in cancers due to whole-body external radiation from a single, high-level exposure (10,000 millirem), and from continuous low-level exposure (500 millirem, the current upper limit for individual exposure recommended by federal guidance).

Because of the extensive scientific research on radiation and the large number of studies of exposed persons, these estimates have a higher degree of certainty than the risk estimates for most chemical carcinogens.

Genetic Effects

Both high-level and low-level radiation may cause other adverse health effects besides cancer, including genetic defects in the children of exposed parents or mental retardation in the children of mothers exposed during pregnancy. The risk of genetic effects due to radiation exposure, however, is much lower than the risk of developing cancer.

By breaking the electron bonds that hold molecules together, radiation can damage human DNA, the inherited compound that controls the structure and function of cells. Radiation may damage DNA directly by displacing electrons from the DNA molecule, or indirectly by changing the structure of other molecules in the cell, which may then interact with the DNA. When this happens, a cell can be destroyed quickly or its growth or function may be altered through a change (mutation) that may not be evident for many years. (Figure 20) At low radiation doses, however, the possibility of such a change causing a clinically significant illness or other problem is believed to be remote.

In addition, cells have the ability to repair the damage done to DNA by radiation, chemicals, or physical trauma. How well cellular repair mechanisms work depends on the kind of cell, the type and dose of radiation, the individual and other biological factors.

Health Effects of Radon

Radon accounts for more than half of our total average annual exposure to radiation, about 200 millirem per year. (Figure 21) Radon is a known cause of lung cancer in humans. The most recent National Academy of Science (NAS) report on radon, *The Health Effects of Exposure to Radon* (the BEIR VI Report, published in 1999), stated that radon is the second leading cause of lung cancer and a serious public health problem. The NAS report estimated that about 12 percent of lung cancer deaths in the United States are attributable to exposure to radon in indoor air—about 15,000 to 22,000 lung cancer deaths each year. In a second NAS report published in 1999 on radon in drinking water, the NAS estimated that about 89 percent of the fatal cancers caused by radon in drinking water were due to lung cancer from inhalation of radon released to indoor air, and about 11 percent were due to stomach cancer from consuming water containing radon.

Radon decay products can attach themselves to tiny dust particles in indoor air, which are easily inhaled into the lungs. The particles then attach to the cells lining the lungs and emit a type of ionizing radiation called alpha radiation. This can damage cells in the lungs, leading to lung cancer. Our knowledge of the health effects of radon comes from extensive studies of miners and of people exposed to radon in their homes. Experimental studies in animals and

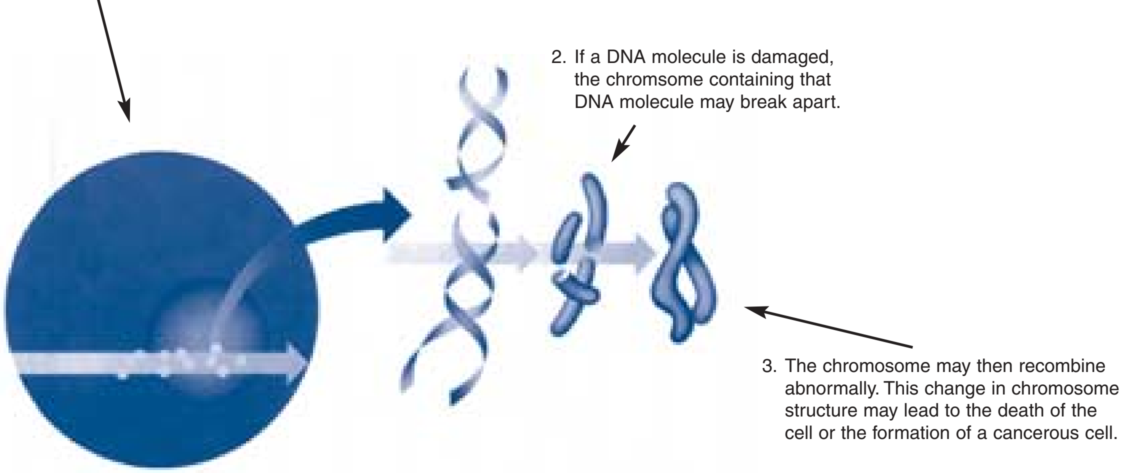


Figure 20. Genetic damage from radiation

Source: U.S. Environmental Protection Agency

Table 3: Estimated Lifetime Cancer Risk from Increased Radiation Exposure

Type of exposure to whole-body external radiation	Increase in cancers per 1,000 people (above that expected for a similar but unexposed population)
Single, high-level exposure to 10,000 millirem	8 cancers (about 3%)
Continuous low-level exposure to 500 millirem	5.6 cancers (about 2%)

Source: National Academy of Sciences

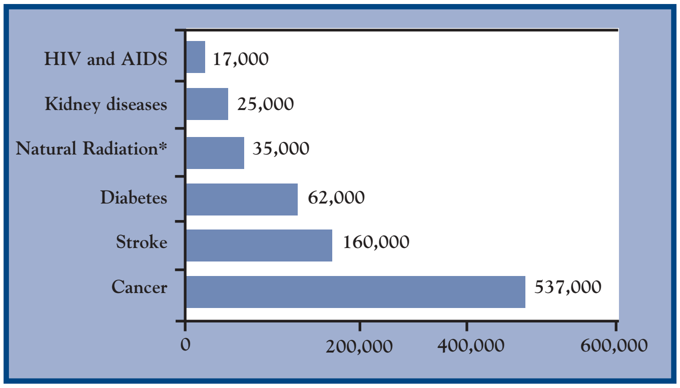
Health Effects of Radon

molecular and cellular studies provide supporting evidence and some understanding of the mechanisms by which radon (i.e., alpha radiation) causes lung cancer.

A person's risk of getting lung cancer from radon depends upon several variables, including the level of radon in the home, the amount of time spent in the home, and whether the person is a smoker. The risk of lung cancer is especially high for cigarette smokers exposed to elevated levels of indoor radon. NAS found evidence of an interaction between radon and cigarette smoking that increases the lung cancer risk to smokers beyond what would be expected from the additive effects of smoking and radon. In most cases, radon in soil under homes is the biggest source of exposure to radon. However, there are public health concerns associated with drinking water containing radon. When radon in water is ingested, it is distributed throughout the body. Some of it will decay and emit radiation while in the body, increasing the risk of cancer in irradiated organs (although this increased risk is significantly less than the risk from inhaling radon).

Most of the damage is not from radon gas itself, which is removed from the lungs by exhalation, but from radon's short-lived decay products (half-life measured in minutes or less). When inhaled, these decay products may be deposited in the airways of the lungs and subsequently emit alpha particles as they decay further. The increased risk of lung cancer from radon primarily results from alpha particles irradiating lung tissues. When an alpha particle passes through a cell nucleus, DNA is likely to be damaged, and available data indicate that a single alpha particle passing through a nucleus can cause genomic changes in a cell, including mutation and transformation. Since alpha particles are more massive and more highly charged than other types

Figure 21. Annual deaths from natural radiation and selected other causes.



Source: U.S. Environmental Protection Agency (radiation estimates) and National Center for Health Statistics (1997 data).

*An estimated 20,000 from radon and 15,000 from natural sources other than radon.

of ionizing radiation, they are more damaging to the living tissue.

An important finding of the BEIR VI report is that even very small exposures to radon can result in lung cancer. The NAS concluded that no evidence currently exists that shows a threshold of exposure below which radon levels are harmless, that is, a level below which it is certain that no increased risk of lung cancer would exist.

Radiation-Related Health Effects from Living near Nuclear Power Plants

Nuclear power plants expose people living near them to small amounts of radiation, less than one millirem per year. (Figure 22) In the United States, the EPA sets strict standards governing radiation emissions, which are enforced by the Nuclear Regulatory Commission. Radiation levels at nuclear power plants are monitored 24–hours–a day. Neighboring soil, cows' milk, fish, and sediment in rivers and lakes are monitored periodically.

In September 1990, a National Cancer Institute study found no evidence of an increase in cancer mortality among people living in 107 counties that host or are adjacent to 62 nuclear facilities in the United States. The research, which evaluated mortality from 16 types of cancer, showed no increase in childhood leukemia mortality rates in the study counties after nuclear facilities were opened. The NCI surveyed 900,000 cancer deaths in counties near nuclear facilities that operated for at least five years prior to the start of the study (the minimum time considered sufficient for related health effects to appear).

The conclusions of the NCI study, the broadest ever conducted, are supported by many other scientific studies in the United States, Canada, and Europe.

Accidental Releases

Many people worry about the risks of radiation not so much because of routine, low-level exposures, but because of the possibility of an accident at the plant. What if an explosion or meltdown at a nuclear reactor released deadly amounts of radiation or radioactive materials into the environment? Public anxiety was heightened in March 1979 by the accident at the Three Mile Island nuclear power plant in Pennsylvania. That accident was followed by a much worse catastrophe at the Chernobyl nuclear power plant in the former Soviet Union in April 1986.

Three Mile Island

Three Mile Island is the only major accident in the history of U.S. commercial nuclear energy. Although some radioactive material escaped from the reactor containment building, the accident caused no deaths or injuries. It resulted in an average dose of eight millirems to people living within 10 miles of the plant (about the same as a chest X-ray) and only 1.5 millirem to people living within a 50-mile radius. The maximum individual dose was less than 100 millirem. Subsequent studies have found no evidence of increases in cancer (including childhood leukemia), thyroid diseases, or other health effects as a result of the accident.

Figure 22.
Nuclear power plant

Chernobyl

The Chernobyl accident, however, was much more serious than Three Mile Island. There was no containment building around the reactor. A chemical explosion set the reactor core on fire, directly releasing large amounts of radioactivity into the atmosphere. Thirty-one plant workers and firefighters, who received doses up to 1.6 million millirem, died from the accident, and more than 130 plant workers and rescuers suffered from confirmed cases of acute radiation sickness. The average radiation dose to the 135,000 people evacuated from the region was 12,000 millirem. The doses included external gamma radiation, beta radiation to the skin, and internal doses to the thyroid.

During the first year after the accident, excess radiation doses to adults in seven Western European countries ranged from 130 millirem in Switzerland, to 95 millirem in Poland, to 2 millirem in southern England. Nearly 3 million acres of farmland in Ukraine were contaminated by radioisotopes and plutonium, and may be unusable for decades. Chernobyl was a graphic example of just how serious the health and environmental consequences of a catastrophic nuclear accident can be.

Could such an accident happen again? While there are still some Chernobyl-type reactors operating in Eastern Europe that are cause for concern, remedial measures were taken to enhance the safety of these reactors. Safety upgrades, performed between 1987 and 1991, essentially remedied the design deficiencies that contributed to the accident.

Reactor Safety Standards

Most of the world's nuclear power plants are built differently than Chernobyl and operate according to much stricter safety standards. They have redundant safety systems to prevent the kind of explosion and fire that released radioactive material into the environment at Chernobyl. National and international nuclear regulatory bodies keep a watchful eye on reactor operations and target potentially unsafe conditions and practices. If companies do not take prompt action to correct such safety problems, they can be forced to shut down their reactors.

As new reactors replace older reactors, the new designs will include safety features such as the use of gravity and convection in cooling water systems rather than mechanical pumps and motors that might fail. New control room designs will also reduce the possibility of human error, a significant factor in both the Three Mile Island and Chernobyl accidents. The Nuclear Energy Institute, an industry group, argues that the advanced plants will be able to meet safety goals that are more than 100 times more stringent than those of current nuclear plants.

The haunting specters of Chernobyl and, to a lesser extent, Three Mile Island, will linger in the public's memory for years to come. But there are other issues related to nuclear power, particularly the management and disposal of highly radioactive waste that pose potential risks to public safety and the environment. These issues are discussed in Chapter 4.

Determining Your Exposure

Most of the exposure levels described in this guidebook are averages and may not reflect your own individual exposure or that of members of your family. Depending on where you live, your lifestyle, and your occupation, you could be exposed to more or less radiation than the average person.

For example, if you live in "mile-high" Denver, Colorado, your average annual dose from cosmic radiation is about 50 millirem per year. If you live in Leadville, Colorado, at an altitude of two miles, your cosmic radiation dose is closer to 125 millirem per year. However, if you live on a coastal plain, like Florida, you receive only about 26 millirem per year from cosmic radiation.

Some parts of the country have higher concentrations of radon and radioactive minerals in the soil than others. In Ohio, for example, a line of Ohio Black Shale runs through the center of the state from south to north, along part of the Lake Erie shore, and in the northwestern parts of the state. Many people who live over this shale experience higher doses from radon than those who live elsewhere in Ohio. Also, very high levels (hundreds or even thousands of pCi/L) of radon have been found in homes built in the area known as the Reading Prong in the Northeastern United States. (See Radon, Chapter 2, page 18 and The Health Effects of Radon, Chapter 3, page 37.)

Other factors that help determine your exposure include:

- The consumer products you use regularly
- The number of medical and dental procedures using radiation that you undergo annually
- The kind of work you do. (Airline flight crews receive many times the average radiation exposure from cosmic rays while in the air, an extra 100 millirem per year on average.)
- Whether you smoke
- The kind of house you live in

You can use Table 4 to do a rough calculation of your annual exposure to radiation.

Determining Levels of Risk

To establish standards for protecting the public from environmental hazards, including radiation, regulators often use a type of analysis called *risk assessment*. Risk Assessment includes four steps:

1. **Hazard identification**. In this step, researchers determine whether a substance causes cancer or other health effects. Human data has confirmed that ionizing radiation can cause cancer in the human body. Factors to determining the hazard associated with exposure to particular radiation include the following:

- Amount of radioactivity
- Type of radiation involved
- Duration of exposure
- Distance from the source

Other factors that contribute to the risk of harm resulting from exposure to radiation include:

- Types of cells and specific parts of the body that absorb the radiation
- The exposed person's age, sex, physical condition, and genetic tendency either to resist or be affected by radiation

(See Measuring Human Exposure in this Chapter, page 32.)

2. **Dose-response assessment**. This step determines the relationship between the amount of exposure and the likelihood of developing cancer and other health effects. The accuracy of this assessment is based on the quality of information available from similar exposures. The data on radiation dose-response relationships are very reliable at high doses. Scientists extrapolate the known dose-response relationship to estimate risk at low levels of exposure. This method is considered by many to be reasonably conservative, but has its critics who consider it either too liberal or too conservative.

3. **Exposure assessment**. This step involves estimating the extent to which people could be exposed to radiation emitted by the source. It includes estimating:

- How much of the source exists,
- How radiation from the source will reach people (e.g., through the air, water, or food), and
- How big a dose they will receive from each medium the radioactive material travels through (e.g., How much contaminated air will they breathe? How much contaminated water will they drink?).

4. **Risk characterization.** This step combines the results of the previous steps to summarize the risk potential of the hazard, and describe the strengths and weaknesses of the risk assessment.

Table 4: What Is Your Estimated Annual Radiation Dose?

Source	Your Average Annual Dose (mrem)
Cosmic radiation at sea level (from outer space)	26
What is the elevation (in feet) of your town? up to 1000, add 2 mrem 1,000 - 2,000, add 5 mrem 2,000 - 3,000, add 9 mrem 3,000 - 4,000, add 15 mrem 4,000 - 5,000 add 21 mrem 5,000 - 6,000, add 29 mrem 6,000 - 7,000, add 40 mrem 7,000 - 8,000, add 53 mrem above 8,000, add 70 mrem	
Terrestrial (from the ground): What region of the US do you live in? Gulf Coast, add 16 mrem Atlantic Coast, add 16 mrem Colorado Plateau, add 63 mrem Elsewhere in United States, add 30 mrem	
Internal radiation (in your body): From food and water, (e.g. potassium and radon in water)	40
From air, (radon)	200
Do you wear a plutonium powered pacemaker? If yes, add 100 mrem	
Do you have porcelain crowns or false teeth? If yes, add .07 mrem	
Travel Related Sources: Add .5 mrem for each hour in the air	
Are X-ray luggage inspection machines used at your airport? Yes, add .002 mrem	
Do you use a gas camping lantern? If yes, add .2 mrem	
Medical Sources X-rays: Extremity (arm, hand, foot, or leg) add 1 mrem Chest X-rays, add 6 mrem Skull/neck, add 20 mrem Upper GI, add 245 mrem Dental X-rays, add 1 mrem Pelvis hip, add 65 mrem Barium enema, add 405 mrem CAT Scan (head and body), add 110 mrem Nuclear Medicine (e.g. thyroid scan), add 14 mrem	
Miscellaneous Sources: Weapons test fallout	1
Do you live in a stone, adobe brick, or concrete building? If yes, add 7 mrem	
Do you wear a luminous wristwatch (LCD)? If yes, add.06 mrem	
Do you watch TV? If yes, add 1 mrem	
Do you use a computer terminal? If yes, add .1 mrem	
Do you have a smoke detector in your home? If yes, add .008 mrem	
Do you live within 50 miles of a nuclear power plant? If yes, add .01 mrem	
Do you live within 50 miles of a coal fired power plant? If yes, add .03 mrem	
TOTAL YEARLY DOSE (in mrem):	

[Note: The amount of radiation exposure is usually expressed in a unit called millimrem (mrem). In the United States, the average person is exposed to an effective dose equivalent of approximately 360 mrem (whole-body exposure) per year from all sources (NCRP Report No. 93).]

Source: U.S. EPA and American Nuclear Society based on Data from the National Council on Radiation Protection and Measurements Reports # 92 - 95 and #100.

Balancing the Benefits and Risks of Radiation

Governmental Risk Assessments and Standards

Because exposure to high-level ionizing radiation is known to cause cancer and other health problems, public health regulators have taken a cautious approach. They assume that any exposure could cause similar effects. They have established protective standards by directly extrapolating the risks from high doses of radiation to minimize the risks of exposure to low doses. Much of the current controversy surrounding radiation is based on whether we should assume low doses also cause health affects.

Since most scientists assume that any radiation exposure entails some risk, how do we decide what level of risk is justified by the benefits of its use? In life, there is always a statistical chance that some people will contract certain diseases. Scientists and public health professionals perform risk assessments to determine the additional likelihood of being harmed from exposure or from certain behaviors. For a carcinogen such as radiation, risk is the additional likelihood of contracting cancer from exposure.

Over the years since radiation was first discovered and used, the government has constantly tightened the standards that limit the amount of radiation to which workers and the public can be exposed. The national and international regulatory standards for radiation exposure are based on more research and more direct evidence of health effects than for almost any other hazardous substance. By setting and enforcing strict exposure standards, governments have tried to balance the benefits of using radiation with the risks.

Individual Judgments

Making judgments on safety for society as a whole is primarily the government's responsibility (see Chapter 5). But each of us as individuals can also avoid unnecessary exposure to radiation, so that we derive the benefits from radiation and do not undergo more risk than necessary (also see Chapter 5).

It is always prudent to avoid unnecessary exposure. However, refusing X-rays or radiation therapy may cost more money, time, convenience, or health problems, than taking advantage of radiation's unique diagnostic and healing properties. Each of us must make such decisions based on our tolerance for risk, and our confidence in doctors and their medical advice.

Society's Judgments, Pro and Con

Society as a whole must balance the risks and benefits associated with nuclear energy, including the use of radiation. Nuclear advocates argue that nuclear power is a proven, secure, and inexhaustible long-term source of energy. They argue that nuclear energy creates little air pollution, and contributes almost nothing to global warming.

Nuclear energy could become increasingly important in the twenty-first century as global energy demands continue to rise, and nonrenewable energy sources, such as fossil fuels and natural gas, are slowly depleted. Proponents say that nuclear power, if properly managed, can benefit humanity and the environment with a level of risk no greater than that we routinely accept as part of our normal lives.

Critics of nuclear power, however, ranging from environmentalists to antiwar activists, point to a variety of problems with nuclear energy, including:

- The dangers inherent in transporting and disposing of the thousands of tons of high-level radioactive waste, now in temporary storage at nuclear power plants across the nation. (See Nuclear Reactor Waste, Chapter 4, page 52.)
- The possibility that radioactive material used by and generated in nuclear reactors could be diverted by rogue nations (or terrorists) to produce nuclear weapons.
- The risk of a dangerous accident, particularly in aging reactors whose protective systems may have been weakened or

whose containment structures may be inadequate to prevent the release of radioactivity into the environment.

- The siting of nuclear plants in densely populated areas, which increases the danger that an accident or terrorist attack could expose large numbers of people to dangerous levels of radiation.
- The unique problems associated with dismantling and decommissioning nuclear facilities, and cleaning up sites after they are closed down.

Some opponents of nuclear energy argue that the problems are so serious that we should shut down the nuclear power industry. A better alternative, nuclear critics claim, would be to focus attention and resources on developing safe, nonpolluting, renewable energy sources such as solar, wind, and geothermal power.

Future Prospects for Nuclear Power

Partly because of these disagreements, the future of nuclear power is mixed. Even advocates acknowledge that few if any new nuclear power plants are likely to be built in the United States in the next decade. In part, this is due to the lack of public support. A March 1999 Associated Press poll, taken 20 years after Three Mile Island, showed that only 45 percent of Americans support the use of nuclear energy, 10 percent fewer than in 1989.

Recent energy supply problems in California, however, have sparked some renewed interest in nuclear power. Another limiting factor is the high cost of building new nuclear plants. In addition, many of the existing plants now nearing the end of their useful lives are unlikely to be replaced, at least right away. Many will seek licenses to operate for a longer time period.

Government and industry experts continue to design safer reactors, work to improve techniques for decontaminating older reactors, and find safer, more secure ways to handle and dispose of radioactive wastes. Some proponents expect nuclear energy to contribute to a growing share of the world's increasing energy needs in spite of continued protests and controversy.

How Are Radioactive Wastes Managed?

4

How Are Radio-active Wastes Managed?

Radioactive Waste Disposal

Radiation offers many important benefits to society. However, every use of radioactive materials—for mining, nuclear power, managing nuclear weapons, nuclear medicine, and scientific research—generates radioactive waste. The overall risk to the public from radioactive waste is lower than from other sources of radiation, such as radon and nuclear medicine. (See Balancing Radiation's Benefits and Risks, Chapter 3, page 43).

Areas where nuclear waste is produced, transported, and stored pose potential risks to the environment and people living close to them. Care must be taken to properly isolate the waste materials from the public and the environment.

Radioactive materials can:

- Travel through air and water (both ground water and surface water)
- Contaminate the air, soil, water supply, and food chain
- Enter the human body through the skin or when humans eat, drink, or inhale.

By responsibly managing the transportation, storage, and disposal of radioactive materials, users and regulators of radiation can greatly reduce the risk to human health and the environment.

This chapter covers these topics:

- Radioactive Waste Disposal
- The Search for Permanent Disposal Solutions
- Radioactive Waste Cleanup
- Transporting Radioactive Waste

Radioactive Waste Disposal

Much of the public anxiety and controversy about nuclear energy and other uses of radioactive materials concerns how radioactive waste is handled, transported, and disposed of. Some high-level waste will remain hazardous for 10,000 years or more, further complicating the problem of ensuring safe, long-term disposal and raising questions about our responsibility to future generations.

Several federal agencies and some states that regulate the risks of radioactive waste require disposal facilities to effectively isolate the waste. Examples:

- EPA has established environmental standards for disposal of radioactive milling wastes.
- EPA sets generally applicable environmental standards for disposal of other radioactive wastes.
- NRC and DOE have established specific regulations for different types of waste (e.g., low-level radioactive waste).
- The Department of Transportation (DOT) and the NRC have established strict safety standards for vehicles and containers used to ship radioactive waste. (See Transporting Radioactive Waste in this Chapter, page 55.)

Types of Radioactive Waste

Radioactive waste is divided into seven general categories:

1. *Spent nuclear fuel* and *High-level waste* include commercial spent reactor fuel and other highly radioactive material which require careful isolation and security.
2. *Transuranic waste* contains manmade radioisotopes heavier than uranium. This waste is produced primarily from defense-related activities, such as nuclear weapons research, production, and cleanup. It generally consists of radioactively contaminated clothing, tools, glassware, equipment, soil, and sludge.
3. *Low-level* waste includes radioactively contaminated industrial or research waste such as paper, rags, plastic bags, packaging materials, protective clothing, organic fluids, and water-treatment resins. It is generated by government facilities, nuclear power plants, industries, and institutional facilities (e.g., universities and hospitals). More than 22,000 commercial users of radioactive materials generate some amount of low-level waste.
4. *Mill tailings* are mining and milling residues of uranium ore that contain low concentrations of naturally occurring radioactive materials.
5. *Mixed waste* is a combination of radioactive materials and hazardous chemical waste.
6. *Orphaned sources* are radioactive contaminants that find their way into non-nuclear facilities such as scrap yards, steel mills, and municipal waste disposal facilities. The contamination usually comes from discarded highly radioactive materials inside metal containers which are mistaken as scrap metals.
7. *Naturally-occurring and accelerator-produced radioactive materials* (NARM) include:

- Radioactive waste products from the operation of atomic particle accelerators, and
- Naturally occurring radioactive materials (NORM), usually from mineral extraction or processing activities, whose natural radioactivity has been technologically enhanced (also referred to as “TENORM” materials).

Radioactive waste categories are based on the *origin* of the waste, not necessarily on the level of radioactivity. For example, some low-level waste is highly radioactive. Radioactive wastes can remain hazardous for a few days or for hundreds and even thousands of years, depending on their radioactive half-lives. (See Ionizing Radiation, Chapter 1, page 12.)

Sites and Methods of Waste Disposal

Several major environmental laws affect the operations of many facilities that generate radioactive waste, including DOE’s nuclear weapons facilities.

- The Resource Conservation and Recovery Act (RCRA), regulates the generation, treatment, storage, and disposal of municipal and industrial hazardous and solid waste.
  - —Facilities that generate hazardous or mixed hazardous and radioactive wastes must obtain RCRA permits from EPA or authorized states to operate. They must also have RCRA permits to treat, store, or dispose of these wastes.
  - —The Hazardous and Solid Waste Amendments to RCRA (1984) require DOE to eliminate contaminant releases at or from its RCRA facilities.
- The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, also known as Superfund) and its 1986 amendments established hazardous and radioactive waste cleanup requirements for contaminated facilities, including those in the weapons complex. EPA has placed a number of DOE’s contaminated weapons sites on the Superfund National Priorities List (NPL) for expedited evaluation and cleanup.

- The Atomic Energy Act as amended established requirements for the management and disposal of radioactive waste that is regulated by DOE, NRC and EPA.

High-Level Waste: Interim Storage

The United States currently has no permanent disposal facility for high-level radioactive waste. The NRC says that interim storage methods can be used safely for 100 years. However, NRC, the nuclear utility industry, and many independent observers believe it is important to find a long-term solution for nuclear waste disposal. Significant obstacles to reaching a solution include scientific challenges and public concerns. (See The Search for Permanent Disposal Solutions in this Chapter, page 49.)

As an interim storage method, nuclear reactor operators keep spent nuclear reactor fuel on site at nuclear power plants and other reactor sites, usually in concrete, steel-lined pools of water (see Nuclear Reactor Waste in this Chapter, page 52.) The water cools the warm fuel and also provides shielding from the radiation. Reactor operating licenses issued by NRC limit the amount of spent fuel that can be kept on site.

Chemical reprocessing of spent fuel from reactors in the U.S. defense program is another type of high-level waste. This process, which has been suspended, recovered unused uranium and plutonium for making nuclear weapons. U.S. policies prohibit the reprocessing of spent fuel from commercial nuclear reactors.

The liquid waste from reprocessing is being temporarily stored in underground tanks or stainless steel silos. These are located on federal reservations in Washington, South Carolina, and Idaho, and at the Nuclear Fuel Services Plant in West Valley, New York. (See Nuclear Weapons Waste in this Chapter, page 51.) Scientists continue to refine techniques for treating this waste so it can be more easily and safely transported and disposed of after a permanent disposal site becomes available.

Transuranic Waste

Transuranic wastes are also temporarily stored in metal drums and shielded casks at the sites where they are generated—primarily nuclear weapons facilities and national laboratories. Eventually they will be shipped to DOE's permanent disposal facility, the Waste Isolation Pilot Plant (WIPP). The WIPP, located near Carlsbad, New Mexico, cleared its last legal challenges and began receiving waste shipments in March 1999.

The WIPP, authorized by Congress in 1979, is the world's first geological repository for the permanent disposal of transuranic wastes and transuranic mixed wastes. (Figure 23)

Figure 23.
Aerial view of the WIPP

Source: U.S. Department of Energy

In 1992, Congress passed the WIPP Land Withdrawal Act, which makes EPA responsible for ensuring that the WIPP complies with the agency's radioactive waste disposal standards and other federal environmental laws and regulations. The law requires that EPA certify that the waste stored in the WIPP can be isolated from the human environment for at least 10,000 years. EPA issued this safety certification for the WIPP on May 13, 1998. The facility must be recertified by EPA every five years throughout its operational life.

As of the end of December 2000 the WIPP had received 128 shipments of transuranic waste from four DOE sites.

Low-Level Radioactive Waste

Most low-level radioactive wastes are solidified, put into drums, and buried in 20-foot-deep trenches, which are backfilled and covered in clay each day. When full, the trenches are capped with clay and a foot of grassy topsoil.

Only a few commercial facilities that permanently dispose of low-level radioactive waste (Figure 24) are operating in the United States. The major facilities are located in:

- Richland, Washington, which accepts waste only from 11 northwest and Rocky Mountain states.
- Barnwell, South Carolina, which is part of the newly formed Atlantic Compact. It was the only facility open to all states (except North Carolina) as of mid-2000 and expects to accept limited amounts of non-Atlantic compact waste in the future.
- Clive, Utah, which accepts large-volume bulk forms of low-level waste, such as soils and building debris that are not routinely accepted by the Richland or Barnwell sites.

DOE also has seven major low-level waste disposal sites (Figure 24) to dispose of wastes resulting from defense-related activities, research, and cleanup.

Under the 1980 Low-Level Radioactive Waste Policy Act, each state must take responsibility for the non-defense related low-level waste generated within its borders. States can act on their own or in a compact with other states. They have established processes for studying and selecting new disposal sites in consultation with citizens and experts and in accordance with federal and state regulations. By July 1, 2000, 44 states had entered into 10 compacts. None of the compacts or states acting alone had successfully opened a new disposal facility (Figure 25) by that date, however.

Disposal facilities must be designed, operated, and controlled after they are sealed to ensure that the maximum annual radiation exposure to any individual from the site does not exceed 25 millirem per year. Actual exposures from existing commercial facilities have been considerably lower than that figure.

Mixed Waste

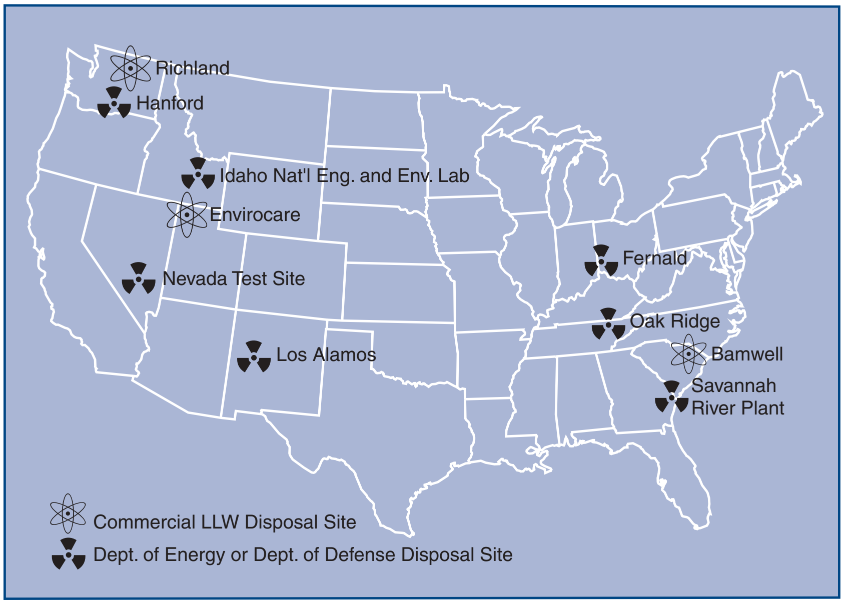
Waste containing both *radioactive material* and *hazardous chemicals* must be treated and disposed of in accordance with the separate laws governing the two different types of waste.

- Under RCRA, EPA and authorized states regulate hazardous waste. RCRA requires that low-level mixed waste be treated before it is sent to an authorized commercial land disposal facility. Technologies, such as incineration and solidification, reduce its toxicity or volume and help ensure that hazardous materials will not migrate into the environment.
- Under the Atomic Energy Act, NRC, DOE, or authorized NRC "Agreement" states are responsible for radioactive waste. High-level and transuranic mixed waste is handled in much the same way as regular high-level or transuranic radioactive waste.

A number of commercial facilities are authorized to treat, store, and dispose of mixed waste. These facilities include:

- Envirocare of Utah, Inc., Clive, Utah

Figure 24. Map of low-level waste disposal sites



Source: U.S. Department of Energy

- Diversified Scientific Services, Inc., Kingston, Tennessee
- Molten Metal Technology, Waltham, Massachusetts
- NSSI, Houston, Texas
- Perma-Fix Environmental Services, Inc., Gainesville, Florida.

The Search for Permanent Disposal Solutions

Proposed High-Level Waste Permanent Disposal Site

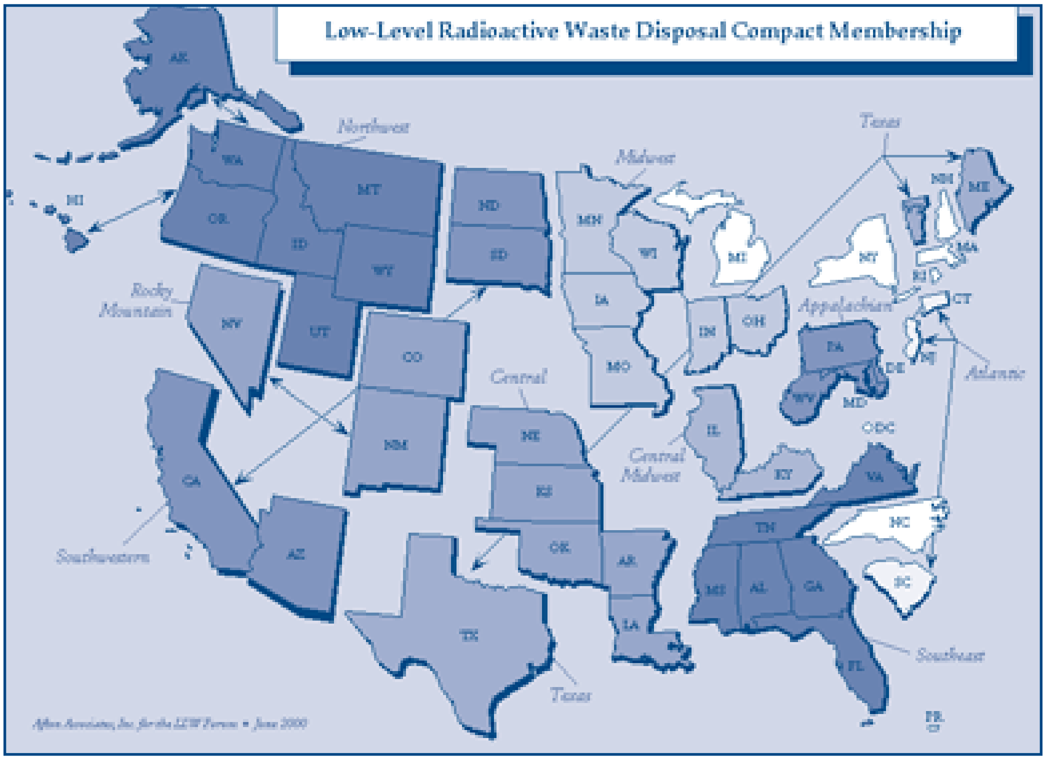
DOE has been evaluating a potential high-level radioactive waste disposal site at Yucca Mountain, Nevada, since 1987. (Figure 26) However, DOE has been unable to move forward with final site selection because of scientific complexities and strong political opposition in Nevada and elsewhere.

In the Nuclear Waste Policy Act of 1982, Congress called for the development of a mined geologic repository to dispose of spent fuel and high-level radioactive waste. DOE identified nine potential sites in 1983 and selected three as candidates for further study in 1984. In 1987, Congress directed DOE to limit its study to the Yucca Mountain site and to determine whether the site would be suitable for development as a repository.

Under the timetable set by Congress in the 1980s, a permanent repository would have begun receiving spent fuel by February 1998. By late 1998, however, DOE announced it would not be ready to make a recommendation on the suitability of the Yucca Mountain site until 2001. The earliest DOE anticipates operating a Yucca Mountain repository is 2010, and many observers believe even this timetable is optimistic.

Meanwhile, according to the Nuclear Energy Institute, the nation's nuclear electric utilities and their customers have committed more than $14 billion, including interest, to a Nuclear Waste Fund. This fund is to pay for the government's spent fuel management program, including the permanent repository, an interim storage facility, and the transportation of spent fuel.

Figure 25. Map of low-level waste state compacts



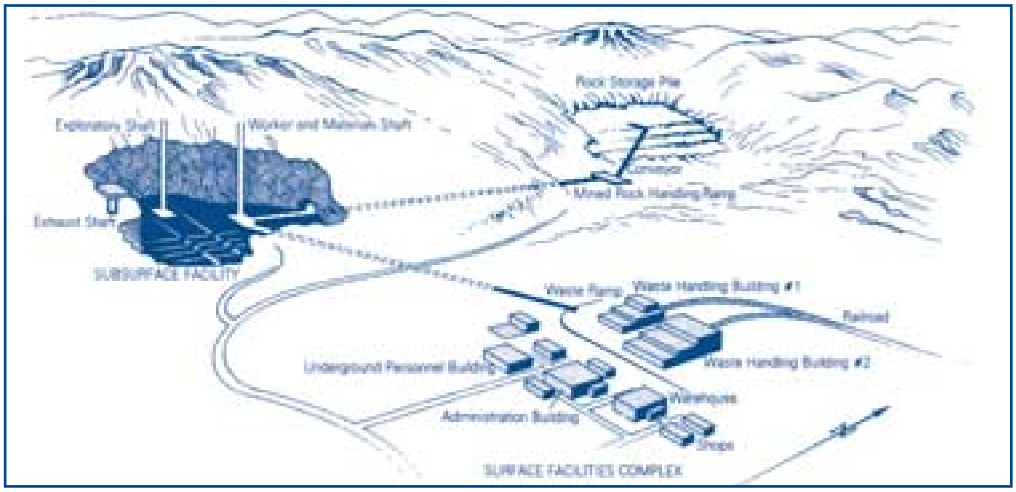
Source: LLW Forum, Inc.

It will cost about $4 billion of that money to determine if the Yucca Mountain site is suitable.

Public Concerns about Permanent Disposal Options

In its March 1995 report, *Future Issues in Environmental Radiation*, a subcommittee of the EPA's Science Advisory Board (SAB) listed radioactive waste management as one of the seven radiation-related issues most likely to have a significant impact on the future quality of the environment. Public

Figure 26.
Artist's sketch of proposed Yucca Mountain disposal facility



Source: U.S. Department of Energy

apprehensions about disposal risks are a significant impediment to achieving permanent solutions. Here are some excerpts from the SAB report:

> Regardless of their categorization, radioactive wastes and the solutions proposed for the disposal problem are feared by many members of the public. This creates a challenging dilemma: on the one hand, the public's perception of the risk of the materials argues strongly for ultimate disposal; on the other, potential risks of the disposal itself are used by opponents to argue against these efforts.
>
> As a result of this conflict, disposal is in a stalemate. Although a majority of the public indicates that radioactive wastes should be disposed of permanently, progress toward this goal is slow, with numerous setbacks, for any form of wastes. On-site storage of high-level radioactive waste is reaching capacity at some locations, and the risks of such storage can only increase as these wastes accumulate ….
>
> As the stalemate continues, waste material inventories continue to accumulate on site in less-than-optimal places such as hospitals … laboratory and university storage rooms and buildings … and on reactor sites. Most of these locations were selected for features other than isolation of waste materials, (and) continued reliance on their use increases the likelihood of the development of radioactive contamination on these sites, and/or release to the environment ….
>
> The scientific community believes that feasible disposal options exist to ensure the long-term isolation of most forms of radioactive wastes; what is lacking is the requisite public support for applying the technologies.

Radioactive Waste Cleanup

One of the most difficult and expensive radiation-related challenges facing the nation in the next century will be to complete the cleanup of contaminated sites. More than 100 nuclear weapons production sites and thousands of facilities have been contaminated by radioactivity and radioactive waste. This cleanup job will last well into the twenty-first century. The contamination is primarily the result of the nation's arms race with the former Soviet Union during the Cold War years following World War II, when a huge industrial complex produced and managed thousands of nuclear weapons.

Figure 27.
DOE's Hanford site

Source: U.S. Department of Energy

In addition, radioactive waste from dismantled nuclear reactors, hospitals that use nuclear medicine, and research laboratories and other facilities that generate low-level waste will require continuing disposal efforts.

Nuclear Weapons Waste

DOE is responsible for the bulk of the nuclear weapons cleanup. In its 1995 report on its cleanup effort, *Closing the Circle on the Splitting of the Atom*, DOE characterized the waste and contamination from nuclear weapons production as "a task that had, for the most part, been postponed into the indefinite future," adding: "That future is now upon us."

DOE's nuclear weapons complex consists of 16 major sites and dozens of smaller sites across the United States. According to the

DOE report, every site in the nuclear weapons complex is contaminated to some degree with radioactive or hazardous materials. Buildings, soil, air, ground water, and surface water at the sites are contaminated. EPA sets the criteria for cleaning up the contamination at these facilities. Some buildings and sites have been cleaned up, but DOE says that most sites have "significant and complicated problems that have been compounded over several decades."

One of the most troubling examples of the Atomic Age's environmental legacy is DOE's Hanford Site in Washington State (Figure 27). It is home to almost two-thirds, by volume, of the entire solid and liquid hazardous and radioactive wastes created by the nuclear weapons program. This volume includes more than 50 million gallons of high-level radioactive waste stored in underground tanks.

Severe contamination problems at the Hanford site include:

- One million gallons or more of high-level mixed waste believed to have leaked from Hanford's deteriorating storage tanks, some of which are at risk of exploding
- Radioactive tritium and other radionuclides detected in the ground water at Hanford which threaten to contaminate the Columbia River
- Widespread contamination with radioactive iodine released from early operations at the Hanford Site
- Large buildings where spent fuel was reprocessed at the Hanford Site (and the Savannah River Plant in South Carolina) so contaminated with radioactive materials that decontamination must be done by remote control to protect the workers

Other weapons sites have similar problems.

- At Fernald, Ohio, several hundred tons of uranium dust were released into the atmosphere and a local river, and drinking water wells were contaminated with uranium.
- At the Rocky Flats Plant in Colorado, traces of plutonium have been found in the soil and sediments. Leaking drums filled with plutonium-contaminated waste were stored in the 1950s and early 1960s outside in an area near the plant. When workers tried to clean up contaminated soil in the late 1960s, strong winds blew plutonium-contaminated dust across a large area, spreading the contamination and threatening the safety of cleanup workers.

DOE has begun cleaning up the weapons complex. Some sites have been fully decontaminated and turned over for other uses. DOE is working to:

- Develop more effective remediation technologies,
- Involve the public in decisions about where and how to treat and dispose of nuclear waste, and
- Involve the public in decisions about the future of decontaminated sites.

But the job will not be finished until 2070 at the earliest. Meanwhile, places like Hanford and Rocky Flats will continue to pose some of the nation's most urgent and high-risk radiation management problems.

Nuclear Reactor Waste

Every 12 to 24 months, each nuclear reactor is shut down, and the oldest fuel assemblies—those that have become depleted in uranium fuel—are removed from the reactor. Each year, the 100-plus operating nuclear power plants in the United States produce about 2,000 metric tons of high-level radioactive waste in the form of spent fuel.

While the material is highly radioactive when removed from the reactor, it loses about 50 percent of its radioactivity in three months and about 80 percent after a year. About one percent remains radioactive for thousands of years. Because the United States has not yet built a permanent repository for long-term disposal of spent fuel (see Sites and Methods of Waste Disposal, this Chapter, page 46), the fuel assemblies are temporarily stored at the reactor site. Steel-lined, concrete vaults filled with water, called spent fuel pools, and above-ground steel or steel-reinforced concrete containers with steel inner canisters are usually used for storage. (Figures 28)

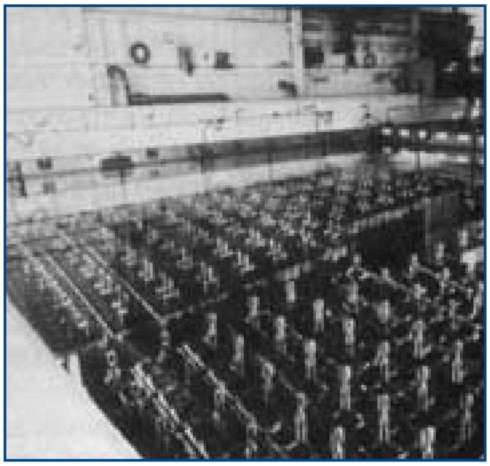
The nuclear reactor structures, which produce radioactive spent fuel, themselves become radioactive over time. Eventually they must be shut down, and cleaned up, dismantled, or sealed off until the radioactivity has decayed to a point where it no longer presents a hazard.

These processes, called *decontamination* and *decommissioning*, produce additional quantities of low-level radioactive waste, as well as fission products and other radioactive components that require safe and secure storage or disposal. Some of the contaminated metal from reactors may be salvaged and recycled for other uses. (See Orphaned Sources and Contaminated Scrap Metal in this Chapter, page 54.)

Low-Level Radioactive Waste

Government facilities, nuclear reactors, fuel fabrication facilities, uranium fuel conversion plants, industries, universities, research institutes, and medical facilities generate low-level radioactive waste. In addition to DOE facilities, more than 22,000 *commercial* users of radioactive materials generate some amount of this waste. The cleanup of contaminated buildings and sites will generate still more low-level waste in the future.

Figure 28.
Spent fuel in pool storage at a nuclear power plant



Source: U.S. Department of Energy

Only about one percent of the total low-level waste stream comes from hospitals, medical schools, universities, and research laboratories. Much of this waste can be safely stored on site until its radioactivity has decayed to background levels.

NRC regulates the medical, academic, and industrial uses of nuclear materials generated by nuclear reactors through a comprehensive inspection and enforcement program. Some 32 states have entered into agreements with NRC to assume regulatory authority over certain radioactive materials, including some radioisotopes.

As disposal costs have gone up, large-quantity waste generators have increasingly turned to predisposal waste processing to reduce the volume of low-level waste that must be sent to disposal facilities. This involves measures such as:

- Separating radioactive from nonradioactive components
- Incinerating waste at specially designed incinerators
- Using hydraulic presses to compact the waste before it is packaged for disposal, which can reduce the volume of bulk waste by up to 90 percent
- Decontaminating, reusing, or recycling radioactive materials whenever possible

While these activities significantly reduce the volume of waste to be disposed of, they also *concentrate* the radioactivity and thus require more stringent disposal safeguards.

Low-level wastes must be properly packaged and disposed of to minimize the chance of exposure to people or the environment. Disposal sites must have features that will isolate the waste from the environment. Radiation levels around disposal facilities must be monitored carefully to ensure that they meet regulatory standards.

Orphaned Sources and Contaminated Scrap Metal

Many DOE reactors have been shut down in recent years, and hundreds of reactors, processing facilities, and storage tanks will be dismantled as part of the cleanup from the nation's nuclear weapons program. (See Nuclear Weapons Waste in this Chapter, page 51.) Dismantling these facilities creates large amounts of scrap steel and other metals, some of which is contaminated by radioactivity.

Scrap metal and other waste can also be contaminated by so-called *orphaned* radioactive sources. These are primarily specialized industrial devices, such as those used for measuring the moisture content of soil and the density or thickness of materials. These devices often contain a small amount of radioactive material sealed in a metal casing or housing. If equipment containing a sealed radioactive source is disposed of improperly or sent out for recycling, the sealed source may wind up in a metal recycling facility. If the item does not have markings identifying its original owners, the source is called an orphaned source.

Approximately 200 lost, stolen, or abandoned licensed sources are reported each year. Orphaned sources are one of the most frequently reported radioactive contaminants in shipments received by scrap metal facilities. If an orphaned source is melted during reprocessing, it can contaminate entire batches of scrap metal, the processing equipment, and even the entire facility. The radiation can also pose a hazard to facility workers and to consumers if contaminated recycled metal were to be used in consumer products.

EPA is working with state, federal, and international radiation protection organizations to ensure a national supply of clean metal for general use. In 1998, EPA determined that uncontrolled, orphaned sources and contaminated metal imports pose a higher risk to the public and workers than the recycling of scrap metal from nuclear facilities (which is only one tenth of one percent of the metal used in the United States annually). Therefore, EPA has directed its efforts towards orphaned waste and contaminated metal imports as the more significant problem.

The agency's orphaned sources initiative, now being carried out in conjunction with the Conference of Radiation Control Programs Directors, has established a nationwide system that provides quick and effective information on identification, removal, and disposal of orphaned sources.

The lesser problem, preparation of contaminated scrap metal from domestic nuclear facilities for recycling, continues to follow guidance developed by the NRC and DOE in the 1970s. These standards apply to materials that are contaminated on the surface only and can be decontaminated. DOE suspended the recycling of all contaminated metal in July 2000.

Naturally Occurring Radioactive Materials

Radioactive materials that occur in nature and become concentrated through human activities (such as mineral extraction and processing) are considered radioactive wastes. These are receiving increasing attention from the federal and state governments.

These materials are known as NORM (naturally occurring radioactive materials) or TENORM (technologically enhanced NORM). They are a subset of a broader category of wastes, NARM (naturally occuring and accelerator-produced radioactive materials) which also includes radioactive waste produced during the operation of atomic particle accelerators for medical, research, or industrial purposes. (See Types of Radioactive Waste in this Chapter, page 46.) The radioactivity contained in the waste from accelerators is generally short lived, less than one year, and constitutes a very small percentage of the nation's total radioactive waste stream.

NORM and TENORM, however, are of growing concern because some of this waste contains relatively high concentrations of radioactivity. Even NORM with a lower concentration of radioactivity can pose disposal problems because of its high volume. Metal mining and processing, for example, will generate an estimated 20 billion metric tons of waste over the next 20 years. NORM is also a problem because some of it is used in construction, concrete, and road-building, resulting in contamination of the environment and possible human radiation exposure.

There were no federal regulations covering disposal of NARM with high radioactivity concentrations as of mid-2000. EPA is working to improve the government's understanding of the radiological hazards posed by all these materials, and is working with the states as they develop guidance related to NORM and TENORM. At the request of Congress, EPA sponsored a study of guidance and risk assessment approaches to TENORM. This study was conducted by the National Academy of Sciences and completed in January 1999.

Transporting Radioactive Waste

The federal government's plans to create permanent disposal facilities for radioactive waste lead to continuing public concern over the safe transport of these hazardous materials to their final resting places. Tens of thousands of shipments will be required to dispose of spent fuel from the nation's nuclear reactors, high-level defense waste stored in nuclear weapons complexes, and transuranic waste designated for the WIPP in New Mexico. Even more shipments will be needed for the continuing stream of low-level waste.

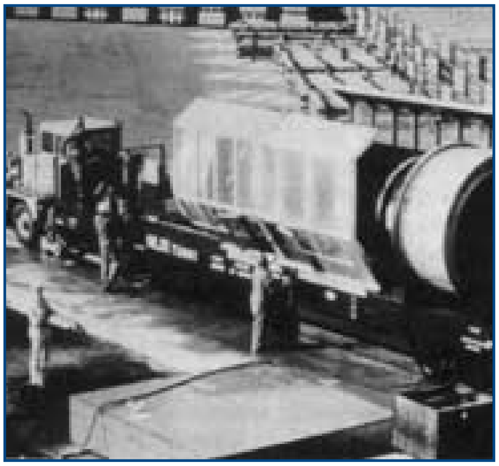
Two federal agencies, DOT and NRC, are primarily responsible for overseeing radioactive waste transportation. They must minimize the risk of any accidental releases of radiation and carry out a range of regulations:

- All radioactive waste shipments must comply with federal standards for packaging, labeling, handling, loading, and unloading.
- Transportation workers must be highly qualified and receive special training.
- Shipment routes must follow federal guidelines, avoiding highly populated areas wherever possible.
- Transport vehicles for some waste types must meet special safety standards, including capabilities for satellite tracking and constant communication.
- Drivers and state and local officials must receive special emergency response training.

High-level and transuranic wastes must be transported in airtight, specially shielded stainless steel containers designed to prevent radioactive releases even in a severe accident or other emergency. The containers (Figures 29 and 30), constructed with inner and outer containment vessels, must survive extreme durability tests including the following:

- A 30-foot fall onto a steel-reinforced concrete pad
- A 40-inch drop onto a 6-inch steel spike
- A 30-minute exposure to a fire of 1,475 degrees Fahrenheit

Figure 29.
Truck transporting radioactive waste

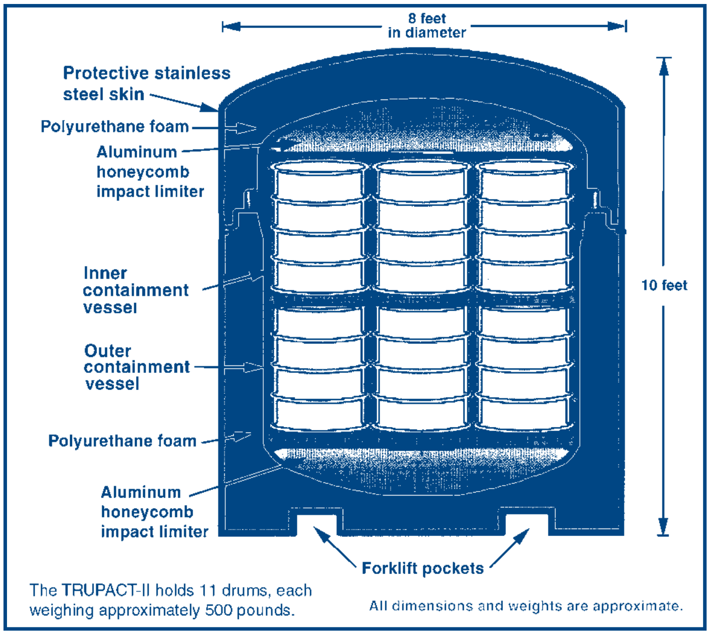


Source: U.S. Department of Energy

- Submersion in 50 feet of water for eight hours

Some critics continue to question the safety of radioactive waste shipments and the adequacy of container testing. To date, however, the safety record for waste shipments has been good, much better than for shipments of other hazardous materials.

Figure 30. Transuranic Waste shipping containers



Source: U.S. Department of Energy

As of mid-1998, four accidents had occurred during spent fuel shipments. None of them released radioactive material. Between 1971 and 1999, 62 accidents occurred during the transport of low-level radioactive waste in the United States. Of these, only four resulted in the release of radioactive materials. The radioactive material was quickly cleaned up and repackaged with no measurable radiation exposure to people along the routes or to the emergency response personnel.

How Is the Public Protected from Radiation?

5

How Is the Public Protected from Radiation?

Government Responsibilities in Protecting the Public

The U.S. government and state governments play important roles in ensuring that radiation is responsibly managed to protect the public and the environment from the risks of exposure to ionizing radiation. Other organizations, including local governments, Native American Tribes, and international bodies, share in this responsibility.

Each of us as individuals also plays a key role by learning about radiation and making our opinions known in writing or at public forums and meetings. Individuals can have an effect on decisions about such issues as:

- Balancing the benefits and risks of radiation
- Safe disposal of radioactive waste
- Appropriate levels of cleanup for contaminated sites and facilities

Each of us, as individuals, can also take reasonable precautions to limit our own exposure.

This chapter provides an overview of how these public and individual responsibilities for protection from the harmful effects of radiation are carried out. Topics include:

- Government Responsibilities in Protecting the Public
- Government Controls on Exposure to Radiation
- Major Federal Legislation
- Responsible Federal Agencies
- Federal, State, and Local Government Functions
- Other Roles in Managing Radiation

Government Responsibilities in Protecting the Public

The federal government's primary responsibilities in protecting the public include:

- Educating the public on radiation and its benefits and risks
- Regulating the storage, transportation, and disposal of radioactive waste
- Controlling the sources and uses of radiation, and setting and enforcing protective standards
- Conducting research to determine potential health effects and to find more effective ways to reduce radiation exposures
- Providing guidance on appropriate precautions by individuals

The first two responsibilities above have been discussed in previous chapters. This chapter discusses appropriate precautions individuals can take against overexposure, governmental controls and standards for use of radiation, and government research responsibilities.

Controlling Risks of Exposure to Radiation: Federal and Individual Roles

The federal government regulates manmade and some naturally occurring radioactive materials by setting emissions, exposure, and cleanup standards. Allowable exposure levels are set to provide the appropriate level of protection for both workers and the public. (Table 4) The federal government began setting radiation standards in 1957. NRC and EPA have primary responsibility

Table 4: Dose Standards for ionizing radiation exposure in the United States (expressed in terms of annual effective dose)

Population and source of radioactivity	Dose Limit (mrem/yr)
Occupational limit	5,000
General Public	
Limit for any licensed facility (excluding medical)	100
Limit for nuclear power facility	25
Limit for waste repository (excluding Yucca Mountain)	15
NAS recommendation for Yucca Mountain	2-20
EPA recommended "action level" for indoor radon	800 (approx.)

Source: Lawrence Berkeley National Laboratory

for radiation protection except at DOE facilities where DOE regulates its radiation-related activities.

In 1995 the U.S. Environmental Protection Agency's Science Advisory Board (SAB), a panel of independent experts that advises EPA on the scientific aspects of its regulatory responsibilities, studied the current state of knowledge about radiation and provided EPA with guidance on how it should approach radiation issues for the next 30 years. The SAB report, *Future Issues in Environmental Radiation*, concluded that:

- High priority governmental controls over sources and standards of radiation are already in place and undergoing continual refinement.
- The greatest potential for further reduction in public exposure is through individual protective actions.

The SAB found that the greatest potential for reducing overall public exposure to controllable sources of radiation was not through more government regulation, but by individual action, primarily by avoiding unnecessary exposure to medical radiation and by reducing exposure to indoor radon.

How You Can Limit Your Radiation Exposure?

Some recommended precautions that all individuals should take to limit exposure to radiation include:

- Test your home for radon, and reduce radon levels if necessary. (See Health Effects of Radon, Chapter 3, page 37, and Controlling Exposure to Radon in this Chapter, page 61.)
- Evaluate medical uses of radiation, and weigh benefits and risks. (See Controlling Medical Exposures in this Chapter, page 60.)
- Minimize exposure to ultraviolet radiation from the sun by:
  - —Wearing protective clothing and sunglasses
  - —Wearing sunscreen
  - — Limiting exposure to midday sun
- Participate in public decision-making on issues such as facility sites and standards.

You will find more details on some of these precautions in the following sections.

Government Controls on Exposure to Radiation

Controlling Radiation in the Air

Radioactive materials can enter the atmosphere several ways:

- By natural processes, such as the interaction of cosmic radiation with nitrogen to produce radioactive carbon-14
- By human activities that generate radiation or enhance natural radiation
- By wind or some other natural or human activity stirring up dust containing radioactive particles

Once airborne, particles can remain suspended in the air for a long time, or they can settle in water, on the soil, or on surfaces of plants, where they can enter the food chain. Rain or snow can also remove radioactive particles from the air. (Figure 31)

Under the Clean Air Act of 1970 and its amendments, EPA established standards to regulate the release to the air of manmade radiation by most governmental and industrial facilities.

- EPA's National Emissions Standards for Hazardous Air Pollutants for *radionuclides* require facilities to limit their radionuclide air emissions so that no member of the public is exposed to more than 10 millirem of radiation per year.
- Facilities must submit annual reports documenting their emissions, and they may be subject to annual inspections.

Facilities regulated by NRC, such as nuclear power plants, hospitals, medical research facilities, research reactors, and uranium fuel cycle facilities, are subject to similar limits.

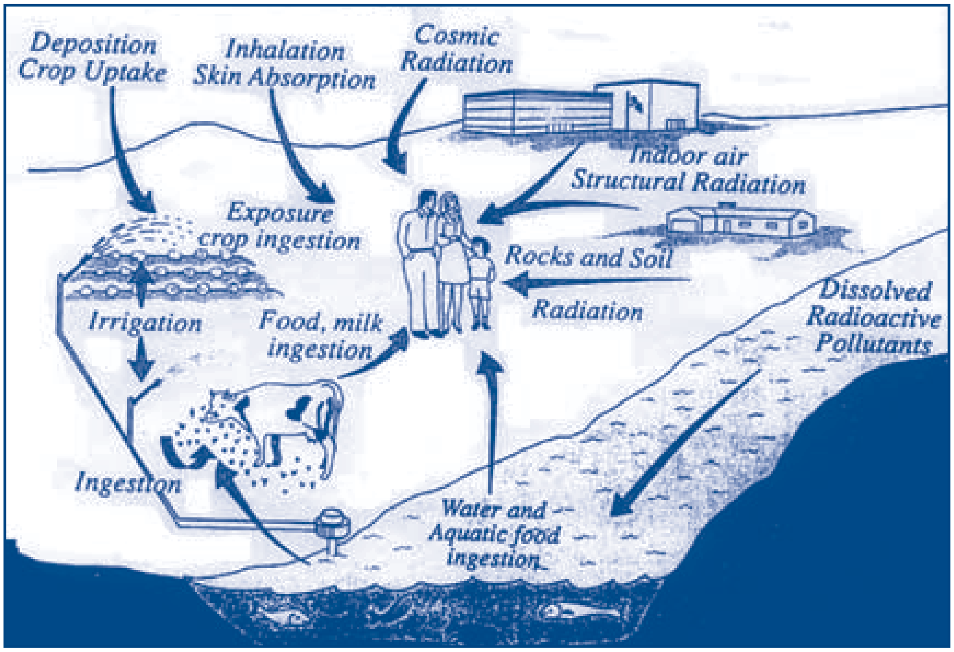
EPA is also responsible for taking steps to reduce indoor exposures from radon. (See Health Effects of Radon, Chapter 3, page 37 and Controlling Radon Exposure in this Chapter, page 61.)

Controlling Radiation in Water

Radioactive materials can enter water in several ways:

- By being deposited in surface water from the air
- By entering groundwater or surface water

Figure 31. Major pathways by which dispersed radionuclides can affect living organisms



Source: U.S. Department of Energy

from the ground through erosion, seepage, or human activities such as mining

Some radioactive particles dissolve and move along with the water. Others are deposited in sediments or on soil or rocks.

Two federal laws govern the regulation of radiation in water:

- **The Safe Drinking Water Act** (SDWA) directed EPA to set standards for drinking water contaminants that may adversely affect human health. Under the SDWA, EPA set limits for some radioactive materials in drinking water. Public water supplies must comply with EPA's national primary drinking water regulations, which are based on the agency's drinking water standards.

  In November 1999, EPA proposed a National Primary Drinking Water Regulation (NPDWR) for radon in drinking water based on a multimedia approach designed to achieve greater risk reduction by addressing radon risks in indoor air, with public water systems providing protection from the highest levels of radon in their ground water supplies. The framework for this proposal is set out in the Safe Drinking Water Act as amended in 1996. This statutory-based framework reflects the characteristics uniquely specific to radon among drinking water contaminants. SDWA directs EPA to promulgate a maximum contaminant level (MCL) for radon in drinking water, but also to make available a higher alternative maximum contaminant level (AMCL) accompanied by a multimedia mitigation (MMM) program to address radon risks in indoor air.

  For more information on radon in drinking water, call EPA's Drinking Water Hotline (1-800-426-4791) or visit the EPA Web site at www.epa.gov/safewater.

- **The Federal Water Pollution Control Act, as amended by the Clean Water Act**, prohibits the discharge of radioactive wastes or other pollutants into U.S. navigable waters without a permit. EPA and authorized states have the authority to issue permits in accordance with water quality standards.

The government also controls radiation in water by requiring low-level radioactive waste disposal facilities to be located away from floodplains. These facilities are also designed to divert water away from the waste, or collect and remove radionuclides from water that has come in contact with the waste. This precaution minimizes the amount of radioactive material released into water, keeping it out of the food chain and away from people.

Controlling Medical Exposures

Government Controls and Guidance

The U.S. Food and Drug Administration (FDA) and other federal and state agencies regulate medical procedures that use radiation. Radiologists, health physicists, NRC, EPA, state agencies, the National Council on Radiation Protection and Measurements, and other responsible parties are continually looking for ways to reduce risk while taking advantage of the benefits from medical uses of radiation.

Government agencies also issue guidance designed to reduce unnecessary use of radiation in diagnosis and treatment and to ensure that technicians, equipment, and techniques meet standards that minimize radiation exposure. Within these standards, however, patients and health care providers must decide when to use radiation on a case-by-case basis.

The National Institutes of Health (NIH) points out that the radiation doses involved in medical procedures have been decreasing over the past two decades as X-ray films and equipment have been improved. In addition, the ability to target radiation more precisely to one part of the body has resulted in less exposure to the rest of the body. In the NIH's view, with the development of better machines and the use of computers to plan treatment, the safety and effectiveness of radiotherapy has steadily improved.

In the overwhelming majority of cases, according to NIH, "the benefits of medical radiation far outweigh the risks associated with it." For example:

- Diagnostic tests using radiation allow doctors to treat patients without using invasive and life-threatening procedures.
- Radiation, surgery, and chemotherapy are the mainstays of cancer treatment and are used in combination, depending on the cancer.
- Certain tumors can be treated successfully with radiotherapy alone.

"But," notes the NIH, "there is a tradeoff. In this sense, radiation is no different than any other diagnostic or therapeutic agent, except that we have more information than usual." For example, doctors try to avoid exposure of large parts of the body to radiation because this can cause serious side effects like cancer. About five percent of all *secondary cancers*—cancers that develop after treatment for the initial cancer—have been linked to radiotherapy.

Individual Actions You Can Take

You can minimize your exposure from medical radiation by taking these actions:

- Discuss your treatment with your doctor to determine if it is really the best alternative.
- Ask if MRI (magnetic resonance imaging), ultrasound, and other nonionizing diagnostic techniques are possible options.
- Get a second opinion if you have any reservations.
- Always avoid radiation exposure if you have reason to believe it is unnecessary.

Controlling Exposure to Radon

Government Guidance

EPA and the U.S. Surgeon General recommend testing all homes below the third floor for radon and taking steps to reduce indoor radon levels to below four picocuries per liter (pCi/L), the level above which EPA recommends that homeowners voluntarily take steps to reduce radon exposures. This level is cost and technology-based, meaning that it takes into account the limits of the technology currently available and affordable to address residential radon levels. There is currently no known safe level of exposure to radon decay products. Any level of exposure, no matter how small, may pose some increased risk of lung cancer. (See Health Effects of Radon, Chapter 3 page 37.) Testing your home is the only way to know if you and your family are at risk from radon in indoor air.

Individual Actions You Can Take

Testing for radon is easy:

- Buy a low-cost, radon test kit from a qualified laboratory through the mail or in hardware and home-improvement stores.
- Hire a professional to do the testing. In this case, EPA recommends choosing a qualified measurement company or individual (e.g., home inspector). Check with your state radon office; most states require radon professionals to be licensed, certified or registered.

If you find high radon concentrations:

- A variety of methods are used to reduce radon in homes, schools, and other buildings. Simple systems using pipes and fans may be used to reduce radon. Such systems are called sub-slab depressurization and do not require major changes to a home. These systems remove radon gas from below the concrete floor and the foundation before it can enter the building.
- The typical cost for a contractor to install a sub-slab depressurization system ranges from $500 to $2500, about the same cost as other common home repairs and routine maintenance.
- With the technology available today, elevated radon levels can be reduced to below four pCi/L more than 95 percent of the time, and to below two pCi/L an

estimated 70 to 80 percent of the time.

New homes can be built to be radon-resistant.

- In many areas of the country, construction of new homes with radon-resistant features is becoming common practice or is required by code.
- EPA estimates the costs of building new homes radon-resistant to be about $350 to $500.

EPA has developed a number of publications on radon which provide information on how indoor air radon problems can be fixed. (See Appendix C.) EPA also has a National Radon Program to inform the public about radon risks, provide grants for state radon programs, and develop standards for radon-resistant buildings. For more information, call EPA's radon hotline (1-800-SOS-Radon) or visit EPA's web site (www.epa.gov/iaq/radon).

Monitoring Radiation Levels in the Environment

To keep track of levels of radioactivity in the air, water, and food chain, EPA operates a national network of monitoring stations. The Environmental Radiation Ambient Monitoring System samples air, precipitation, surface and drinking water, and milk to track any radioactivity that reaches the public through the different environmental and food pathways. The system processes about 2,000 samples per month and conducts 6,000 analyses of the data, which are published in the quarterly journal *Environmental Radiation Data.* These reports can also be viewed at www.epa.gov/narel.

Controlling UV Radiation Exposure

Overexposure to the sun's ultraviolet (UV) rays threatens human health by causing:

- Immediate painful sunburn
- Skin cancer
- Eye damage
- Immune system suppression
- Premature aging

Children are highly susceptible to harmful UV radiation. Just one or two blistering sunburns in childhood may double the risk of developing melanoma, a highly malignant form of skin cancer. An estimated 80 percent of lifetime sun exposure occurs before the age of 18.

Individual Actions You Can Take

Sunburn, skin cancers, and other sun-related adverse health effects are largely *preventable* when sun protection is practiced early and consistently. The best sun protection is achieved by practicing a combination of recommended sun-safe behaviors:

- Limit sun exposure during the hours when the sun's rays are the strongest, between 10am and 4pm.
- Seek shade, such as trees or umbrellas, whenever possible.
- Wear a wide-brimmed hat, sunglasses, and long-sleeved, tightly woven clothing.
  —A wide-brimmed *hat* protects the face from direct sun's rays but not from rays reflected from lower-level surfaces.
  —*Clothing* can physically block out the sun's harmful rays.
  —*Sunglasses* can block out 100 percent of UVA and UVB radiation to protect the eyes from damage.
- Use a broad-spectrum sunscreen with a sun protective factor (SPF) of at least 15.
- Avoid tanning salons. Artificial UV radiation can be as damaging as sunlight.
- Limit exposure to reflective surfaces such as snow and water. UV rays can be reflected off of sand, tile, water, snow, and buildings.

Controlling Occupational Exposures

People who work at nuclear power plants or in laboratories where radioactive materials are used, wear thermoluminescent dosimeters (TLDs) and/or film badges on the job. These devices measure cumulative whole-body exposures to ensure the exposure is not above regulatory limits.

Table 5: Major Federal Legislation on Radiation Protection

Law	Year Passed	Agencies	Description
The Atomic Energy Act (AEA)	1946, amended in 1954	NRC EPA DOE	• Establishes roles and responsibilities for control of nuclear materials. NRC, DOE, and EPA manage use, possession, and disposal of regulated materials. • Charges EPA with setting generally applicable environmental standards to protect the environment from listed radioactive materials. EPA has issued standards for (a) environmental releases of radioactivity from nuclear fuel cycle facilities (nuclear power reactors and supporting facilities), (b) disposal of radioactive materials from uranium ore refining, and (c) the disposal of high-level and transuranic radioactive waste anywhere except Yucca Mountain.
The Clean Air Act (CAA)	1970, amended in 1977 and 1990	EPA	• Establishes the National Emissions Standards for Hazardous Air Pollutants to regulate air pollution from various sources. • Section 112 applies specifically to airborne emissions or releases of radionuclides (radioactive particles) into the environment and requires EPA to protect public health and the environment from these emissions. EPA developed standards that limit air emissions of radionuclides to the environment from various sources. EPA implements these standards across the country through its regional offices.
The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act (SARA)	1980, amended in 1986	EPA	CERCLA and SARA require that cleanup of hazardous substances be conducted in a manner protective of human health. EPA has established site-specific methods to implement the mission established by CERCLA as it relates to cleanup and remediation of radioactively contaminated sites.
The Energy Policy Act	1992	EPA NRC NAS	Directs the NAS to develop scientific recommendations and EPA to issue public health and safety standards for the operation of the potential high-level nuclear waste repository at Yucca Mountain. NRC will implement EPA's standards for Yucca Mountain.
The Federal Water Pollution Control Act, as amended by the Clean Water Act	1972, amended in 1977 and 1987	EPA	Prohibits discharge of radioactive wastes or other pollutants into U.S. navigable waters without a permit. EPA and authorized states have authority to issue permits in accordance with national water quality standards.

Table 5: Major Federal Legislation on Radiation Protection, con't

Law	Year Passed	Agencies	Descriptions
The Hazardous Materials Transportation Act	1975	DOT	Authorizes the DOT to set standards for the transport of radioactive and other hazardous materials in interstate and foreign commerce.
The Indoor Radon Abatement Act	1988	EPA	Instructs EPA to reduce indoor exposures from radon.
The Low-Level Radioactive Waste Policy Act	1980	States	Makes each state responsible for ensuring that adequate disposal capacity is available for commercial low-level nuclear waste generated within its borders. Encourages states to join compacts to develop needed disposal capacity.
The Nuclear Waste Policy Act	1982, amended in 1987	DOE	• Authorizes DOE to develop two geologic repositories to dispose of civilian spent nuclear fuel. • Assigns responsibilities for nuclear waste management to specific federal agencies and creates the Nuclear Waste Fund to pay for nuclear waste disposal costs from nuclear power user fees. • Charges EPA with developing generally applicable standards for repositories and NRC with developing specific technical requirements. • 1987 amendment directs DOE to investigate only one potential repository site: Yucca Mountain, Nevada.
The Safe Drinking Water Act (SDWA)	1974, amended in 1996	EPA	Requires EPA to publish standards for drinking water contaminants that may adversely affect human health. EPA has set limits on radionuclides in drinking water along with numerous other physical, chemical, and biological constituents.
The Uranium Mill Tailings Radiation Control Act (amendment to AEA)	1978	DOE NRC EPA	• Directs DOE to provide for stabilization and control of uranium mill tailings from inactive sites in a safe and environmentally sound manner to minimize radiation hazards to the public. DOE is cleaning up 24 sites and more than 5,000 "vicinity properties" (contaminated off-site locations). • Charges EPA with developing standards of general application for both inactive and active uranium mill tailings sites. • Directs NRC to regulate operation and closure of active uranium mill tailing sites.
The Waste Isolation Pilot Plant Land Withdrawal Act	1992	DOE	Gives EPA regulatory oversight authority over many of DOE's activities at the WIPP in southeastern New Mexico near Carlsbad.

Radiation workers are also rigorously trained to handle radioactive materials safely, to protect themselves and the public from possible radiation hazards. The responsible authorities and government agencies, in order to determine the cause and help prevent recurrences, investigate accidents that result in even slight radiation exposure or the release of small amounts of radioactivity. If an investigation reveals carelessness or neglect, the government can impose heavy fines and even shut down the responsible facilities.

Responsible Federal Agencies

The federal government's radiation management and protection programs are authorized by more than 20 laws enacted since 1946. Table 5 outlines the major laws federal agencies use to set standards and issue regulations for radiation protection.

Nuclear Regulatory Commission (NRC)

NRC protects public health and safety and the environment by ensuring that nuclear materials are used safely. NRC's regulatory functions apply to both nuclear power plants and other civilian users of nuclear materials, including nuclear medicine at hospitals, academic activities at educational institutions, research, and industrial applications. NRC ensures that these facilities operate in compliance with strict safety standards by:

- Licensing facilities that possess, use, or dispose of nuclear materials
- Establishing standards governing the activities of licensees
- Inspecting licensed facilities to ensure compliance with its requirements

NRC carries out its programs either directly or through the *Agreement State Program*, in which NRC relinquishes its regulatory authority for most facilities to qualified participating states. Under this arrangement, Agreement States perform the licensing and inspection functions. They must provide at least as much health and safety protection as NRC standards prescribe.

NRC limits the amount of radiation that workers or members of the public can be exposed to from nuclear power plants and industrial and medical facilities that are licensed to use nuclear materials. NRC also conducts research, testing, and training programs, and has the authority to regulate low-level and high-level radioactive waste facilities. NRC enforces its own standards as well as some of EPA's standards for protecting the public from radiation.

Department of Energy (DOE)

DOE's important responsibilities for protecting the public from radiation include:

- Issuing standards and guidelines and enforcing some of EPA's radiation standards for protecting workers and the public at DOE facilities.
- Developing the disposal system for spent nuclear fuel from the nation's civilian nuclear power plants. (See Sites and Methods of Waste Disposal, Chapter 4, page 46.) This activity is funded completely by a tax paid by the users of nuclear-generated electricity.
- Managing the cleanup and disposal of radioactive materials that resulted from nuclear weapons production at federally owned facilities during the Cold War. (See Nuclear Weapons Waste, Chapter 4, page 51.)
- Cooperating with state governments, tribal governments, the public, and private industry to clean up other locations around the United States that were contaminated with radiation as a result of government programs.
- Providing technical advice and assistance to states and the private sector for managing and disposing of low-level radioactive waste.

Environmental Protection Agency (EPA)

Since its establishment in 1970 as part of the executive branch of the federal government, EPA has been responsible for protecting the public health and the environment from avoidable exposures to radiation. In carrying out this mission, EPA:

- Issues standards and guidance to limit radiation exposures and conducts a national monitoring program to keep track of radiation levels in the environment. (See Monitoring Radiation Levels in the Environment, this Chapter 4, page 62.)
- Works with industry, the states, and other government agencies to inform the public about radiation risks and to promote actions that reduce human exposure.
- Assesses radiation effects on people and the environment, studies radiation measurement and control, and provides technical assistance to states and other federal agencies.
- Administers the National Radon Program and evaluates new and developing radiation control and cleanup technologies.
- Provides technical assistance and support for cleaning up radioactively contaminated sites.

EPA sets standards for the management and disposal of radioactive wastes and guidelines relating to control of radiation exposure under the Atomic Energy Act, the Clean Air Act, and other legislation. (Table 5) The legislation describes the result EPA must produce (for example, “protect the public health” with an “ample margin of safety”). EPA must determine what levels or limits are considered protective and specify measures or processes for putting these measures in place. In 1989, for example, under the Clean Air Act, EPA published standards limiting emissions of radioactive materials from all federal and industrial facilities. (See Controlling Radiation in the Air, Chapter 4, page 59.)

Department of Defense (DOD)

DOD is in charge of the safe handling and storage of nuclear weapons and other military uses of nuclear energy under its custody. These uses include fueling nuclear-powered ships and research reactors, cleaning up and decommissioning military bases, and practicing nuclear medicine. (DOE remains responsible for the safe handling of radioactive material at DOE defense weapons production facilities.)

Department of Transportation (DOT)

DOT, in cooperation with NRC and the States, governs the packaging and transport of radioactive materials. (See Transporting Radioactive Waste, Chapter 4, page 55.) The department regulates both the carriers and the drivers who transport these materials. DOT’s Research and Special Programs Administration (RSPA) is responsible for issuing hazardous materials regulations for radioactive materials that are compatible with the regulations of the International Atomic Energy Agency (IAEA). (See Role of International Organizations in this Chapter, page 70.)

Department of Health and Human Services (HHS)

The Food and Drug Administration (FDA) carries out HHS radiation responsibilities. FDA’s Center for Devices and Radiological Health sets standards for X-ray machines, microwave ovens, and other electronic products to ensure that the radiation these items produce does not endanger human health. FDA, in conjunction with the Department of Agriculture, also regulates the use of radiation on food. (See Food Irradiation, Chapter 3, page 29.)

Occupational Safety and Health Administration (OSHA)

OSHA, part of the Department of Labor, has the mission of saving lives, preventing injuries, and protecting the health of America’s workers. Under of the authority of the Occupational Safety and Health Act of 1970, OSHA develops and enforces regulations to protect workers who are not covered by other agencies from radiation exposure.

The National Academy of Sciences (NAS)

While not part of the federal government, NAS frequently conducts studies at the government's request and advises federal agencies on scientific and technical aspects of radiation issues. For years, NAS has been heavily involved in the government's search for a solution to the high-level and transuranic nuclear waste disposal problem. The NAS's Committee on the Biological Effects of Ionizing Radiation (BEIR Committee) and its predecessors have been issuing influential reports on radiation and its health effects for the past 35 years.

National Council on Radiation Protection and Measurements (NCRP)

NCRP is a nonprofit corporation chartered by Congress in 1964 to study the scientific and technical aspects of radiation protection. With NRC and EPA, NCRP recommends radiation standards that help form the basis for federal, state, and local regulations to protect the public health and the environment from radiation hazards. NCRP's members, chosen on the basis of their scientific expertise, come from universities, medical centers, national and private laboratories, and industry. NCRP's international counterpart is the International Commission on Radiological Protection. (See ICRP in this Chapter, page 70.)

Federal, State, and Local Government Functions

Responding to Emergencies

The 1979 accident at Three Mile Island nuclear power plant changed the approach to responding to nuclear accidents in the U.S. (See Accidental Releases, Chapter 3, page 39.) As a result of the accident, NRC requires all domestic nuclear power plants to develop and test emergency plans.

A number of federal and state agencies have various roles in preparing for and responding to radiological emergencies:

- State and local emergency government response agencies have primary responsibility for immediate response and public protection in a radiological emergency.
- Seventeen U.S. government agencies cooperated in developing the Federal Radiological Emergency Response Plan. This plan provides for coordinated federal assistance to state and local governments dealing with the risks posed by accidental releases of radioactive material. Depending on the situation, EPA, NRC, DOD, NASA, DOE, HHS, the Federal Emergency Management Agency, and/or the Department of Agriculture may play significant roles in any federal response.
- EPA's Radiological Emergency Response Team (RERT) provides quick response and support for incidents involving radiological hazards. The RERT can monitor and assess radioactivity in the environment from an accident to define the extent of exposure.
- EPA determines the exposure levels at which protective actions, such as staying indoors or evacuating the area, should be considered in case of a release or potential release of radioactive material to the environment.
- DOE's Federal Radiological Monitoring and Assessment Center coordinates the primary federal equipment and material for environmental and personnel monitoring immediately following an emergency.

Setting Standards

Radiation is classified as a class A carcinogen. This means there is specific scientific evidence proving that radiation can cause cancer. EPA sets radiation protection standards so that the maximum allowable dose to a member of the public is protective of human health and the environment. (For the purpose of setting radiation standards, *protective* means not adding significantly to the average risk of developing cancer.)

When setting standards, EPA considers additional factors, including:

- The *benefits* provided by the source of radiation
- The *size* of the dose received
- The *frequency* of exposure
- The *feasibility* and *cost* of avoiding exposure

EPA also considers public comments before finalizing its standards.

NCRP and The International Commission on Radiological Protection also have a role in recommending standards within the United States. (See Responsible Federal Agencies in this Chapter, p. 65.) The recommendations issued by these organizations provide the scientific basis for radiation protection efforts throughout the country. Governmental organizations, including NRC, the U.S. Public Health Service, EPA, and state governments, use recommendations from ICRP and NCRP as the scientific basis for their protection activities.

EPA sets radiation standards that minimize the public's exposure to various sources of radioactivity, including both manmade and, in some instances, natural sources. (See Natural Sources, Chapter 2, page 18.) For example:

- EPA's drinking water standards control the public's exposure to both natural and man-made sources of radiation. Water departments and other suppliers of drinking water must comply with limits on the radionuclide content in public water supplies.
- EPA's regulations for high-level radioactive waste disposal limit the exposure of the public from such facilities to no more than 15 millirems per year.
- For abandoned uranium mines, EPA limits the concentration of naturally occurring radium and thorium left behind at the site to no more than five picocuries per gram in the upper 15 centimeters of soil.

In enforcing EPA's exposure standards for the nuclear industry, NRC limits the air and water emissions of radionuclides from nuclear reactors to levels that would expose no member of the public to more than 25 millirems of radiation per year.

For occupational exposures at nuclear plants, NRC limits the sum of both internal and external doses to workers to 5,000 millirem per year. Actual annual occupational exposures in the U.S. nuclear energy industry average much less than 5,000 millirem. The average worker dose in the U.S. nuclear energy industry in 1995 was about 160 millirem, less than 5 percent of the NRC limit.

EPA and NRC co-chair the Interagency Steering Committee on Radiation Standards, which includes representatives of the DOE, DOD, and other federal agencies. The committee works to foster early resolution and coordination of regulatory issues associated with radiation standards.

Issuing Guidance

When radiation hazards exist but legally binding regulations are inappropriate, EPA issues guidance, recommends action levels, and/or undertakes public education efforts that will help protect the public from excessive exposures. For example:

- EPA's radon program recommends an action level of 4 pCi/L. EPA recommends, but does not require, that homeowners reduce radon levels below the action level in their homes (see The Health Effects of Radon, Chapter 3, page 37.)
- EPA's radon educational efforts help reduce exposure to natural radiation.
- EPA's *SunWise* school program is a comprehensive health and science related program designed to educate children

about overexposure to ultraviolet radiation from the sun and how it can affect their health in the future.

- EPA's 1987 guidelines help federal agencies to develop radiation exposure standards for workers. These standards recommend the maximum amount of radiation that workers in nuclear power, medicine, industry, mining, and waste management can safely receive.

Conducting Site Cleanup

Government agencies and private companies alike are required by law to clean up any hazardous and radioactive substances that could endanger public health and welfare and the environment. CERCLA gives EPA the authority to determine the degree of public hazard posed by contaminated sites. EPA places the most serious problem sites on the Superfund National Priorities List (NPL) for expedited study and cleanup. For sites on the NPL, EPA works closely with the affected states, with input from the public, to develop and monitor site assessment and cleanup schedules.

EPA also supports efforts to clean up the many non-NPL sites in the United States contaminated with radioactive material, including those contaminated with mixed waste—a combination of radioactive and hazardous chemical waste (See Mixed Waste, Chapter 4, page 48.)

Other Roles in Managing Radiation

Role of the States and Native American Tribes

States have additional responsibilities for protecting the public and the environment that go beyond responding to radiological emergencies. Both EPA and NRC are authorized to delegate some of their regulatory authority over radioactive materials to the states.

- EPA can authorize states to regulate hazardous wastes under the RCRA.
- NRC can delegate regulation of radioactive materials from facilities (except nuclear power plants) within their jurisdictions to states, called Agreement States, that have reached an agreement with the NRC under the Atomic Energy Act of 1954.
- NRC may also delegate to Agreement States regulation of low-level waste disposal facilities under the Low-Level Radioactive Waste Policy Act of 1980. The law makes the states responsible, either individually or in groups called compacts, for ensuring adequate disposal capacity for the low-level radioactive waste generated within their borders.
- DOE must consult the state if it is considering building a high-level waste storage or disposal facility within state borders, under the Nuclear Waste Policy Act of 1982. If a state objects to the siting of such a facility, both houses of Congress must vote to overturn the state's veto.
- Native American tribes that may be affected by a potential waste disposal site are also guaranteed the same rights as affected states under the 1982 Act. In the early 1990s, several tribes actively participated in feasibility studies as potential hosts to a proposed interim storage facility for spent nuclear fuel until a permanent repository is built. (See Sites and Methods of Waste Disposal, Chapter 4, page 46.) Tribes with treaty claims to lands currently occupied by DOE nuclear weapons facilities, such as the Hanford Site in Washington, are participating in the decontamination and cleanup of those territories. Some tribes are voicing concerns about additional exposure from the transport of nuclear waste.
- States and tribes also play a role, with NRC and DOT, in regulating the transportation of radioactive materials within their borders. (See Transporting Radioactive Waste, Chapter 4, page 55.) and in preparing for accidents or emergencies involving nuclear waste shipments.

- For TENORM, states are developing a variety of standards and guidances. Many states have developed regulations for the management and disposal of radium-contaminated pipe scale from the oil and gas industry. Some states have issued guidance to address the disposal of sludge and residues resulting from the treatment of water at public water supplies.
- OSHA delegates some worker protection responsibilities to the states.
- Most states regulate the specifications for X-ray equipment.

Role of International Organizations

National governments have primary responsibility for ensuring the safety of nuclear operations within their borders. As the Chernobyl accident dramatically demonstrated, however, radiation from nuclear accidents can spread rapidly across international boundaries. (See Accidental Releases, Chapter 3, page 39.)

Several international organizations have been formed to help establish and ensure compliance with worldwide radiation protection standards.

- **The International Commission on Radiological Protection (ICRP)**, established in 1928, provides worldwide recommendations and guidance on radiation protection. Its members come from 20 countries and include scientists, physicians, and engineers. While ICRP has no formal power to impose its proposals on anyone, legislation in most countries adheres closely to ICRP recommendations. Congress chartered in 1964 the U.S. counterpart to the ICRP, the National Council on Radiation Protection and Measurements (NCRP).
- **The International Atomic Energy Agency (IAEA)** is a 131-member independent organization operating under the protection of the United Nations. IAEA was organized in 1956 to promote peaceful uses of nuclear energy. It applies nuclear safety and radiation protection standards to its own operations and to activities that make use of IAEA materials, equipment, facilities, and services. Countries that receive IAEA assistance are required to observe health and safety measures prescribed by the agency.
- **The Nuclear Energy Agency (NEA)** is an arm of the Organization for Economic Cooperation and Development (OECD). NEA is a 23-member body that promotes the exchange of information on nuclear waste issues; conducts and sponsors international research and development projects; and coordinates research, site investigations, and underground demonstration projects by its members. NEA also recommends nuclear safety standards to OECD member nations.
- **The International Commission on Radiological Units and Measurements (ICRU)** recommends the units used in designating radiation protection levels. The ICRU was created in 1925.
- **The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)** was established in 1955 to evaluate doses, effects, and risks from ionizing radiation on a global scale. UNSCEAR is one of the international organizations studying the Hiroshima and Nagasaki survivors. (See Studying Radiation's Effects on Humans, Chapter 3, page 33.) Based on its studies, UNSCEAR makes risk estimates that are used by the IAEA, the NEA, and other organizations to set radiation exposure standards.

Your Role as a Citizen

Since we are constantly exposed to many different sources of background radiation throughout our lives, there is no way to reduce our exposure to zero. Hence, we cannot guarantee that we are completely safe from the possible effects of radiation. As is true for many other aspects of life, the very fact of living means we have to accept a certain amount of risk from the radiation all around us.

As concerned citizens, the key question we need to ask and try to help answer is:

> How much exposure to radiation beyond the normal levels of uncontrollable natural radiation should society tolerate in order to balance the risks and the benefits of radiation?

Public participation can play a significant role in the way the government manages risk, including the risk of exposure to radiation. In a democracy, when citizens speak up at public hearings, write to their elected representatives and regulatory agencies, march on picket lines, and file lawsuits, their opinions count. The voices of citizens influence the debate that helps determine what laws and regulations are written, where and when facilities are built, and what levels of releases and exposure will be permitted by the government.

In fact, many government agencies are increasingly inviting this kind of public participation—called stakeholder involvement—in their decision-making process. They are doing so by

- Publishing scientific and regulatory information on public issues, both in hard copy and on their World Wide Web sites
- Holding public meetings and hearings and teleconferences
- Encouraging citizens to submit written comments on proposed policies and programs

The goal of these outreach efforts is to involve citizens more directly in determining the appropriate balance between, for example, sustaining our nations economic strength and other social values, such as maintaining environmental quality.

Ultimately, we must rely on our elected officials and the regulators who are responsible for enforcing their decisions to find the best balance of social, political, and scientific factors for the benefit of society as a whole. Citizens can help them do their jobs more effectively by learning about and doing their best to understand the environmental and other consequences of technological change, including the benefits and risks associated with radiation in all its forms. The more we know, the better equipped we will be to help ensure that society develops and uses radiation wisely.

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Appendix A: Glossary of Radiation Terms

Acute Exposure: A single exposure to a substance which results in biological harm or death. Usually characterized by a brief exposure lasting no more than a day, as compared to longer, continuing exposure over a period of time (chronic exposure).

Agreement State: A State that has signed an agreement with the Nuclear Regulatory Commission allowing the State to regulate the use of by-product radioactive material within that State.

ALARA: Acronym for "As Low As Reasonably Achievable." It means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology and in relation to benefits to the public health and safety, and other societal and socioeconomic considerations.

Alpha particle: A positively charged particle ejected spontaneously from the nuclei of some radioactive elements. It has low penetrating power and a short range (a few centimeters in air). The most energetic alpha particle will generally fail to penetrate the dead layers of cells covering the skin and can be easily stopped by a sheet of paper. Alpha particles are hazardous when an alpha-emitting isotope is inside the body.

Atom: The smallest unit of an element that cannot be divided or broken up by chemical means. It consists of a central core of protons and neutrons (except hydrogen which has no neutrons), called the nucleus. Electrons revolve in orbits in the region surrounding the nucleus.

Atomic energy: Energy released in nuclear reactions. Of particular interest is the energy released when a neutron initiates the breaking up of an atom's nucleus into smaller pieces (fission), or when two nuclei are joined together under millions of degrees of heat (fusion). It is more correctly called nuclear energy.

Atomic Energy Commission: Federal agency created in 1946 to manage the development, use, and control of nuclear energy for military and civilian applications. Abolished by the Energy Reorganization Act of 1974 and succeeded by the Energy Research and Development Administration (now part of the U. S. Department of Energy) and the U. S. Nuclear Regulatory Commission.

Atoms for Peace: President Eisenhower's 1954 initiative to allow the peaceful uses of atomic energy to be available to other nations.

Background radiation: Radiation from cosmic sources and terrestrial sources, including radon. It does not include radiation from source or byproduct nuclear materials regulated by the Nuclear Regulatory Commission. The average individual exposure from background radiation is about 300 millrems per year.

Beta particle: A charged particle emitted from a nucleus during radioactive decay, with a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Large amounts of beta radiation may cause skin burns, and beta emitters are harmful if they enter the body. Beta particles may be stopped by thin sheets of metal or plasitc.

Biological effectiveness factor: Neutrons and alpha particles do more harm per unit dose than photons or beta particles. An experimentally determined value for this difference is referred to as the relative biological effectiveness (RBE) and is mostly restricted to uses in the field of radiobiology. Each species tested, each target organ within that species, and each radionuclide chosen might give a different RBE. For humans, a conservative upper limit of the RBE, called the quality factor (Q) or the radiation weighting factor (WR), is used to determine the dose equivalent.

Carcinogen: A cancer-causing substance.

Chain reaction: A reaction that initiates its own repetition. In a fission chain reaction, a fissionable nucleus absorbs a neutron and fissions spontaneously, releasing additional neutrons. These, in turn, can be absorbed by other fissionable nuclei, releasing still more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in nonfissionable material or by escape from the system.

Charged particle: An ion. An elementary particle carrying a positive or negative electric charge.

Chronic exposure: Exposure to a substance over a long period of time resulting in adverse health effects.

Compact: A group of two or more States formed to dispose of low-level radioactive waste on a regional basis. Forty-four States have formed ten compacts.

Contamination: The deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or people. It may also be airborne, external, or internal (inside components or people).

Cooling tower: A heat exchanger designed to aid in the cooling of water that isused to cool exhaust steam exiting the turbines of a power plant. Cooling towers transfer exhaust heat into the air instead of into a body of water.

Core: The central portion of a nuclear reactor containing the fuel elements, moderator, neutron poisons, and support structures.

Core melt accident: An event or sequence of events that result in the melting of part of the fuel in a nuclear reactor core.

Cosmic radiation: Ionizing radiation, both particulate and electromagnetic, originating in outer space.

Criticality: A term used in reactor physics to describe the state when the number of neutrons released by fission is exactly balanced by the neutrons being absorbed and escaping the reactor core. A reactor is said to be "critical" when it achieves a self-sustaining nuclear chain reaction, as when the reactor is operating.

Cumulative dose: The total dose to an individual resulting from repeated exposures of ionizing radiation to the same portion of the body, or to the whole body, over a period of time.

Curie (Ci): The basic unit used to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion (3 X 10^{10}) disintegrations per second, which is approximately the activity of 1 gram of radium. A curie is also a quantity of any radionuclide that decays at a rate of 37 billion disintegrations per second. It is named for Marie and Pierre Curie, who discovered radium in 1898.

Decay, radioactive: The decrease in the amount of any radioactive material with the passage of time due to the spontaneous emission of radiation from the atomic nuclei (either alpha or beta particles, often accompanied by gamma radiation).

Decommission: The process of closing down a nuclear facility and reducing radioactivity at the facility to a level safe for unrestricted use.

Decontamination: The reduction or removal of contaminated radioactive material from a structure, area, object, or person. Decontamination may be accomplished by: (1) treating the surface to remove or decrease the contamination, (2) letting the material stand so that the radioactivity is decreased as a result of natural radioactive decay, or (3) covering the contamination to limit the radiation emitted.

Dose, absorbed: Represents the amount of energy absorbed from the radiation in a gram of any material. It is expressed numerically in rads.

Dose equivalent (also called biological dose): is a measure of the biological damage to living tissue from the radiation exposure. It takes into account the type of radiation and the absorbed dose. For example when considering beta, X-ray, and gamma ray radiation, the equivalent dose (expressed in rems) is equal to the absorbed dose (expressed in rads). For alpha radiation, the equivalent dose is assumed to be twenty times the absorbed dose. It is expressed numerically in rem.

Dose rate: The ionizing radiation dose delivered per unit time. For example, rem per hour.

Dosimeter: A small portable instrument (such as a film badge, thermoluminescent, or pocket dosimeter) for measuring and recording the total accumulated personnel dose of ionizing radiation.

Electromagnetic radiation: Radiation consisting of electric and magnetic waves. A traveling wave motion resulting from changing electric or magnetic fields. It ranges from X-rays (and gamma rays) with short wavelength, through the ultraviolet, visible, and infrared regions, to radar and radio waves with relatively long wave length.

Electron: An elementary particle with a negative charge and a mass 1/1,837 that of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom.

Element: One of the 103 known chemical substances that cannot be broken down further without changing its chemical properties. Some examples include, hydrogen, nitrogen, gold, lead, and uranium.

Entomb: A method of decommissioning a nuclear facility in which radioactive contaminants are encased in long-lived material, such as concrete. The entombment structure is maintained and monitored until the radioactivity decays to a level allowing decommissioning and ultimately, safe unrestricted use of the property.

Epidemiological studies: Studies of the distribution of disease and other health issues as related to age, sex, race, ethnicity, occupation, economic status, or other factors.

Fallout, nuclear: The slow decent of minute particles of radioactive debris in the atmosphere following a nuclear explosion.

Film badge: Photographic film used for measurement of ionizing radiation exposure for personnel monitoring purposes. The film badge may contain two or three films of differing sensitivities, and it may also contain a filter that shields part of the film from certain types of radiation.

Fissile material: Although sometimes used as a synonym for fissionable material, this term has acquired a more restricted meaning. Namely, any material fissionable by thermal (slow) neutrons. The three primary fissile materials are uranium-233, uranium-235, and plutonium-239.

Fission (fissioning): The splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy. Two or three neutrons are usually released during this type of transformation. Fissioning is also referred to as burning.

Fuel cycle: The series of steps involved in supplying and managing fuel used in nuclear power reactors. It can include mining, milling, isotopic enrichment, fabrication of fuel elements, use in a reactor, reenrichment of the fuel material, refabrication into new fuel elements, and waste disposal.

Fuel rod: A long, slender tube that holds fissionable material and managing (fuel) used in nuclear reactor use. Fuel rods are assembled into bundles called fuel elements or fuel assemblies, which are loaded individually into the reactor core.

Fusion: A reaction in which at least one heavier, more stable nucleus is produced from two lighter, less stable nuclei. Reactions of this type are responsible for enormous release of energy, as in the energy of stars, for example.

Gamma radiation: High-energy, short wavelength, electromagnetic radiation emitted from the nucleus. Gamma radiation frequently accompanies alpha and beta emissions. Gamma rays are very penetrating and are best stopped or shielded by dense materials, such as lead. Gamma rays are similar to X-rays

Geiger counter (or Geiger-Mueller counter): A radiation detection and measuring instrument. It consists of a gas-filled tube containing electrodes, between which there is an electrical voltage, but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of the radiation field. It is the most commonly used portable radiation instrument.

Half-life: The time in which one half of the atoms of a particular radioactive substance decay into another nuclear form. Half-lives vary from millionths of a second to billions of years.

Hazardous Waste: By-products that can pose a substantial or potential hazard to human health or the environment when improperly managed. Hazardous waste has at least one of four characteristics—ignitable, corrosive, reactive, or toxic, or is listed in regulations as hazardous.

High-level waste: Highly radioactive material resulting from the reprocessing of spent nuclear fuel and other highly radioactive material that, under current law, must be permanently isolated.

Ion: (1) An atom that has too many or too few electrons, causing it to have an electrical charge, and therefore, be chemically active. (2) An electron that is not associated (in orbit) with a nucleus.

Ionization: The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiation can cause ionization.

Ionizing radiation: Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Some examples are alpha, beta, gamma, and X-rays. High doses of ionizing radiation may produce severe skin or tissue damage.

Irradiation: Exposure to radiation

Isotope: One of two or more atoms with the same number of protons, but different numbers of neutrons in their nuclei. For example, carbon-12, carbon-13, and carbon-14 are isotopes of the element carbon, the numbers denote the approximate atomic weights. Isotopes have very nearly the same chemical properties, but often different physical properties (for example, carbon-12 and -13 are stable, carbon-14 is radioactive).

Linear- no-threshold-hypothesis: The theory that the number of cancers and other effects of exposure to low levels of radiation are proportionate to the number of cancers from exposure to high levels of radiation. The precise effects are uncertain because it is very difficult to directly measure the effects of low levels of radiation.

Manhatten Project: The U.S. government program to develop the first atomic weapons during World War II.

Mill-tailings: Naturally radioactive residue from the processing of uranium ore. Although the milling process recovers about 93 percent of the uranium, the residues, or tailings, contain several naturally-occurring radioactive elements, including uranium, thorium, radium, polonium, and radon.

Molecule: A group of atoms held together by chemical forces. A molecule is the smallest unit of a compound that can exist by itself and retain all of its chemical properties.

Neutron: An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen.

Non-ionizing radiation: Radiation that has lower energy levels and longer wavelengths. It is not strong enough to affect the structure of atoms it contacts, but it does heat tissue and can cause harmful biological effects. Examples include radio waves, microwaves, visible light, and infrared from a heat lamp.

NARM/NORM: Naturally Occurring and Accelerator-Produced Radioactive Materials (NARM) include by-products of petroleum production, coal ash, phosphate fertilizer production, drinking water treatment, and other industrial processes. NORM is a subset of NARM and includes everything in NARM except accelator-produced materials. The federal government has not developed a comprehensive policy for NORM/NARM disposal.

Nuclear energy: The heat energy produced by the process of nuclear reaction (fission or fusion) within a nuclear reactor or by radioactive decay.

Nuclear power plant: An electrical generating facility using a nuclear reactor as its power (heat) source. The coolant that removes heat from the reactor core is normally used to boil water. The steam produced by the boiling water drives turbines that rotate electrical generators.

Nuclear tracers: Radioisotopes that give doctors the ability to "look" inside the body and observe soft tissues and organs, in a manner similar to the way X-rays provide images of bones. A radioactive tracer is chemically attached to a compound that will concentrate naturally in an organ or tissue so that a picture can be taken.

Nucleus: The small, central, positively charged region of an atom that carries the atom's nuclei. All atomic nuclei contain both protons and neutrons (except for ordinary hydrogen, which has a single proton). The number of protons determines the total positive charge, or atomic number.

Nuclide: A general term referring to all known isotopes, both stable (279) and unstable (about 5,000), of the chemical elements.

Photon: A quantum (or packet) of energy emitted in the form of electromagnetic radiation. Gamma rays and X-rays are examples of photons.

Picocurie: One trillionth of a curie.

Plutonium: A very heavy element formed when uranium-238 absorbs neutrons. Like uranium, it has two principal isotopes that are fissile.

Poison, neutron: In reactor physics, a material other than fissionable material, in the vicinity of the reactor core that will absorb neutrons. The addition of poisons, such as control rods or boron, into the reactor is said to be an addition of negative reactivity.

Positron: Particle equal in mass, but opposite in charge, to the electron (a positive electron).

Power reactor: A reactor designed to produce heat for electric generation, as distinguished from reactors used for research, for producing radiation or fissionable materials, or for reactor component testing.

Proton: An elementary nuclear particle with a positive electric charge located in the nucleus of an atom.

Quality factor: The factor by which the absorbed dose (rad) is multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiation, the biological damage (rem) to an exposed individual. It is used because some types of radiation, such as alpha particles, are more biologically damaging internally than other types.

Rad: The unit of absorbed dose, which is the amount of energy from any type of ionizing radiation (e.g., alpha, beta, gamma, etc.) deposited in any medium (e.g., water, tissue, air). A dose of one rad means the absorption of 100 ergs (a small but measurable amount of energy) per gram of absorbing tissue.

Radiation: Energy in the form of waves or particles sent out over a distance.

Radiation sickness (or syndrome): The complex of symptoms characterizing the disease known as radiation injury, resulting from excessive exposure (greater than 200 rads) of the whole body (or large part) to ionizing radiation. The earliest of these symptoms are nausea, fatigue, vomiting, and diarrhea, which may be followed by loss of hair, hemorrhage, inflammation of the mouth and throat, and general loss of energy. In severe cases, where the radiation exposure has been approximately 1,000 rad or more, death may occur within two to four weeks.

Radiation standards: Exposure limits, permissible concentrations, rules for safe handling, regulations for transportation, and regulations controlling the use of radiation and radioactive material.

Radiation warning symbol: An officially prescribed symbol (a magenta or black trefoil) on a yellow background that must be displayed where certain quantities of radioactive materials are present or where certain doses of radiation could be received.

Radioactive contamination: Deposition of radioactive material in any place where it may harm persons, equipment, or the environment.

Radioactivity: The emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nucleus of an unstable isotope. Also, the rate at which radioactive material emits radiation.

Radioisotope: An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. Approximately 5,000 natural and artificial radioisotopes have been identified.

Radionuclide: A radioactive nuclide. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

Radiology: The branch of medicine dealing with the diagnostic and therapeutic applications of radiation, including X-rays and radioisotopes.

Radon (Rn): A radioactive element that is one of the heaviest gases known. Its atomic number is 86. It is found naturally in soil and rocks and is formed by the radioactive decay of radium.

Reactor, nuclear: A device in which nuclear fission may be sustained and controlled in a self-supporting nuclear reaction. There are different designs.

Recycling: The reuse of slightly contaminated materials.

Rem: The unit of measurement of dose equivalent. The rem value takes into account both the amount, or dose, of radiation and the biological effect of the specific type of radiation. Rem equals the absorbed dose multiplied by the quality factor. (100 rem = 1 sievert)

Reprocessing: The mechanical and chemical process of separating out usable products (like uranium and plutonium) from spent or depleted reactor fuel then re-enriching and re-fabricating them inor new fuel elements.

Risk: In many health fields, risk means the probability of incurring injury, disease, or death. Risk can be expressed as a value that ranges from zero (no injury or harm will occur) to one hundred percent (harm or injury will definitely occur).

Risk assessment: Qualitative and quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence of hazards.

Roentgen: A unit of exposure to ionizing radiation. It is the amount of gamma or X-rays required to produce ions resulting in a charge of 0.000258 coulombs/kilogram of air under standard conditions.

Somatic effects of radiation: Effects of radiation limited to the exposed individual, as distinguished from genetic effects, which may also affect subsequent unexposed generations.

Spent (depleted) fuel: Nuclear reactor fuel that has been used to the extent that it can no longer effectively sustain a chain reaction.

Subatomic particles: The matter that makes up atoms. It includes particles such as neutrons, protons, electrons, and many more.

Superfund: The program operated under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Superfund Amendments and Reauthorization Act (SARA) that funds and carries out EPA hazardous waste emergency and long-term removal and remedial activities.

Terrestrial radiation: Radiation that is emitted by naturally occurring radioactive materials in the earth, such as uranium, thorium, and radon.

Thermoluminescent dosimeter: A small device used to measure radiation dose by measuring the amount of visible light emitted from a crystal in the detector. The amount of light emitted is proportional to the radiation dose received.

Thermonuclear: An adjective referring to the process in which very high temperatures are used to bring about the fusion of light nuclei, such as those of the hydrogen isotopes deuterium and tritium, with the accompanying liberation of energy.

Ultraviolet radiation: Radiation of a wavelength between the shortest visible violet rays and low energy X-rays.

Unstable isotope: A radioactive isotope.

Uranium: The heaviest element normally found in nature. The principal fuel material used in today's nuclear reactors is the fissile isotope uranium-235.

Uranium Mill Tailings: See Mill Tailings.

Waste, radioactive: Solid, liquid, and gaseous materials from nuclear operations or TENORM activities that are radioactive or become radioactive and for which there is no further use.

Whole body exposure: An exposure of the body to radiation, in which the entire body, rather than an isolated part, is irradiated.

X-rays: One type of electromagnetic radiation which arises as electrons are deflected from their original paths or inner orbital electrons change their energy levels around the atomic nucleus. Like gamma rays, X-rays require more shielding to reduce their intensity than do beta or alpha particles.

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- Glossary of Nuclear Terms, http://ie.lbl.gov/education/glossary/glossaryf.htm, Lawrence Berkely Laboratory
- Glossary of Nuclear Terms, Frontline, PBS, http://www.pbs.org/wgbh/pages/frontline/shows/reaction/etc/terms.html
- Terms of Environment, Environmental Protection Agency, http://www.epa.gov/OCEPAterms/intro.htm.

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Appendix B: List of Acronyms

AC	alternating current
AEC	Atomic Energy Commission
ALARA	as low as reasonably achievable
BEIR	U.S. Committee on Biological Effects of Ionizing Radiation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CAA	Clean Air Act
DoD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
EMF	electric and magnetic fields
EPA	U.S. Environmental Protection Agency
FDA	Food and Drug Administration
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICRU	International Commission of Radiological Units and Measurements
MRI	magnetic resonance imaging
NARM	naturally occurring and accelerator-produced radioactive materials
NAS	National Academy of Sciences
NCI	National Cancer Institute
NCRP	National Council on Radiation Protection and Measurements
NEA	Nuclear Energy Agency of the Organization for Economic Cooperation and Development
NEI	Nuclear Energy Institute
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
NIMBY	not in my backyard
NORM	naturally occurring radioactive materials
NPL	National Priority List for the Superfund program
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
pCi/L	picocuries per liter
PET	positron emission tomography
RCRA	Resource Conservation and Recovery Act
rad	radiation absorbed dose
rem	roentgen equivalent man
RERT	EPA Radiological Emergency Response Team
RF	radio frequency
RTG	radioisotope thermoelectric generator
SAB	EPA's Science Advisory Board
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
TENORM	technologically enhanced naturally occurring radioactive material
TLD	thermoluminescent dosimeter

TRANSCOM	Transportation Tracking and Communication System
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WIPP	Waste Isolation Pilot Plant

Appendix C: Additional Resources and References

Appendix

Additional Resources and References

American Nuclear Society
555 North Kensington Avenue
La Grange Park, Illinois 60526
Phone: 708/352-6611
Fax: 708/352-0499
Email: nucleus@ans.org
http://www.ans.org
The American Nuclear Society is a not-for-profit, international, scientific and educational organization. Its membership includes approximately 13,000 individuals representing 1,600 plus corporations, educational institutions, and government agencies.

Concerned Citizens for Nuclear Safety
107 Cienega
Santa Fe, NM 87501
Phone: 505/ 982-5611
Fax: 505/986-0997
Email: ccns@nets.com
http://www.nuclearactive.org/
Concerned Citizens for Nuclear Safety is a nonprofit, nonpartisan organization that works to increase public awareness about radioactivity and the nuclear industry. It particularly focuses on Los Alamos National Laboratory (LANL) and the Waste Isolation Pilot Plant (WIPP).

Conference of Radiation Control Program Directors, Inc.
205 Capital Avenue
Frankfort, KY 40601
Phone: 502/227-4543
Fax: 502/227-7862
http://www.crcpd.org/
The Conference of Radiation Control Program Directors, Inc. (CRCPD) is a non-profit professional organization whose primary membership is made up of individuals in state and local government who regulate the use of radiation sources, and others interested in radiation protection.

Health Physics Society
1313 Dolley Madison Boulevard
Suite 402
McLean, Virginia 22101
Phone: 703/790-1745
Fax: 703/790-2672
Email: hps@BurkInc.com
http://www.hps.org
The Health Physics Society is an international professional scientific organization that is active in all aspects of radiation protection including information dissemination, standards development, education, preparation of position papers, and promotion of scientific conferences and committees.

Idaho State University
Department of Physics and Health Physics
Radiation Information Network
Campus Box 8106
Pocatello, ID 83209
Phone: 208/236-2350
Fax: 208/236-4649
Email: office@apollo.physics.isu.edu
http://www.physics.isu.edu/radinf/
This Idaho State University's Radiation Information Network web site contains a wide range of information about Radiation and the professions of Radiation Protection.

Institute for Energy and Environmental Research
6935 Laurel Avenue
Takoma Park, MD 20912
Phone: 301/270-5500
Fax: 301/270-3029
Email: ieer@ieer.org
http://www.ieer.org
The Institute for Energy and Environmental Research is a nonprofit organization funded primarily through private foundation grants. It provides activists, policymakers, journalists, and the public with understandable scientific and technical information on energy and environmental issues, particularly nuclear materials and technologies.

International Atomic Energy Agency
P.O. Box 100, Wagramer Strasse 5
A-1400 Vienna, Austria
Phone: +431-2600-0
Fax: +431-2600-7
Email: Official.Mail@iaea.org
http://www.iaea.org/worldatom/
The International Atomic Energy Agency (IAEA) serves as the world's central intergovernmental forum for scientific and technical co-operation in the nuclear field, and as the international inspector of nuclear safeguards and verification measures in civilian nuclear programs.

International Commission on Radiological Protection
S-171 16 Stockholm, Sweden
Phone: +46-8-7297275
Fax: +46-8-7297298
Email: jack.valentin@ssi.se
http://www.icrp.org
The Commission works to advance for the public benefit the science of radiological protection, in particular by providing recommendations on all aspects of radiation protection.

National Council on Radiation Protection and Measurements
7910 Woodmont Avenue, Suite 800
Bethesda, MD 20814-3095
Phone: 301/657-2652
Fax: 301/907-8768
Email: ncrp@ncrp.com
http://www.ncrp.com
The National Council on Radiation Protection and Measurements (NCRP) seeks to formulate and disseminate information, guidance and recommendations on radiation protection and measurements which represent the consensus of leading scientific thinking.

National Institute of Environmental Health Sciences
Department of Health and Human Services
P.O. Box 12233
111 Alexander Drive
Research Triangle Park, NC 27709
Phone: 919/541-3345
http://www.niehs.nih.aol
The National Institute of Environmental Health Sciences (NIEHS) undertakes biomedical research, prevention and intervention efforts, and training, education, technology transfer, and community outreach. It focuses on human health and human disease that result from three interactive elements: environmental factors, individual susceptibility, and age.

National Safety Council/
Environmental Health Center
1025 Connecticut Ave., NW, Suite 1200
Washington, DC 20036
Phone: 202/293-2270
Fax: 202/293-0032
ehc@nsc.org
http://www.nsc.org/ehc.htm
The Environmental Health Center is a division of the National Safety Council, a nongovernmental, nonprofit public service organization. EHC provides information and resources on a range of environmental issues.

Nevada Nuclear Waste Project Office
1802 N. Carson Street, Suite 252
Carson City, NV 89701
Phone: 775/687-3744
Fax: 775/687-5277
Email: nwpo@govmail.state.nv.us
http://www.state.nv.us/nucwaste

The State of Nevada's agency for nuclear Projects works to assure that the health, safety, and welfare of Nevada's citizens, environment and economy are adequately protected with regard to any federal high-level nuclear waste disposal activities in the state.

New Mexico Environmental Evaluation Group
7007 Wyoming Blvd NE, Suite F-2
Albuquerque, NM 87109
Phone: 505/828-1003
Fax: 505/828-1062
Email: lindak@eeg.org
http://www.eeg.org
The New Mexico Environment Evaluation Group (EEG) is an interdisciplinary group of scientists and engineers funded by the U.S. Department of Energy. EEG provides independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) to ensure the protection of public health and safety, and the environment of New Mexico.

New Mexico WIPP Transportation Safety Program
2040 South Pacheco
Santa Fe, NM 87505
Phone: 505/827-5950
http://www.emnrd.state.nm.us/wipp
The State of New Mexico has implemented the WIPP Transportation Safety Program to ensure the safe and uneventful transportation of radioactive waste to the Department of Energy's Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico.

Nuclear Energy Institute
176 I Street, NW, Suite 400
Washington, DC 20006
Phone: 202/739-8009
Fax: 573/445-2135
Email: swp@nei.org
http://www.nei.org
The Nuclear Energy Institute represents the commercial nuclear energy industry. It advocates policies that ensure the beneficial uses of nuclear energy and related technologies.

Nuclear Information and Resources Service
1424 16th Street NW, Suite 404
Washington, DC 20036
Phone: 202/328-0002
Fax: 202/462-2183
Email: nirsnet@nirs.org
http://www.nirs.org
The Nuclear Information and Resources Service is the information and networking center for citizens and environmental organizations concerned about nuclear power, radioactive waste, radiation, and sustainable energy issues.

Southern States Energy Board
6325 Amherst Court
Norcross, GA 30092
Phone: 770/242-7712
Fax: 770/242-0421
http://www.sseb.org/cpa_rmt.htm
The Southern States Energy Board (SSEB) is a non-profit interstate compact organization of 16 southern states and two territories. SSEB develops, promotes and recommends policies and programs which protect and enhance the environment without compromising the needs of future generations. It has a Radioactive Materials Transportation Committee which participates in the policymaking process concerning the U.S. Department of Energy's radioactive materials transportation programs.

Union of Concerned Scientists
2 Brattle Square,
Cambridge, MA 02238-9105
Phone: 617-547-5552
Email: ucs@ucsusa.org
http://www.ucsusa.org
The Union of Concerned Scientists is an independent nonprofit organization representing scientists and other citizens around the country. It does research, public education and citizen advocacy particularly on environmental and related issues.

U.S. Department of Energy
600 Maryland Avenue, NW, Suite 760
Washington, DC 20024
Phone: 202/488-6220
National Transuranic Waste Program
P.O. Box 3090
Carlsbad, NM 88221-3090
Phone: 505/234-7302
Email: infocntr@wipp.carlsbad.nm.us
http://www.wipp.carlsbad.nm.us
The U.S. Department of Energy is the federal agency responsible for developing and managing the country's nuclear weapons, and for managing its waste and cleaning up its facilities. In addition, DOE has more 30,000 scientists and engineers conducting research. The National Transuranic Waste Program manages the Waste Isolation Pilot Plant (WIPP) Facility.

U.S. Environmental Protection Agency
Ariel Rios Building
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460
Phone: 202/564-9290
http://www.epa.gov/radiation
The U.S. Environmental Protection Agency (EPA) is an independent federal agency that works to protect human health and to safeguard the natural environment – air, water, and land.

U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852-2738
Phone: 301/415-7000
http://www.nrc.gov
The U.S. Nuclear Regulatory Commission (NRC) is an independent federal agency responsible for overseeing the use of nuclear materials in the United States. NRC's scope of responsibility includes regulation of commercial nuclear power reactors; medical, academic, and industrial uses of nuclear materials; and the transport, storage, and disposal of nuclear materials and waste.

University of Michigan
Nuclear Engineering and Radiological Sciences
1906 Cooley Building
2355 Bonisteel Blvd.
Ann Arbor, MI 48109
Phone: 734/764-4260
Fax: 734/763-4540
Email: nuclear@umich.edu
http://www.engin.umich.edu/~nuclear
The University of Michigan's Department of Nuclear Engineering and Radiological Sciences conducts research and provides education on range of issues including radiation detection, fission power, fusion power, radiological health, and waste management.

Western Governors' Association
600 17th Street
Denver, CO 80202-5452
Phone: 303/623-9378
Email: wga@csn.gov
http://www.westgov.org/wipp
The Western Governors' Association is an independent, non-partisan organization of governors from 18 western states, two Pacific-flag territories and one commonwealth. The Association addresses key policy and governance issues in natural resources, the environment, human services, economic development, international relations and public management.

State Radiation Program Contacts
List of state radiation program contacts available at: http://www.hsrd.ornl.gov/nrc/asframe.htm

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Appendix D: Brief Chronology of Radioactive Materials and Radioactive Waste in the United States

Appendix

Brief Chronology of Radioactive Materials and Radioactive Waste in the United States

1895	Roentgen discovers X-rays.
1896	First diagnostic X-ray in US.
1898	Marie & Pierre Curie coin word "radioactivity."
1903	Marie and Pierre Curie awarded the Nobel Prize for Physics.
1905	Albert Einstein develops theory about the relationship of mass and energy.
1910	Curie unit defined as activity of 1 gram of radium.
1915	The British Roentgen Society adopted a resolution to protect people from overexposure to X-rays.
1922	Many American organizations adopted the British protection rules.
1925-1929	The saga of radium dial painters unfolds.
1928	Organization of US Advisory Committee on X-ray and Radium Protection (predecessor of National Council on Radiation Protection).
1939	Enrico Fermi patents first reactor (conceptual plans).
1942	The Manhattan Project is formed to secretly build the atomic bomb before the Germans.
1942	Enrico Fermi demonstrates the first self-sustaining nuclear chain reaction in a lab at the University of Chicago.
1946	Atomic Energy Act is passed; establishes Atomic Energy Commission.
1946	The U.S. Advisory Committee was reorganized and renamed the National Committee on Radiation Protection and operating out of the Bureau of Standards.
1951	First electricity is generated from atomic power at EBR-1 Idaho National Engineering Lab, Idaho Falls.
1954	Atomic Energy Act of 1954 is passed to promote the peaceful uses of nuclear energy through private enterprises and to implement President Eisenhower's Atoms for Peace Program.
1954	The first nuclear submarine, U.S.S. Nautilus, is launched.
1955	Arco, Idaho becomes the fist U.S. town to be powered by nuclear energy.
1957	The first U.S. large-scale nuclear power plant begins operating in Shipingport, Pennsylvania.
1957	United Nations establishes the International Atomic Energy Agency (IAEA)

Appendix

Brief Chronology of Radioactive Materials and Radioactive Waste in the United States

1958	Bureau of Radiological Health organized within US Public Health Service.
1959	Federal Radiation Council (FRC) formed to advise the US President about radiation matters, especially standards.
1962	The first commercial low-level waste disposal site was established in Beatty, Nevada.
1968	Nuclear Nonproliferation Treaty calling for halting the spread of nuclear weapons capabilities is signed.
1970	U.S. Environmental Protection Agency is formed. Responsibilities include radiation protection.
1970	National Environmental Policy Act is signed requiring the Federal government to review the environmental impact of any action - such as construction of a facility - that might significantly affect the environment.
1971	Six commercial low-level waste sites operating.
1972	Computer axial tomography, commonly known as CAT scanning, is introduced. A CAT scan combines many high-definition cross-sectional X-rays to produce a two-dimensional image of a patients anatomy.
1972	AEC reveals that since 1946 radioactive waste was dumped off shore of US coast; biggest dumps near San Francisco, CA, 47,500 55-gallon drums.
1974	Atomic Energy Commission is abolished and the Nuclear Regulatory Commission and the Energy Research and Development Administration are established.
1975	West Valley, New York low-level waste site closed after water overflowed from two of its burial trenches.
1976	The Resource Conservation and Recovery Act (RCRA) is passed to protect human health and the environment from the potential hazards of waste disposal.
1977	The U.S. Department of Energy replaces the Energy Research and Development Administration.
1977	Maxey Flats, Kentucky low-level waste site closed after some radioactive materials migrated from the site and the state imposed additional sur charges making disposal uneconomical.
1978	Sheffield, Illinois low-level waste site closed after reaching capacity.
1979	Three Mile Island (Middletown, Pa) nuclear power plant suffers hydrogen explosions and a partial core meltdown.
1979	Beaty, Nevada and Richland, Washington low-level waste sites closed temporarily because damaged and leaking nuclear waste containers were being delivered.
1980	The Low-Level Radioactive Waste Policy Act is passed, making states responsible for the disposal of their own low-level nuclear waste, such as from the hospitals and industry.
1980	The Comprehensive Environmental Response, Compensation, and Liability Act (also known as Super fund) is passed in response to the discovery in the late 1970s of a large number of abandoned, leaking hazardous waste dumps.
1983	The Nuclear Waste Policy Act of 1982 is signed, authorizing the development

	of a high-level nuclear waste repository.
1985	Because no low-level waste state compacts had yet been ratified or sites selected, Congress amended the act to create siting milestones, deadlines for compliance, and penalties for failure to meet the deadlines. It provided that on Jan. 1, 1993, the three states with sites (Washington, South Carolina and Nevada) could refuse to accept low-level waste generated outside their borders by states that are not in their respective compacts.
1986	Chernobyl Nuclear Reactor meltdown and fire occur in the Soviet Union. Much radioactive material is released.
1987	Nuclear Waste Policy Amendments Act designates Yucca Mountain, Nevada, for scientific investigation as only candidate site for the US's first geological repository for high-level radioactive waste and spent nuclear fuel.
1989	DOE changes its focus from nuclear materials production to environmental cleanup by forming the Office of Environmental Restoration and Waste Management.
1991	The United States and Soviet Union sign historic agreement to cut back on long-range nuclear weapons by ore than 30 percent over the next seven years.
1992	The Waste Isolation Pilot Plant (WIPP) Land Withdrawal Act withdraws public lands for WIPP, a test repository for transuranic nuclear waste located in a salt deposit deep under the desert.
1993	The Beatty, Nevada, low-level waste site closed to low-level waste.
1996	The United Nations approves the Comprehensive Test Ban Treaty which bans nuclear test explosions
1999	An accident at the uranium processing plant at Tokaimura, Japan, exposed fifty-five workers to radiation. One worker later dies.
1999	The Waste Isolation Pilot Plant began receiving shipments of transuranic waste.

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Appendix E: Major Uses of Radioisotopes

Appendix

Major Uses of Radioisotopes

Americium-241 – Used in many smoke detectors for homes and businesses ... to measure levels of toxic lead in dried paint samples ... to ensure uniform thickness in rolling processes like steel and paper production ... and to help determine where oil wells should be drilled.

Cadmium-109 – Used to analyze metal alloys for checking stock, scrap sorting.

Calcium-47 – Important aid to biomedical researchers studying the cellular functions and bone formation in mammals.

Californium-252 – Used to inspect airline luggage for hidden explosives ... to gauge the moisture content of soil in the road construction and building industries ... and to measure the moisture of materials stored in soils.

Carbon-14 – Major research tool. Helps in research to ensure that potential new drugs are metabolized without forming harmful by-products. Used in biological research, agriculture, pollution control, and archeology.

Cesium-137 – Used to treat cancerous tumors ... to measure correct patient dosages of radioactive pharmaceuticals ... to measure and control the liquid flow in oil pipelines ... to tell researchers whether oil wells are plugged by sand ... and to ensure the right fill level for packages of food, drugs and other products. (The products in these packages do not become radioactive.)

Chromium-51 – Used in research in red blood cell survival studies.

Cobalt-57 – Used as a tracer to diagnose pernicious anemia.

Cobalt-60 – Used to sterilize surgical instruments ... and to improve the safety and reliability of industrial fuel oil burners. Used in cancer treatment, food irradiation, gauges, and radiography.

Copper-67 – When injected with monoclonal antibodies into a cancer patient, helps the antibodies bind to and destroy the tumor.

Curium-244 – Used in mining to analyze material excavated from pits ... and slurries from drilling operations.

Gallium-67 – Used in medical diagnosis.

Iodine-123 – Widely used to diagnose thyroid disorders and other metabolic disorders including brain function.

Iodine-125 – Major diagnostic tool used in clinical tests and to diagnose thyroid disorders. Also used in biomedical research.

Iodine-129 – Used to check some radioactivity counters in in vitro diagnostic testing laboratories.

Iodine-131 – Used to treat thyroid disorders. (Former President George Bush and Mrs. Bush were both successfully treated for

Graves' disease, a thyroid disease, with iodine- 131.)

Iridium-192 – Used to test the integrity of pipeline welds, boilers and aircraft parts and in brachytherapy/tumor irradiation.

Iron-55 – Used to analyze electroplating solutions and to detect the presence of sulphur in the air. Used in metabolism research.

Krypton-85 – Used in indicator lights in appliances such as clothes washers and dryers, stereos, and coffee makers ... to gauge the thickness of thin plastics and sheet metal, rubber, textiles and paper... and to measure dust and pollutant levels.

Nickel-63 – Used to detect explosives, and in voltage regulators and current surge protectors in electronic devices, and in electron capture detectors for gas chromatographs.

Phosphorus-32 – Used in molecular biology and genetics research.

Phosphorus-33 – Used in molecular biology and genetics research.

Plutonium-238 – Has powered more than 20 NASA spacecraft since 1972.

Polonium-210 – Reduces the static charge in production of photographic film and other materials.

Promethium-147 – Used in electric blanket thermostats ... and to gauge the thickness of thin plastics, thin sheet metal, rubber, textile and paper.

Radium-226 – Makes lightning rods more effective.

Selenium-75 – Used in protein studies in life science research.

Sodium-24 – Used to locate leaks in industrial pipe lines and in oil well studies.

Strontium-85 – Used to study bone formation and metabolism.

Sulphur-35 – Used in survey meters by schools, the military and emergency management authorities. Also used in cigarette manufacturing sensors and medical treatment.

Technetium-99m – Used in genetics and molecular biology research. The most widely used radioactive pharmaceutical for diagnostic studies in nuclear medicine. Different chemical forms are used for brain, bone, liver, spleen and kidney imaging and also for blood flow studies.

Thallium-201 – Used in nuclear medicine for nuclear cardiology and tumor detection.

Thallium-204 – Measures the dust and pollutant levels on filter paper ... and gauges the thickness of plastics, sheet metal, rubber, textiles and paper.

Thoriated Tungsten – Used in electric arc welding rods in construction, aircraft, petrochemical and food processing equipment industries. They produce easier starting, greater arc stability and less metal contamination.

Thorium-229 – Helps fluorescent lights last longer.

Thorium-230 – Provides coloring and fluorescence in colored glazes and glassware.

Tritium – Major tool for biomedical research. Used for life science and drug metabolism studies to ensure the safety of potential new drugs ... for self-luminous aircraft and commercial exit signs ... for luminous dials, gauges and wrist watches ... to produce luminous paint, and for geological prospecting and hydrology.

Uranium-234 – Used in dental fixtures like crowns and dentures to provide a natural color and brightness.

Uranium-235 – Fuel for nuclear power plants and naval nuclear propulsion systems … and used to produce fluorescent glassware, a variety of colored glazes and wall tiles.

Xenon-133 – Used in nuclear medicine for lung ventilation and blood flow studies.

Source: U.S. Nuclear Regulatory Commission, “The Regulation and Use Of Radioisotopes in Today's World” (NUREG/BR-0217)

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