**Radiation and Its Health Effects**

Radiation Basics

Detecting Radiation

Measuring Radiation

Information for Radiation Workers

High Radiation Doses

Radiation Exposure and Cancer



# Radiation Basics

Radiation is energy given off by matter in the form of rays or high-speed particles. All matter is composed of atoms. Atoms are made up of various parts; the nucleus contains minute particles called protons and neutrons, and the atom's outer shell contains other particles called electrons. The nucleus carries a positive electrical charge, while the electrons carry a negative electrical charge. These forces within the atom work toward a strong, stable balance by getting rid of excess atomic energy (radioactivity). In that process, unstable nuclei may emit a quantity of energy, and this spontaneous emission is what we call radiation.

For additional information, see the following topics on this page:

- Physical Forms of Radiation
- Radioactive Decay
- Nuclear Fission
- Ionizing Radiation
  - Alpha Particles
  - Beta Particles
  - Gamma Rays and X-Rays
  - Neutrons

## Physical Forms of Radiation

As previously indicated, matter gives off energy (radiation) in two basic physical forms. One form of radiation is pure energy with no weight. This form of radiation — known as electromagnetic radiation — is like vibrating or pulsating rays or "waves" of electrical and magnetic energy. Familiar types of electromagnetic radiation include sunlight (cosmic radiation), x-rays, radar, and radio waves.

The other form of radiation — known as particle radiation — is tiny fast-moving particles that have both energy and mass (weight). This less-familiar form of radiation includes alpha particles, beta particles, and neutrons, as explained below.

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## Radioactive Decay

As previously indicated, large unstable atoms become more stable by emitting radiation to get rid of excess atomic energy (radioactivity). This radiation can be emitted in the form of positively charged alpha particles, negatively charged beta particles, gamma rays, or x-rays, as explained below.

Through this process — called radioactive decay — radioisotopes lose their radioactivity over time. This gradual loss of radioactivity is measured in half-lives. Essentially, a half-life of a radioactive material is the time it takes one-half of the attoms of a radioisotope to decay by emitting radiation. This time can range from fractions of a second (for radon-220) to millions of

years (for thorium-232). When radioisotopes are used in medicine or industry, it is vital to know how rapidly they lose their radioactivity, in order to know the precise amount of radioisotope that is available for the medical procedure or industrial use.

TOP

## Nuclear Fission

In some elements, the nucleus can split as a result of absorbing an additional neutron, through a process called nuclear fission. Such elements are called fissile materials. One particularly notable fissile material is uranium-235. This is the isotope that is used as fuel in commercial nuclear power plants.

When a nucleus fissions, it causes three important events that result in the release of energy. Specifically, these events are the release of radiation, release of neutrons (usually two or three), and formation of two new nuclei (fission products).

TOP

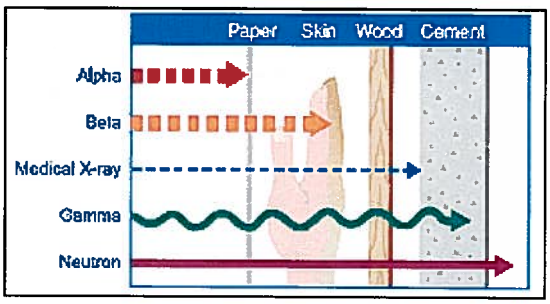
## Ionizing Radiation

Radiation can be either ionizing or non-ionizing, depending on how it affects matter. Non-ionizing radiation includes visible light, heat, radar, microwaves, and radio waves. This type of radiation deposits energy in the materials through which it passes, but it does not have sufficient energy to break molecular bonds or remove electrons from atoms.

By contrast, ionizing radiation (such as x-rays and cosmic rays) is more energetic than non-ionizing radiation. Consequently, when ionizing radiation passes through material, it deposits enough energy to break molecular bonds and displace (or remove) electrons from atoms. This electron displacement creates two electrically charged particles (ions), which may cause changes in living cells of plants, animals, and people.

Ionizing radiation has a number of beneficial uses. For example, we use ionizing radiation in smoke detectors and to treat cancer or sterilize medical equipment. Nonetheless, ionizing radiation is potentially harmful if not used correctly. Consequently, the U.S. Nuclear Regulatory Commission (NRC) strictly regulates commerical and institutional uses of nuclear materials, including the following five major types of ionizing radiation:

- Alpha Particles
- Beta Particles
- Gamma Rays and X-Rays
- Neutrons




TOP

## Alpha Particles

Alpha particles are charged particles, which are emitted from naturally occurring materials (such as uranium, thorium, and radium) and man-made elements (such as plutonium and americium). These alpha emitters are primarily used (in very small amounts) in items such as smoke detectors.

In general, alpha particles have a very limited ability to penetrate other materials. In other words, these particles of ionizing radiation can be blocked by a sheet of paper, skin, or even a few inches of air. As a result, alpha particles do not usually make anything radioactive.

Nonetheless, materials that emit alpha particles are potentially dangerous if they are inhaled or swallowed, but external exposure generally does not pose a danger.

TOP

## Beta Particles

Beta particles, which are similiar to electrons, are emitted from naturally occurring materials (such as strontium-90). Such beta emitters are used in medical applications, such as treating eye disease.

In general, beta particles are lighter than alpha particles, and they generally have a greater ability to penetrate other materials. As a result, these particles can travel a few feet in the air, and can penetrate skin. Nonetheless, a thin sheet of metal or plastic or a block of wood can stop beta particles. As a result, like alpha particles, they do not usually make things radioactive.

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## Gamma Rays and X-Rays

Gamma rays and x-rays consist of high-energy waves that can travel great distances at the speed of light and generally have a great ability to penetrate other materials. For that reason, gamma rays (such as from cobalt-60) are often used in medical applications to treat cancer and sterilize medical instruments. Similarly, x-rays are typically used to provide static images of body parts (such as teeth and bones), and are also used in industry to find defects in welds.

Despite their ability to penetrate other materials, in general, neither gamma rays nor x-rays have the ability to make anything radioactive. Several feet of concrete or a few inches of dense material (such as lead) are able to block these types of radiation.

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## Neutrons

Neutrons are high-speed nuclear particles that have an exceptional ability to penetrate other materials. Of the five types of ionizing radiation discussed here, neutrons are the only one that can make objects radioactive. This process, called neutron activation, produces many of the radioactive sources that are used in medical, academic, and industrial applications (including oil exploration).

Because of their exceptional ability to penetrate other materials, neutrons can travel great distances in air and require very thick hydrogen-containing materials (such as concrete or water) to block them. Fortunately, however, neutron radiation primarily occurs inside a nuclear reactor, where many feet of water provide effective shielding.

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*Wednesday, October 20, 2010*

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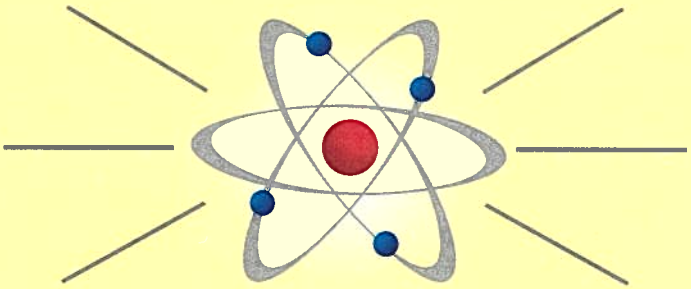
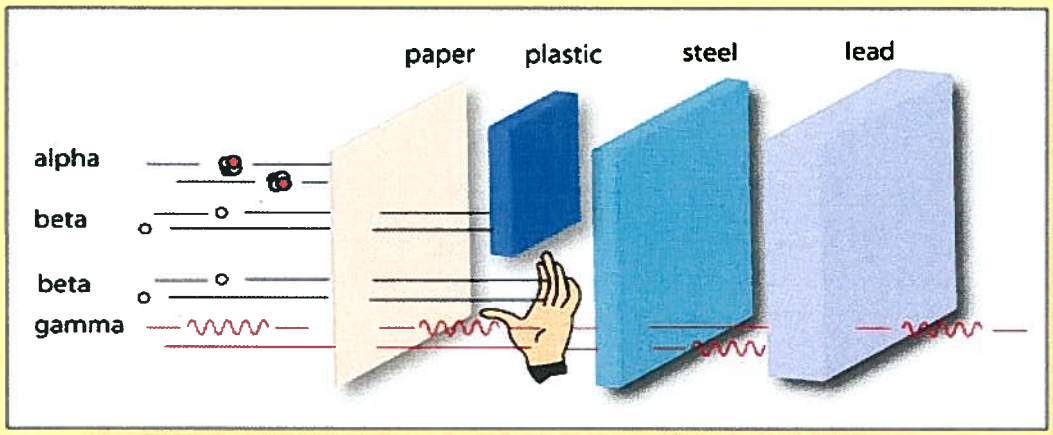
*Protecting People and the Environment*

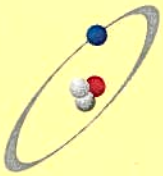
# WHAT IS RADIATION?

**Radiation is energy given off (radiated) from an unstable atom.**



**Types of Radiation include alpha, beta, gamma, and neutrons.**



**Tritium (radioactive hydrogen) emits weak beta radiation.**

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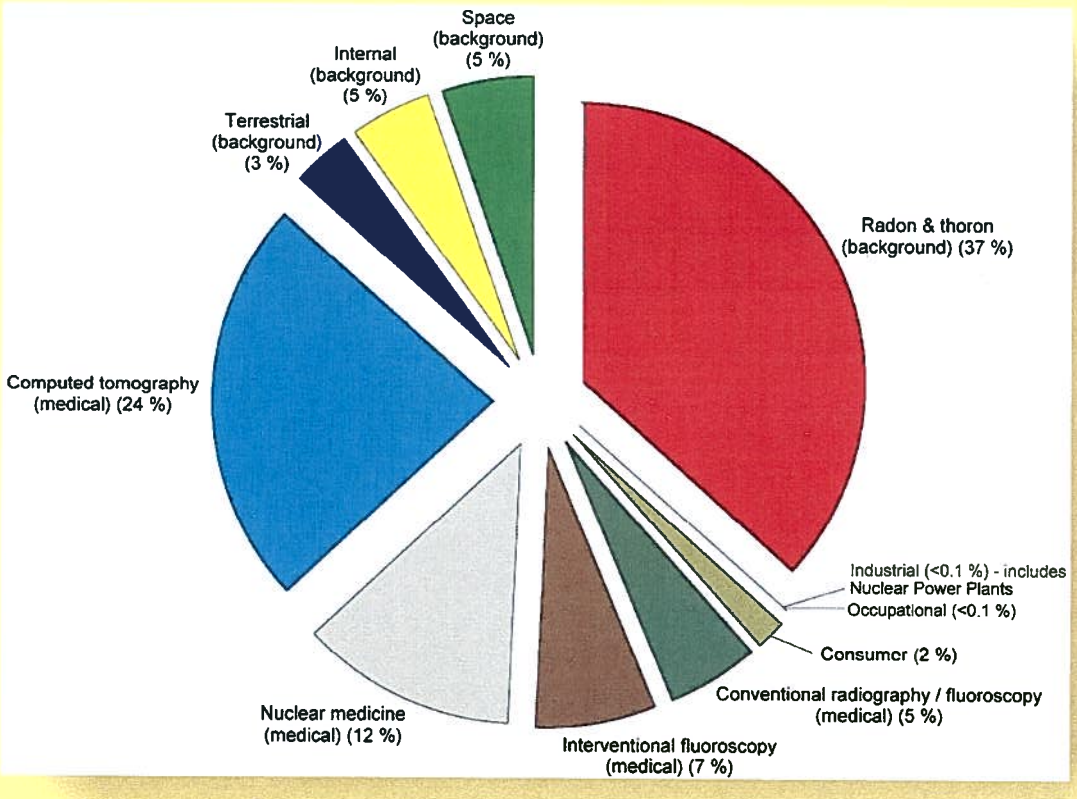
# US AVERAGE YEARLY RADIATION DOSE

**620 MREM PER YEAR**
**50% Natural Background, 48% Medical, 2% Other**




National Council on Radiation Protection Publication 160

**Consumer includes cigarette smoking, building materials, and air travel.**
**Internal is dose from our own bodies (natural Potassium 40, Tritium, and Carbon 14).**

**Radiation Protection**

Radiation All Around Us

Radiation and Its Health Effects

How NRC Protects You

Radiation and National Security

Related Information



# Radiation and Its Health Effects

More than 100 years ago, scientists discovered that many elements commonly found on Earth occur in different configurations at the most basic (atom) level. These various configurations (called isotopes) have identical chemical properties, but different physical properties. In particular, some isotopes (known as radioisotopes) are radioactive, meaning that they emit energy in several different forms. This energy emission is what we call radiation.

Over time, we have come to think of radiation in terms of its biological effect on living cells. For low levels of radiation exposure, these biological effects are so small that they may not even be detectable. In addition, the human body has defense mechanisms against many types of damage induced by radiation. Consequently, radiation may have one of three biological effects, with distinct outcomes for living cells: (1) injured or damaged cells repair themselves, resulting in no residual damage; (2) cells die, much like millions of body cells do every day, being replaced through normal biological processes; or (3) cells incorrectly repair themselves, resulting in a biophysical change.

The exact effect depends on the specific type and intensity of the radiation exposure. In general, however, a 3-millirem exposure imposes the same chance of death — 1 in a million — as each of the following common life experiences:

- Spending 2 days in New York City (because of the air quality)

- Riding 1 mile on a motorcycle or 300 miles in a car (because of the risk of collision)

- Eating 40 tablespoons of peanut butter (because of aflotoxin) or 10 charbroiled steaks

- Smoking 1 cigarette

## Measuring Radiation's Effects

| Activity | Millirems |
|---|---|
| Typical yearly dose, all sources | 360.00 |
| Full set of dental X-rays | 40.00 |
| Chest X-ray | 8.00 |
| Flying round-trip from D.C. To Los Angeles | 5.00 |
| Living outside nuclear power plant for a year | 0.10 |

| Health risk | Expected life lost |
|---|---|
| Smoking a pack of cigarettes a day | 6 years |
| Being 15 percent overweight | 2 years |
| Working in construction | 227 days |
| Working in nuclear plant (1,000 mrem/yr) | 51 days |
| Typical annual background radiation dose (360 mrem/yr) | 19 days |

For additional information, see the following topics:

- Radiation Basics
- Detecting Radiation
- Measuring Radiation
- Information for Radiation Workers
- High Radiation Doses
- Radiation Exposure and Cancer

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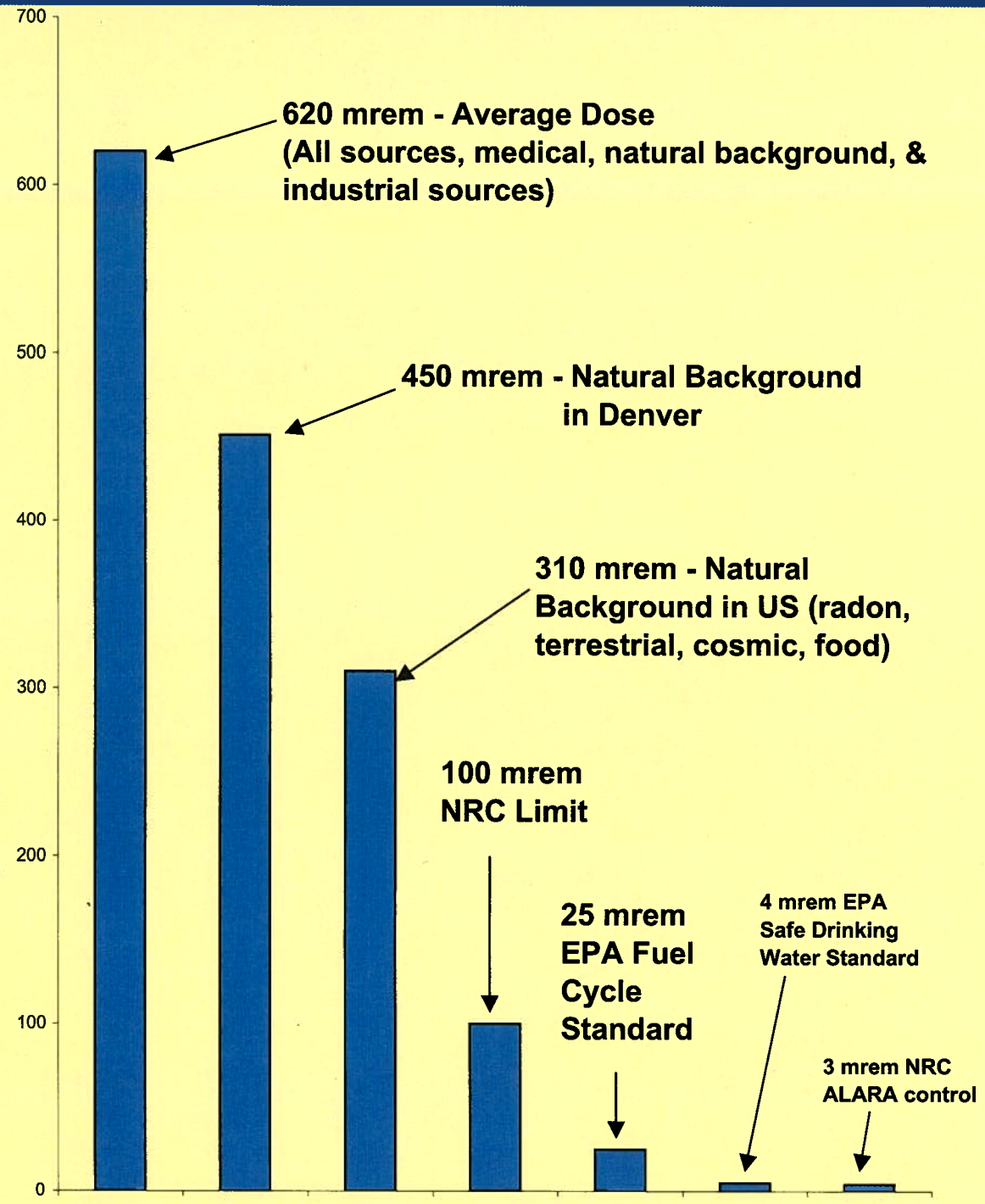
*Wednesday, October 20, 2010*

# BACKGROUND RADIATION COMPARED TO SAFETY STANDARDS



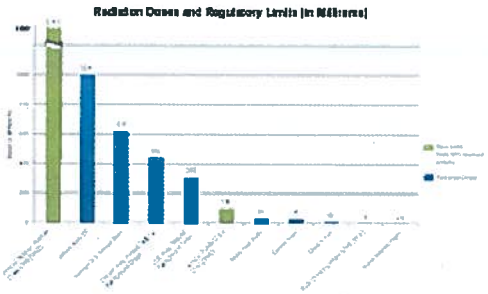

Dose from groundwater contamination is zero or very close to zero.

Radiation All Around Us
Sources of Radiation
Uses of Radiation
Doses in Our Daily Lives

Home > About NRC > Radiation Protection > Radiation All Around Us > Doses in Our Daily Lives

# Doses in Our Daily Lives

On average, Americans receive a radiation dose of about 0.62 rem (620 millirem) each year. Half of this dose comes from natural background radiation. Most of this background exposure comes from radon in the air, with smaller amounts from cosmic rays and the Earth itself. (The chart to the right shows these radiation doses in perspective.) The other half (0.31 rem or 310 mrem) comes from man-made sources of radiation, including medical, commercial, and industrial sources. In general, a yearly dose of 620 millirem from all radiation sources has not been shown to cause humans any harm.




View Larger Image

On this page:

- Doses from Medical Procedures
- Radioactivity in Food
- Personal Annual Radiation Dose Calculator

## Doses from Medical Procedures

| Medical Procedure Doses | |
|---|---|
| **Procedure** | **Dose (mrem)** |
| X-Rays-single exposure | |
| Pelvis | 70 |
| Abdomen | 60 |
| Chest | 10 |
| Dental | 1.5 |
| Hand/Foot | 0.5 |
| Mammogram (2 views) | 72 |
| Nuclear Medicine | 400 |
| CT | |
| Full body | 1,000 |
| Chest | 700 |
| Head | 200 |

Medical procedures account for nearly all (96%) human exposure to man-made radiation. For example, a chest x-ray typically gives a dose of about 0.01 rem (10 millirem) and a full-body CT gives a dose of 1 rem (1,000 mrem), as shown in the table to the left.

Among these medical procedures, x-rays, mammography, and CT use radiation or perform functions similar to those of radioisotopes. However, they do not involve radioactive material and, hence, are not regulated by the U.S. Nuclear Regulatory Commission (NRC). Instead, most of these procedures are regulated by State health agencies. In fact, among these procedures, the NRC and its Agreement States only license and regulate the possession and use of radioactive materials for nuclear medicine.

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## Radioactivity in Food

All organic matter (both plant and animal) contains some small amount of radiation from radioactive potassium-40 ($^{40}K$), radium-226 ($^{226}Ra$), and other isotopes. In addition, all water on Earth contains small amounts of dissolved uranium and thorium. As a result, the average person receives an average internal dose of about 30 millirem of these materials per year from the food and water that we eat and drink, as illustrated by the following table. (Amounts are shown in picocuries per kilogram.)

| Natural Radioactivity in Food | | |
|---|---|---|
| **Food** | **$^{40}K$ (pCi/kg)** | **$^{226}Ra$ (pCi/kg)** |
| Bananas | 3,520 | 1 |
| Carrots | 3,400 | 0.6 - 2 |
| White Potatoes | 3,400 | 1 - 2.5 |
| Lima Beans (raw) | 4,640 | 2 - 5 |
| Red Meat | 3,000 | 0.5 |
| Brazil Nuts | 5,600 | 1,000 - 7,000 |
| Beer | 390 | --- |
| Drinking Water | --- | 0 - 0.17 |

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## Personal Annual Radiation Dose Calculator

We live in a radioactive world, and radiation has always been all around us as a part of our natural environment. As explained above, the annual average dose per person from all sources is about 360 mrem, but it is not uncommon for any of us to receive more than that average does in a given year (largely as a result of medical procedures). To find your personal annual radiation dose, use the interactive Personal Annual Radiation Dose Calculator or this printer friendly worksheet.

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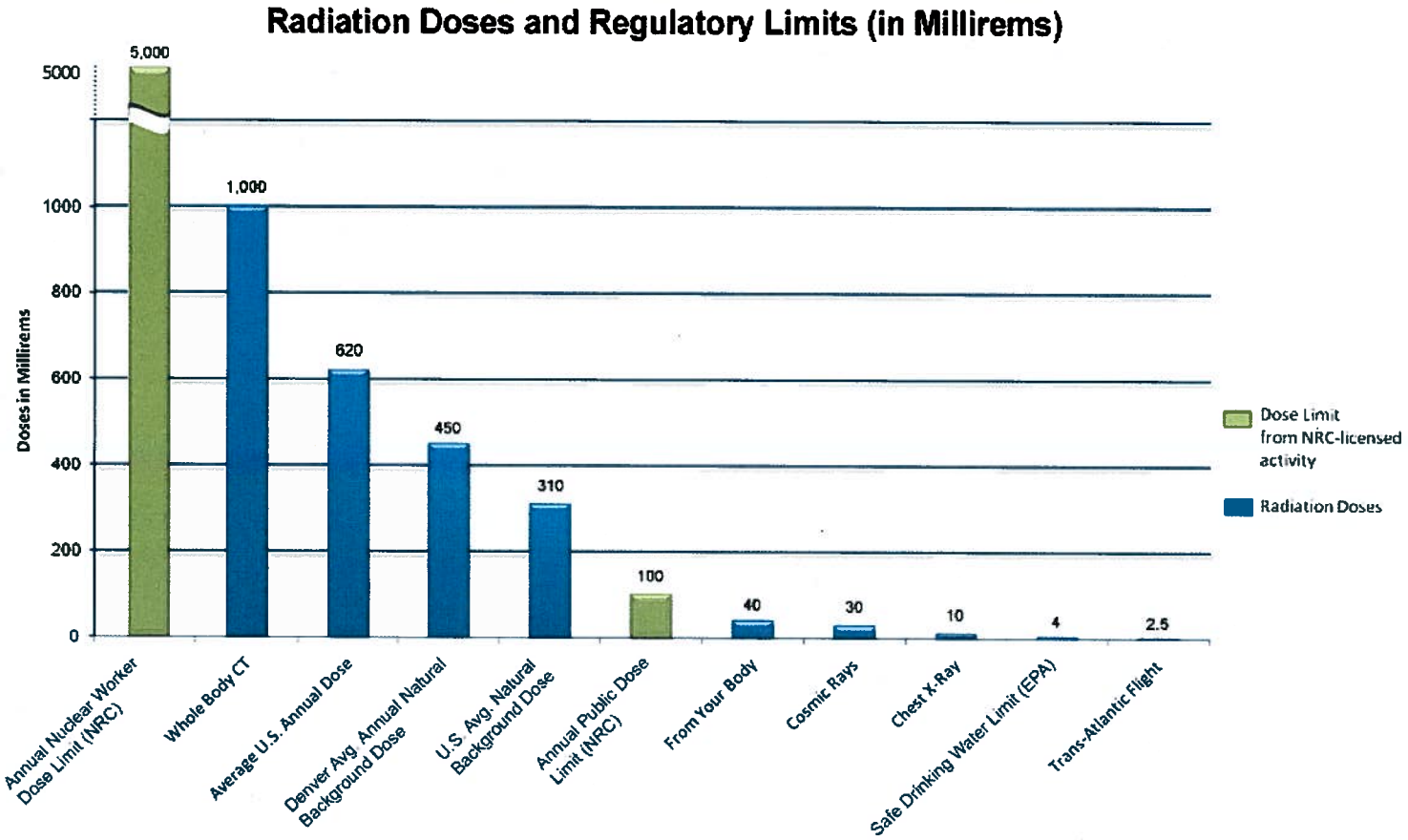
Radiation Doses and Regulatory Limits (in Millirems)
Doses in Millirems
5000
1000
800
600
400
200
0
5,000
1,000
620
450
310
100
40
30
10
4
2.5
Annual Nuclear Worker Dose Limit (NRC)
Whole Body CT
Average U.S. Annual Dose
Denver Avg. Annual Natural Background Dose
U.S. Avg. Natural Background Dose
Annual Public Dose Limit (NRC)
From Your Body
Cosmic Rays
Chest X-Ray
Safe Drinking Water Limit (EPA)
Trans-Atlantic Flight
Dose Limit from NRC-licensed activity
Radiation Doses

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Protecting People and the Environment

# Natural Radioactivity in Everyday Life

## Salt Substitute

415,000 pCi/l, Potassium-40

900 pCi/l, Potassium-40
205 pCi Potassium-40 per Orange

Naturally occurring radioactive materials are in air, water, soil, and the foods we eat.

## Broccoli

1,200 pCi/kg Potassium-40
6,000 pCi/kg, Carbon-14

## Seawater

300 pCi/l, Potassuim-40
2 to 8 pCi/l, Tritium

## Soil

1,000 to 30,000 pCi/l,
Potassium-40

## Beer

390 pCi/l,
Potassium-40

## Milk

2,000 pCi/l,
Potassium-40

## Granite

1700 pCi/l,
Potassium-40

## Person

100,000 pCi Potassium-40 = 18 mrem/yr
1,430 pCi/kg, Carbon-14
620 pCi H-3 (about 9 pCi/kg)

**Radiation All Around Us**

Sources of Radiation

Uses of Radiation

Doses in Our Daily Lives

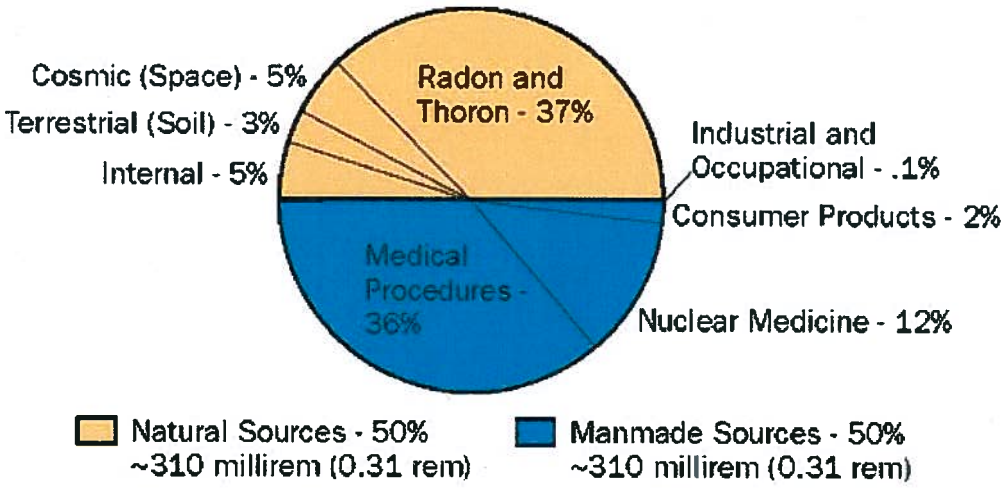


# Sources of Radiation

Since the beginning of time, all living creatures have been, and are still being, exposed to radiation. Nonetheless, most people are not aware of all the natural and man-made sources of radiation in our environment.

A chart of the public's exposure to ionizing radiation (displayed below) shows that people generally receive a total annual dose of about 620 millirem. Of this total, natural sources of radiation account for about 50 percent, while man-made sources account for the remaining 50 percent.

**Sources of Radiation Exposure in the United States**




Source: NCRP Report No.160(2009)
Full report is available on the NCRP Web site at www.NCRPpublications.org

For additional information, see the following topics:

- Natural Background Sources
- Man-Made Sources

**Nuclear Materials**

Special Nuclear Material

Source Material

Byproduct Material

Medical, Industrial, and Academic Uses of Nuclear Materials

Source Material Facilities

Uranium Recovery Facilities

Fuel Cycle Facilities

Materials Transportation



# Medical, Industrial, and Academic Uses of Nuclear Materials

**Recent Info**

- Medical Use Licensing (Part 35) and Toolkit
- Enforcement Actions

**Regulatory Initiatives**

- General License Registration and Tracking
- Rulemaking Dockets

**Licensee Toolkits**

- See our toolkit index page

## What We Regulate

NRC and the Agreement States regulate the following activities associated with medical, industrial, and academic uses of nuclear materials. The Agreement States administer about 75 percent of licensees while NRC administers the remainder of the licensees.

- Sealed Sources and Devices - NRC and the Agreement States perform safety evaluations of the ability of sealed sources and devices to safely contain radioactivity under the conditions of their possession and use. These evaluations are summarized in registrations that NRC maintains in the National Sealed Source and Device Registry.
- Product Manufacturing and Distribution - issuance of licenses authorizing commercial distribution of products containing radioactive materials to other licensees and members of the public.
- Medical Uses - use of nuclear materials to monitor, image, or treat metabolic processes or tissues in humans.
- Veterinary Uses - use of nuclear materials to treat animals
- Industrial Uses - the use of nuclear materials in industrial devices such as, irradiators, gauging devices, well-logging devices, and industrial radiography systems.
- Academic and Research Uses - use of nuclear materials in universities, colleges, and other academic institutions for course work, laboratory demonstrations, and research.
- General License Uses - commercial use of nuclear materials by general licensees for activities such as measuring, gauging, or controlling devices, etc.
- Exempt Consumer Product Uses - products containing radioactive materials whose use is exempt from regulation and that are available in the marketplace to the public.

## How We Regulate

NRC regulates medical, industrial, and academic uses of nuclear materials through a combination of regulatory requirements; licensing; safety oversight, including inspection and enforcement; operational experience evaluation; and regulatory support activities. For information on the first three components that applies generally to medical, industrial, and academic uses, see:

- Regulations, Guidance, and Communications
- Licensing
- Inspection

See the How We Regulate page for general information on these activities. Specific information is provided in the licensee toolkits for each regulated activity.

## Related Information

- The Regulation and Use of Radioisotopes in Today's World (NUREG/BR-0217)
- Advisory Committee on the Medical Uses of Isotopes (ACMUI)
- Memorandum of Understanding Between NRC and Food and Drug Administration
- Pa'ina Irradiator
- Public Availability of Material Licensing Applications

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**Medical, Industrial, and Academic Uses of Nuclear Materials**

Sealed Sources and Devices

Product Manufacturing and Distribution

Medical Uses

Veterinary Uses

Industrial Uses

Academic Uses

General License Uses

Exempt Consumer Product Uses

Regulations, Guidance, and Communications

Licensing

Inspection



# Medical Uses of Nuclear Materials

Medical Uses Licensee Toolkit

On this page:

- Role of NRC and Other Agencies in Regulating the Medical Use of Nuclear Materials
- Types of Medical Use Regulated by NRC and Agreement States
  - Diagnostic medical use
  - Therapeutic medical use
  - Medical research use
  - Certain in vitro diagnostic tests (see also General License Uses page)

See also:

Advisory Committee on the Medical Uses of Isotopes (ACMUI)

## Role of NRC and Other Agencies in Regulating the Medical Use of Nuclear Materials

Regulatory authority over the medical use of ionizing radiation is shared among several Federal, state, and local government agencies. NRC (or the responsible Agreement State) has regulatory authority over the possession and use of byproduct, source, or special nuclear material in medicine. Byproduct material is used in some calibration sources, radioactive drugs, bone mineral analyzers, portable fluoroscopic imaging devices, brachytherapy sources and devices, gamma stereotactical surgery devices, and teletherapy units used in medicine. Source material is used for radiation shielding and counterweights in medical devices. A few cardiac pacemakers are still powered by special nuclear material batteries.

With the exception of the use of 1 microcurie carbon-14 urea radioactive drug capsules for in vivo diagnostic use in humans, all internal or external administrations of byproduct material or the radiation therefrom to human patients or human research subjects must be done in accordance with a medical use license (or authorization) issued pursuant to NRC's regulations in 10 CFR Part 35, "Medical Use." NRC licenses the medical use of byproduct materials in diagnostic devices in the practices of dentistry and podiatry. The medical use of plutonium in nuclear powered pacemakers is licensed pursuant to 10 CFR Part 70.

NRC (or the responsible Agreement State) also regulates the manufacture and distribution of these products (see Medical Products Distribution Licensee Toolkit). The Food and Drug Administration oversees the good practices in the manufacturing of radiopharmaceuticals, medical devices, and radiation-producing x-ray machines and accelerators. The states regulate the practices of medicine and pharmacy and administer programs associated with radiation-producing x-ray machines and accelerators.

NRC oversees medical uses of nuclear material through licensing, inspection, and enforcement programs. NRC issues medical use licenses to medical facilities and authorized physician users, develops guidance and regulations for use by licensees, and maintains a committee of medical experts to obtain advice about the use of byproduct materials in medicine. The Advisory Committee on the Medical Uses of Isotopes (ACMUI), comprised of physicians, scientists, and

other health care professionals, meets twice a year to be briefed by, and provide advice to, the NRC staff on current initiatives in the medical uses of radioactive materials.

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## Types of Medical Use Regulated by NRC and Agreement States

### Diagnostic medical use

Use of nuclear materials in radioactive uptake, dilution, excretion, imaging, or localization diagnostic clinical or research procedures. The metabolic or physiological properties of radiolabeled drugs are used to obtain medical information, and the radiation produced from sealed sources are used in diagnostic devices to image body parts or determine tissue density. Diagnostic medical use includes the use of certain portable imaging devices in dentistry and podiatry, as well as bone mineral analysis devices in podiatry.

### Therapeutic medical use

Use of nuclear materials to deliver palliative (pain relieving) or therapeutic doses of radiation to specific tissues or body areas. Although most therapeutic uses of radiation involve the treatment of cancer, therapeutic doses may also be used to treat benign conditions such as the use of intervascular brachytherapy radiation to treat clogged blood vessels (restenosis).

### Medical research use

Research involving human subjects using byproduct materials may only be performed if the licensee has a 10 CFR Part 35 medical use authorization. There are a wide variety of research uses of nuclear materials in human subjects. They include the use of nuclear materials in well-established nuclear medicine procedures to monitor a human research subject's response to a nonradioactive drug or device treatment as well as clinical trials to determine the safety or effectiveness of new radioactive drugs and devices. The particular medical research use must conform with the requirements in 10 CFR Part 35 and the possession and medical use authorizations in the license.

### Certain in vitro diagnostic tests

Some medical facilities or private physicians may only have regulated material in the form of prepackaged in vitro diagnostic test kits. These facilities and physicians do not have "medical use" licenses because these materials are not regulated pursuant to 10 CFR Part 35. The amount of regulated materials used in this form of in vitro diagnostic testing determines whether its use is authorized by a specific license issued pursuant to 10 CFR Part 30 or a general license pursuant to 10 CFR Part 31.11. See the General License Uses page for those materials generally licensed pursuant to 10 CFR 31.11.

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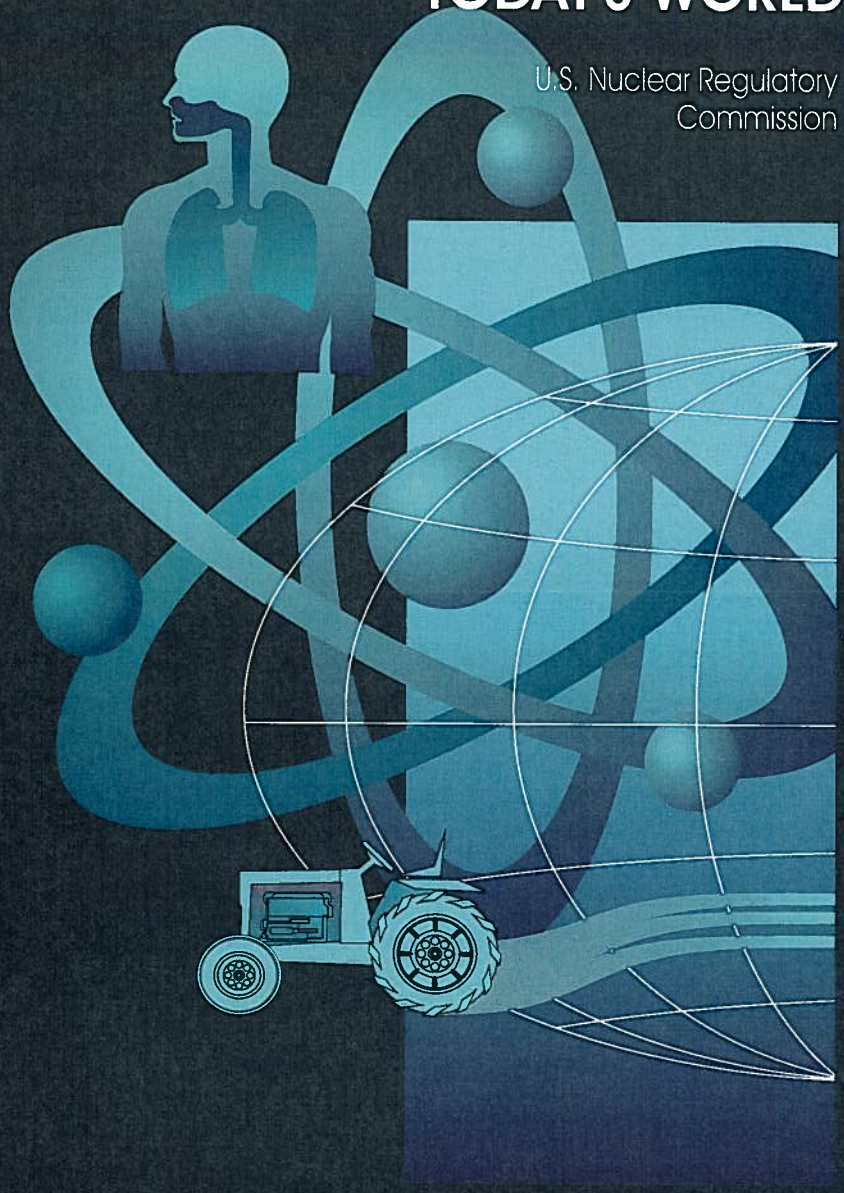
# THE REGULATION AND USE OF RADIOISOTOPES IN TODAY'S WORLD

U.S. Nuclear Regulatory Commission



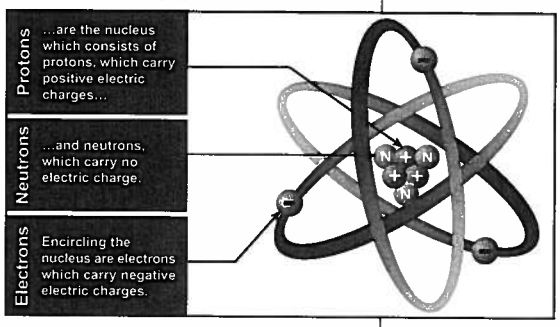
# Introduction

More than 100 years ago, scientists discovered that many elements commonly found on earth occur in different atomic configurations. These varying configurations, called **isotopes**, were found to have identical electronically charged particles and identical chemical properties, but different atomic weights and physical properties.

It was soon discovered that some isotopes of elements were radioactive. The dense central portion (called the **nucleus**) of an atom of the element emits energy in several different forms. Radioisotopes are simply atoms with nuclei that are seeking a more stable nuclear configuration by emitting radiation. Scientists have learned that more radioisotopes could be created by subjecting certain elements to radiation inside a nuclear reactor or bombarding them using a particle accelerator.

Gradually we have learned to harness these radioisotopes for use in our modern, high-tech world. In this brochure are described some of the most common uses for radioisotopes, as well as the relative benefits and hazards involved in their applications. The appendix at the end of this brochure describes various uses of radioisotopes in this country.

**INSIDE THE ATOM**




Also explained are the properties of radiation that enable it to change the physical characteristics of certain materials. Because they emit tell-tale ionizing radiation, extremely small quantities of radioisotopes can be traced and measured using special equipment. This property makes them a useful diagnostic tool in medicine. The radiation from some radioisotopes can penetrate thick metal parts and provide a way to "see" inside objects that are impenetrable to light. Radiation deposits sufficient energy in human tissue to disrupt normal cell function as it passes through, thus providing a unique method of attacking and destroying cancerous cells and tumors. Radiation can also be used to kill bacteria and germs that contaminate medical instruments and some foodstuffs.

Finally, this brochure describes the responsibilities of the U.S. Nuclear Regulatory Commission (NRC), some other Federal agencies, and the States, in regulating the manufacture, use, and possession of radioactive materials.

A few radioisotopes occur naturally but most are man made. A radioisotope is typically described by its name followed by a number, such as carbon-14 (C-14) or fluorine-18 (F-18). The number represents the atomic weight or the total number of protons and neutrons that make up the atom's nucleus.

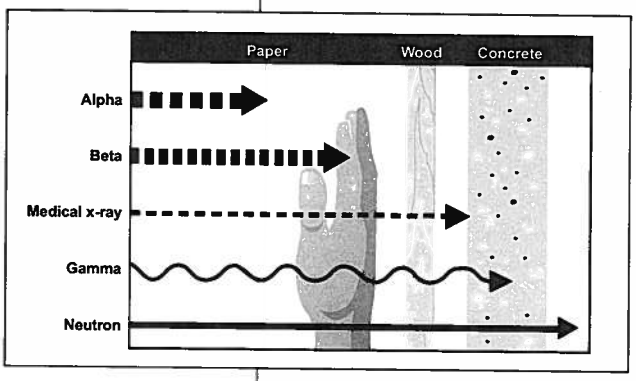
Radioisotopes have unique properties that make them useful tools in solving problems.

Three predominant types of radiation are emitted by radioisotopes: (1) alpha particles, (2) beta particles, and (3) gamma rays. The different types of radiation can penetrate materials of varying thicknesses such as paper, body tissue, or concrete. A single sheet of paper will stop an **alpha particle**, which, because it is heavy, has very little penetrating power. Alpha emitters are typically used in smoke detectors. A thin sheet of metal will stop a **beta particle**, which,

## Why Are Radioisotopes Useful?

### 1. *Radioisotopes emit different kinds of radiation.*

*Penetrating power of radiation*



because it is lighter, is more penetrating than an alpha particle. Beta emitters such as strontium-90 (Sr-90) are used in the treatment of eye disease. **Gamma rays**, which have no charge or weight, can be extremely energetic and highly penetrating. Several **meters** of concrete or several millimeters of other dense materials, such as lead, are needed to block gamma rays. Radioisotopes that emit gamma rays are used frequently in medical applications against tumors, and in industry to check for cracks or flaws in valves and piping. Because of their varying penetrating properties, radioisotopes can be manipulated to perform different tasks.

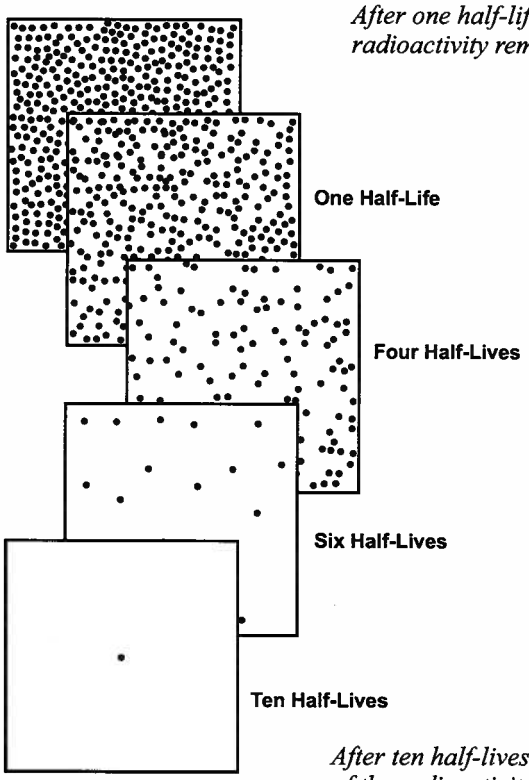
### 2. *The length of a radioisotope's life is predictable.*

The process of radioactive decay, in which radioisotopes lose their radioactivity over time, is measured in **half-lives**. A half-life of a radioactive material is the time it takes one-half of the atoms of the radioisotope to decay by emitting radiation. The half-life of a radioisotope can range from fractions of a second (radon-220) to millions of years (thorium-232). When radioisotopes are used in industry or medicine, it is vital to know how rapidly they disappear, so that the precise amount of radioisotope available for the medical procedure or industrial use is known.

We can trace the movement of a chemical element by using a radioisotope of that element. For instance, the chemical element iodine concentrates naturally in the thyroid. By using a radioactive isotope of iodine as a tracer, a picture can be taken of the material's path through the body and its deposit in a specific organ.

### 3. *Radioisotopes of a chemical element behave in the same manner as a stable, nonradioactive element.*

*Half-life decay*



## Where Do Radioisotopes Come From and Who Regulates Their Use?

Radioisotopes come from three sources: (1) from nature, such as radon in the air or radium in the soil; (2) from machine-produced nuclear interactions in devices, such as **linear accelerators and cyclotrons;** or (3) from nuclear reactors.

A linear accelerator is a long, straight tube in which charged particles gain energy through oscillating electromagnetic fields. A cyclotron is an accelerator in which charged particles travel in an almost circular path, rather than in a straight path as in a linear accelerator. Radioisotopes produced in linear accelerators are used in some modern nuclear medicine procedures.

The nuclear reactors that produce radioisotopes bombard atoms with high-energy neutrons. The research reactors used for this purpose do not produce electricity and are much smaller in size and power than large power reactors. Reasearch reactors are mostly used for training and for identifying the composition of certain elements. *Forty-seven research reactors are licensed by the NRC to operate in the United States. They are located mostly at large universities.*

Because of the potentially hazardous properties of radioisotopes, their use must be closely regulated to ensure that public health and safety are protected.

The licensing and regulation of radioisotopes in the United States are shared by the NRC, the U.S. Environmental Protection Agency (EPA), and many State governments. The EPA is also responsible for, among other things, setting air emission and drinking water standards for radionuclides. The States regulate radioactive substances that occur naturally or are produced by machines, such as linear accelerators or cyclotrons. The Food and Drug Administration (FDA) regulates the manufacture and use of linear accelerators; the States regulate their operation.

## What Is the Role of the Nuclear Regulatory Commission?

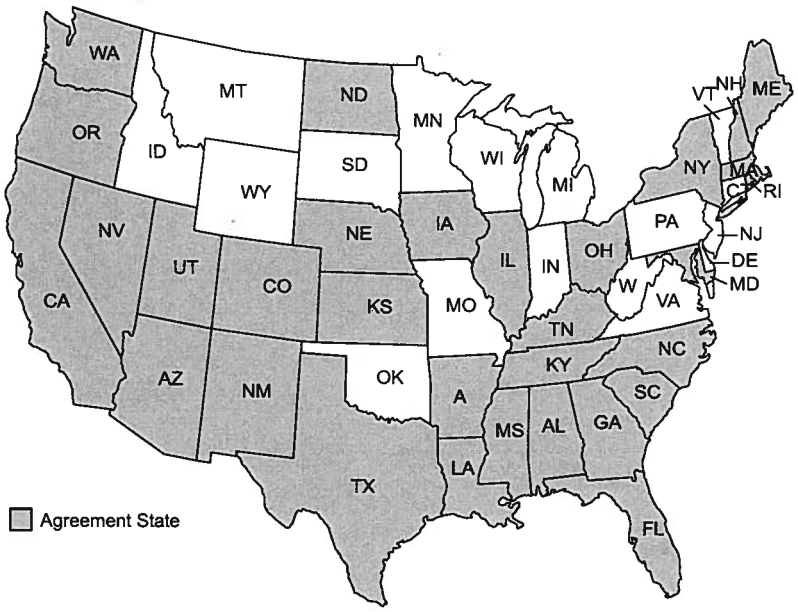
The NRC is the Federal agency given the task of protecting public health and safety and the environment with regard to the safe use of nuclear materials. Among its many responsibilities, the NRC regulates medical, academic, and industrial uses of nuclear materials generated by or from a nuclear reactor. Through a comprehensive inspection and enforcement program, the NRC ensures that these facilities operate in compliance with strict safety standards.

The NRC has relinquished its authority to regulate certain radioactive materials, including some radioisotopes, to most of the States. These States, which have entered into an agreement assuming this regulatory authority from

the NRC, are called **Agreement States**, and are shown on the map below. Agreement States, like the NRC, regulate reactor-produced radioisotopes within their borders and must provide at least as much health and safety protection as the NRC.

The NRC maintains approximately 6,000 licenses for the use of radioactive materials, and the Agreement States maintain approximately 16,000

*Map of Agreement States*




Source: Nuclear Regulatory Commission

materials licenses. Every license specifies the type, quantity, and location of radioactive material that may be possessed and used. When radioactive material is transported, special packaging and labeling are required. Also specified in each license are the training and qualification of workers using the materials, specific procedures for using the materials, and any special safety precautions required. Every licensee is inspected periodically either by the NRC or the Agreement State to ensure that radioactive materials are being used and transported safely. Violators of regulatory requirements are subject to fines and other enforcement actions, including loss of license.

## How Are Radioisotopes Used in Medicine?

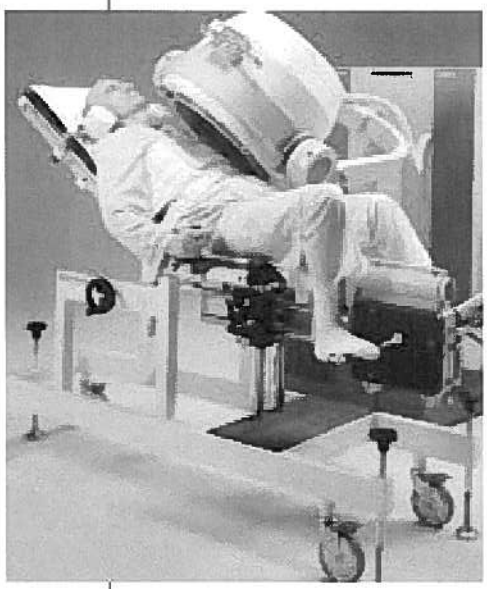
About one-third of all patients admitted to U.S. hospitals are diagnosed or treated using radioisotopes. Most major hospitals have specific departments dedicated to radiation medicine. In all, about 112 million nuclear medicine or radiation therapy procedures are performed annually, with the vast majority used in diagnoses. Radioactive materials used as a diagnostic tool can identify the status of a disease and minimize the need for surgery, reducing the risks from postoperative infection.

### *Diagnostic Applications*

Radioisotopes 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. Radioisotopes carried in the blood also allow doctors to detect clogged arteries or check the functioning of the circulatory system. Some chemical compounds concentrate naturally in specific organs or tissues in the body. For example, iodine collects in the thyroid while various compounds of technetium-99m* (Tc-99m) collect in the bones, heart, and other organs. Taking advantage of this proclivity, doctors can use radioisotopes of these elements as **tracers.** A radioactive tracer is chemically attached to a compound that will

*The "m" refers to "metastate," which pertains to the isotope's short half-life and elevated energy state.

concentrate naturally in an organ or tissue so that a picture can be taken. The process of attaching a radioisotope to a chemical compound is called **labeling**.

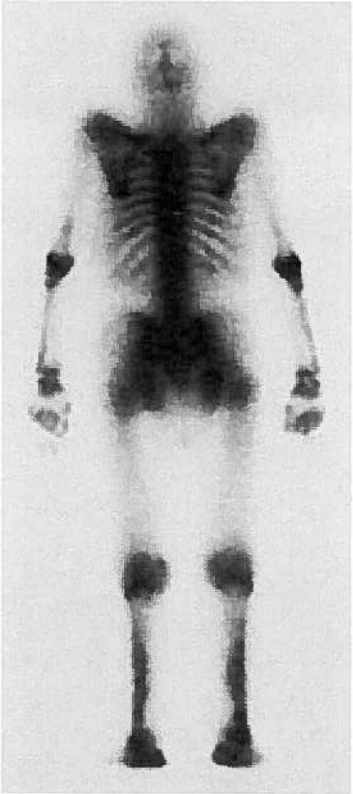


*Gamma camera used to detect dysfunctional activity in body organs*

To detect problems within a body organ, doctors use **radiopharmaceuticals** or radioactive drugs. Radioisotopes that have short half-lives are preferred for use in these drugs to minimize the radiation dose to the patient. In most cases, these short-lived radioisotopes decay to stable elements within minutes, hours, or days, allowing patients to be released from the hospital in a relatively short time.

The radioisotope used in about 80 percent of nuclear diagnostic procedures is Tc-99m. The penetrating properties of its gamma rays and its short (6-hour) half-life help reduce risk to the patient from more prolonged radiation exposure.

Because of their short half-lives, certain radiopharmaceuticals must be produced, shipped to the hospital, and then used within a couple of weeks. Short-lived radionuclides such as Tc-99m, gallium-67, and thallium-201 are often used to diagnose the functioning of



*Tracer used in the body of a 65-year old man indicating bone density problems as a result of a thyroid condition*

*Photo: Courtesy of Appleton & Lange, from "A Clinical Manual of Nuclear Medicine," by John Walker and Donald Margouless, 1984.*

the heart, brain, lung, kidney, or liver. For example, Tc-99m is used to diagnose osteoporosis, a condition caused by calcium deficiency in older people, especially women.

To evaluate the presence of heart disease, a radioisotope is injected into a patient's bloodstream while he or she is exercising on a treadmill. The radioisotope travels toward the heart, allowing doctors to follow the blood flow on a screen. While looking at the image, doctors can check for reduced blood flow through the arteries, a possible signal of heart disease.

**Nuclear imaging** is also used to evaluate brain function. Organic radiochemicals are labeled with F-18 and then injected into the bloodstream. A device called a **gamma camera** detects radiation emitted from the organ, displaying an image that can enable the physician to detect blockages or other dysfunctional activity.

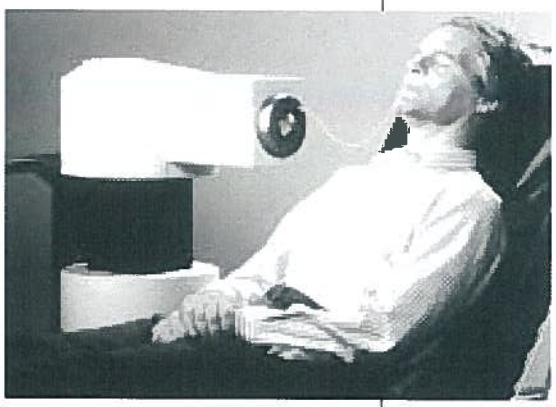
For some diagnostic tests, the patient need not come into contact with radioactivity at all. The tests are performed on blood or other fluids taken from the patient, using a procedure called **radioimmunoassay**. These tests can detect some diseases by identifying and measuring the amounts of hormones, vitamins, enzymes, or drugs in the body.

***Therapeutic Applications***

The same property that makes radiation hazardous can also make it useful in helping the body heal. When living tissue is exposed to high levels of radiation, cells can be destroyed or damaged so they can neither reproduce nor continue their normal functions. For this reason radioisotopes are used in the treatment of cancer (which amounts to uncontrolled cell division). Although some healthy tissue surrounding a tumor may be damaged during the treatment, mostly cancerous tissue can be targeted for destruction.

A device called a **teletherapy unit** destroys malignant tumors with gamma radiation from a radioisotope such as cobalt-60 (Co-60). Teletherapy units use a high-energy beam of gamma rays to reduce or eradicate tumors deep within the body. These units are licensed by the NRC because they use byproduct material that is produced only by a nuclear reactor.

Another treatment, called **brachytherapy**, destroys cells by placing the radioisotope (in the form of a sealed source) directly into the tumor. Generally, two techniques are used for this type of treatment: (1) direct, manual implantation of a radiation source by a physician or (2) automated implantation using a device called a **remote afterloader**. The NRC as well as



*Brachytherapy device*

*Photo: Courtesy of Nucletron International B.V.*

Agreement States license these brachytherapy devices. Using these devices, a small, thin wire or sealed needle containing radioactive material, such as iridium-192 (Ir-192) or iodine-125 (I-125), is inserted directly into the cancerous tissue. The radiation from the isotope attacks the tumor as long as the device is in place. When the treatment is complete, long-lived material (Ir-192) is removed, but the short-lived radioisotopes (I-125) may be left permanently. This technique is used frequently to treat mouth, breast, lung, and uterine cancer.

Brachytherapy and teletherapy procedures are performed only in hospitals or clinics by trained medical personnel. Strict controls and safety requirements set by the NRC or the Agreement States must be followed. For example, treatment rooms must have adequate shielding to prevent scattered radiation from penetrating into an adjacent room. Radiation monitors must be used and patients carefully observed at all times during treatment.

Many types of cancer, such as Hodgkin's disease (cancer of the

lymph glands) and cancers of the cervix, larynx, and skin, can be treated by radiation alone. Boron capture neutron therapy has been used on a trial basis recently to treat potentially fatal brain cancer. In this procedure, the diseased brain tissue incorporates a neutron-absorbing isotope and then is exposed to neutron radiation originating from a nuclear research reactor. The energy and radiation emitted as a result of the neutron activation slow down the growth of cancer cells and, in some cases, completely kill them.

The overall objectives of NRC's safety rules for radiation medicine are to ensure that patients receive only the exposure medically prescribed and that the radiation is delivered in accordance with the physician's instructions.

*NRC regulations require that physicians and physicists have special training and experience to practice radiation medicine. The training emphasizes safe operation of nuclear-related equipment and accurate recordkeeping.*

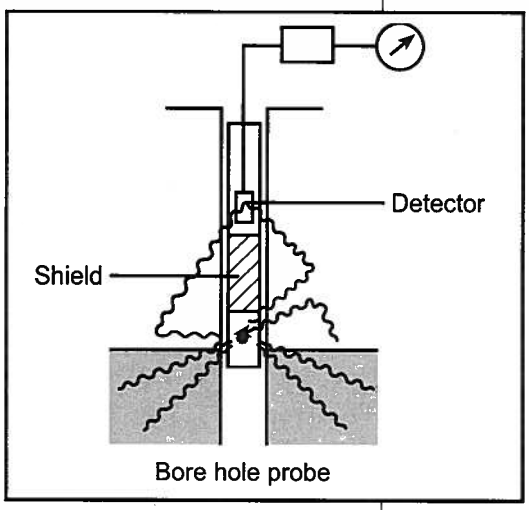
When using radiation as a medical treatment, the physician weighs the potential benefits against the risk of side effects. Intense radiation exposure often destroys tumors that would prove fatal, but side effects such as hair loss,

reduced white blood cell count, and nausea can be severe and must be monitored carefully.

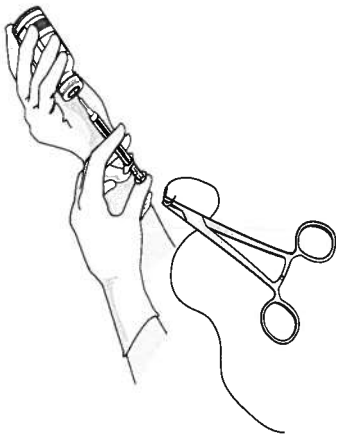
## How Are Radioisotopes Used in Industry?

Radioisotopes are used in many of today's industrial processes. High-tech methods that ensure the quality of manufactured products often rely on radiation generated by radioisotopes. To determine whether a well drilled deep into the ground has the potential for producing oil, geologists use **nuclear well-logging**, a technique that employs radiation from a radioisotope inside the well to detect the presence of different materials. Radioisotopes are also used to sterilize instruments; to find flaws in critical steel parts and welds that go into automobiles and modern buildings; to authenticate valuable works of art; and to solve crimes by spotting trace elements of poison, for example. Radioisotopes can also eliminate dust from film and compact discs as well as static electricity (which may create a fire hazard) from can labels.

*Well-logging device*



### *Irradiation and Treatment of Materials With Radioisotopes*

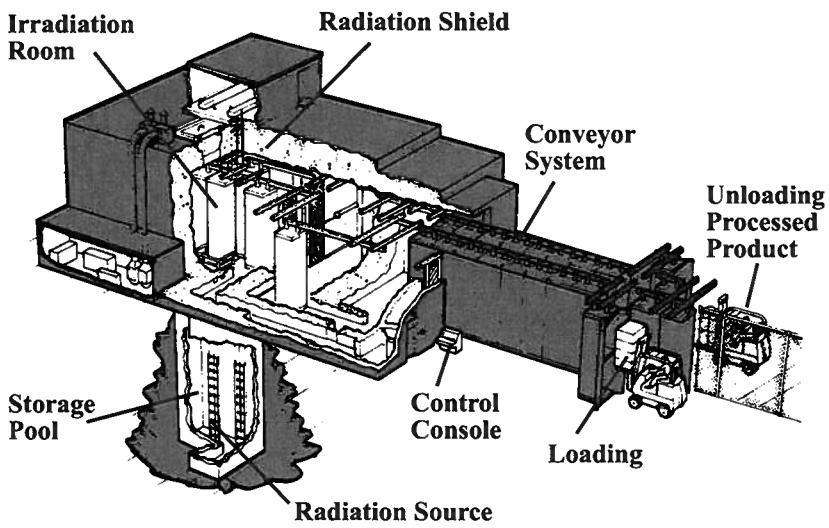


Radiation can destroy germs, bacteria, and other harmful organisms that contaminate medical supplies, blood supplies, and even our food. Over the years, we have learned how to safely treat these items with radiation to sterilize or preserve them when other methods such as boiling or using chemical preservatives are either impractical or not as effective.

Medical supplies, such as rubber gloves, cloth bandages, syringes, and contact lens solution, can be sterilized by using an **irradiator.** An irradiator exposes the materials to gamma radiation, usually from Co-60.

Bacteria in foods can be destroyed by using radiation. Astronauts, for example, take food into space that often has been preserved using radiation. Food irradiation is discussed in greater detail later in this brochure.

*The NRC regulates irradiators to protect workers and the public but, with some exceptions, does not specify the types of products that may be irradiated. The NRC does not evaluate the quality of irradiated products or the*




*An industrial irradiator used for food products consists of a room with concrete walls 2 meters thick and a radiation source (Co-60). A conveyor system automatically moves the products into the room for irradiation and then removes them. When it is necessary for personnel to enter the room, the source is lowered to the bottom of the pool, where water absorbs the radiation energy and protects the workers.*

*Diagram: Courtesy of Food Technology Service, Inc.*

*technical or economic feasibility of product irradiation.*

In the United States, food safety is regulated by the FDA and the U.S. Department of Agriculture (USDA).

There is an important difference between exposing materials to radiation

from an irradiator and exposing them to radiation from a reactor. The gamma radiation from Co-60 in an irradiator kills bacteria and germs, but does not leave any radioactive residue or cause any of the materials exposed to become radioactive themselves. This is because the Co-60 is contained in stainless steel capsules and does not commingle with the product being irradiated. This differs, however, from the effects of neutron radiation. Material **can** become radioactive after exposure to neutrons from a reactor or linear accelerator because the neutrons are absorbed by the nucleus of the atoms in the material, which then form different radioactive isotopes or elements (also referred to as **neutron activation**).

In manufacturing, radiation can change the characteristics of materials, often giving them features that are highly desirable. For example, wood and plastic composites treated with gamma radiation are used for some flooring in high-traffic areas of department stores, airports, hotels, and churches, because they resist abrasion and ensure low maintenance. Some gemstones, such as blue topaz, can be given a more pleasing color using neutron radiation treatment.

*Gauge, luminous watch dial and smoke detector*

Although there might be some residual radiation from neutron bombardment of gemstones and other consumer products, the half-life of these materials is generally so short (seconds or hours) that risk to the public is extremely low. *To ensure that the products are manufactured correctly, manufacturers and distributors of these materials must be licensed by the NRC.*

Today, luminous watch dials are painted with tritium or promethium-147 replacing radium used many years ago. These radioisotopes trigger a chemical reaction with other materials upon contact, which then give off a "glow." These materials are sometimes placed in gun sights or clocks and watches so they can be used at night. One frequently sees "exit" signs illuminated by tritium as safety markers on passenger aircraft, aboard ships, and in many buildings. Some gas lantern mantles are manufactured with the radioisotope thorium to provide a bright light when burned.

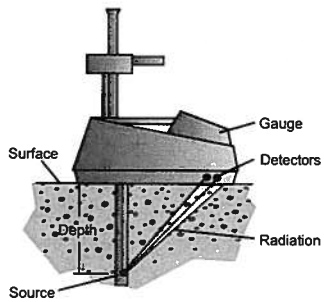
### Measuring and Testing Applications

As radiation from a radioisotope passes through matter, it is scattered or absorbed. The amount of radiation passing completely through depends on the thickness and density of the matter. This property makes radiation useful for many manufacturing quality control processes.

For example, radioisotopes in gauges are used to monitor and control the thickness of sheet metal, textiles, aluminum foil, newspaper, copier paper, plastics, and photographic film as they are manufactured. Radiation penetrates the material as it is processed, and detectors measure the amount of radiation passing through and compare it to the amount that should be detected for the desired thickness of material. If the readings are too high or too low, controls in the manufacturing process can be activated to correct the problem. This is accomplished with a high degree of accuracy, and the materials need not be touched by human hands.

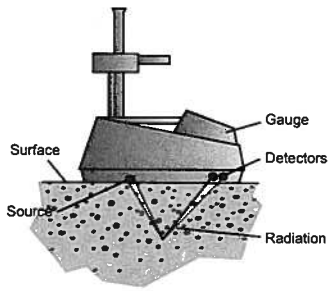
Radioactive tracers can also be used in the machine-tools industry to measure wear on cutting tools and drills. Gauges also play a role in the measurement of everyday objects, such as the amount of glue on a postage stamp, the

**Direct transmission**




*The use of portable gauges is widespread in industries such as agriculture and construction. In the illustration on the left, the gamma source is placed underneath the surface of the ground through a tube. Radiation is then transmitted directly to the detector on the bottom of the gauge, allowing accurate measurements of compaction.*

*On the right, the neutron source remains above the surface, and radiation is emitted into the ground and scattered back to the detector to provide a measurement of the moisture content.*




**Backscatter**

*Portable gauge used to test the structural integrity of roads and bridges*

level of liquid in canned beverages, the amount of air whipped into ice cream, and the amount of tobacco packed into a cigarette. Other gauge and nuclear instrument applications include: (1) monitoring the structural integrity of roads, buildings, and bridges; (2) exploring for oil, gas, and minerals; and (3) detecting explosives in luggage at airports. To ensure adequate water supplies, radioisotopes are used to measure water runoffs from rain and snow, flow rates of streams and rivers, and leakage from lakes, reservoirs, and canals.

Radioisotopes can also be used to test for the presence of certain materials. For example, a small amount of americium-241 is found in most smoke detectors used in homes and offices. This radioisotope is part of the sensing unit that triggers an alarm when smoke is present.

## *Industrial Radiography*

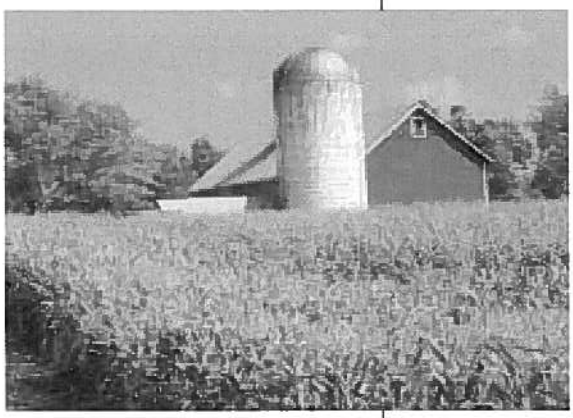
A process called **industrial radiography** is used to inspect many metal parts and welds for defects. A sealed radiation source, usually Ir-192 or Co-60, beams radiation at the object to be checked. Special photographic, or radiographic, film on the opposite side of the source is exposed when it is struck by radiation passing through — like an x-ray. More radiation will pass through if there are cracks, breaks, or other flaws in the metal parts and will be recorded on the film. Therefore, structural problems can be detected by studying the film.

Radiography is used throughout industry. For example, jet engine turbine blades are radiographed to ensure that internal cooling passages are manufactured properly.

*The NRC or Agreement States license radiographers and periodically inspect them to ensure they follow safety procedures.*

*Portable radiography camera used to test for cracks in metal*

## How Are Radioisotopes Used in Agriculture?



Radioisotopes have played an important role in improving agricultural science. Radioisotopes are used as a research tool to develop new strains of food crops that are more resistant to disease, are of higher quality, allow earlier ripening, and produce a higher yield. When insects are sterilized with radiation, they mate without producing offspring, thus providing some control of insect population growth. With fewer pests, food crops can flourish. This technique has eliminated screw worm infestation in the southeastern United States and Mexico and has helped control the Mediterranean fruit fly in California. It has also been used to control mosquitoes and flies throughout the world.

Radioisotope tracers in plant nutrients enable scientists to make discoveries that have increased the effectiveness of fertilizer.

A major factor in successful crop production is the presence of an adequate water supply. Nuclear moisture density gauges can monitor the moisture

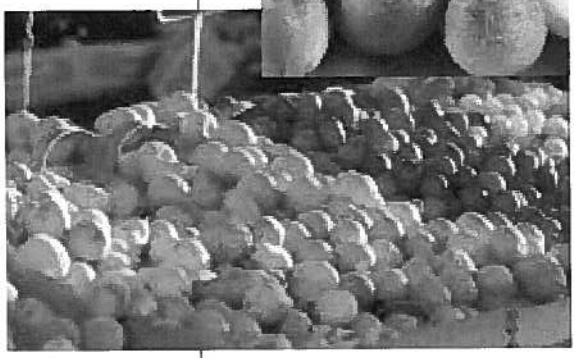
content of soil, helping make the most efficient use of limited water sources.

*The NRC and the Agreement States license byproduct radioactive materials used in these agricultural applications in the United States.*

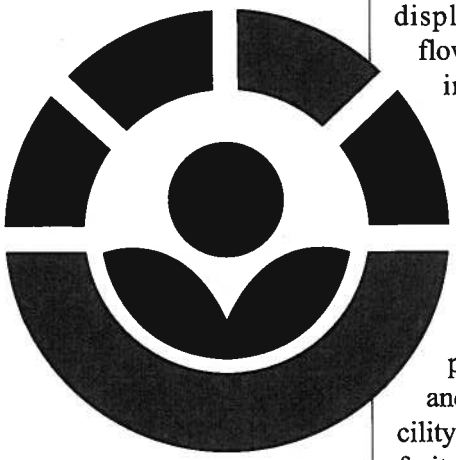
### *Food Irradiation and Its Safety*

Radiation can be used to destroy bacteria in food and control insect and parasite infestation. Since 1963, the FDA has approved irradiation as a method to inhibit sprouting and to delay ripening in many fresh fruits and vegetables. The FDA has more recently approved the use of irradiation to control insects in food, trichina in pork, and bacteria in poultry, spices, and seasonings.

Currently, irradiation is used in the United States on very few food items; however, some spices are irradiated. In 1992, the USDA also approved the commercial irradiation of poultry, and in 1999, approved commercial irradiation of meat.



The FDA has established regulations controlling irradiation of food. Irradiated food must clearly



*Radura logo*

display the radura logo (a green, flower-like, international symbol for irradiation) and words such as "treated with radiation."

Governments in about 37 countries have approved irradiation of some 40 foods. In this country only one commercial facility is devoted solely to irradiating food products. It is located in Florida and licensed by the State. That facility irradiates strawberries and citrus fruits by exposing them to gamma rays from a radioactive source. When not in use, the radiation sources are safely stored in a pool of water.

Although it is a relatively new commercial process, food irradiation has been studied at length for over 40 years. According to the FDA, research to date has turned up no evidence of adverse health effects from irradiation of the treated food. The radiation passes through the food leaving no radioactive residue. Some concerns have been raised regarding the chemical changes that may alter the finished food product. However, research has shown that changes in flavor and texture caused by irradiating food are similar to changes due to canning or freezing. Studies are continuing to ensure that all irradiated food is safe to eat.

Through a method called **radiocarbon dating**, archaeologists can determine when formerly living materials were last alive. This procedure relies on the presence of C-14, a naturally occurring, long-lived radioisotope present in all living things.

The ratio of C-14 to C-12 in the atmosphere has been relatively constant throughout history. When an animal or plant dies, it stops taking in carbon, and the amount of C-14 in its tissue begins to decrease through the process of radioactive decay. Comparing the C-14 to C-12 ratio in dead material with the "living ratio" enables us to calculate how long ago the plant or animal lived. This method was used to determine the approximate age of two major archaeological discoveries in recent decades: the Shroud of Turin and the Dead Sea Scrolls. C-14 analysis has also been used during space missions to test for life on Mars.

Heat generated by radioisotopes is used to power small generators used for remote applications, such as in space exploration.

Radioisotope-powered electrical generators have been used to power exploration space craft, navigational and weather satellites, and communication

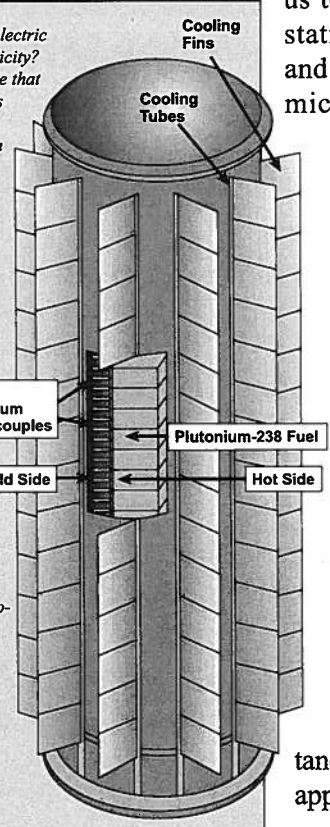
## What Are Other Uses of Radioisotopes?

### *Geology, Archeology, and Space*

## THE ABCs OF RTGs

*How does a radioisotope thermoelectric generator (RTG) produce electricity? The "fuel"—a plutonium isotope that can't explode—"decays," or loses its radioactivity, giving off heat. That heat is absorbed by a device called a* ***thermocouple****, which consists of a compound of two metals—silicon and germanium—that are "doped." "Doping" the metals—adding impurities to them—changes their electrical and thermal properties. As a result, energy moves from the "hot side" of the thermocouple—the side closer to the fuel—to the "cold side," producing a voltage. Gas circulating through cooling tubes keeps the RTG from getting too hot, and fins dissipate the heat.*

*The thermocouple was first demonstrated early in the last century, but the efficiency was too low to be practical. In the 1950s, researchers discovered they could get higher efficiencies from a thermocouple by using "semiconductor" materials such as silicon and germanium. After that, there was no looking back. Today's conversion efficiency is about 5 percent, but with some of the conversion technologies now under development, tomorrow's efficiencies are expected to be at least 20 percent.*




**Height: 45 inches** **Diameter: 18 inches** **Weight: 123.5 pounds**

*Diagram: Courtesy of the Nuclear Energy Institute*

satellites. They allow us to operate weather stations at the North and South Poles, seismic sensing stations in remote locations, and devices placed on the ocean floor for scientific investigations and national defense.

The Department of Energy (DOE) manufactures radioactive thermal generators, which are powered by plutonium-238 and Sr-90. The NRC has provided technical assistance for some of these applications.

A procedure called **activation analysis** is frequently used to identify trace quantities of materials such as glass, tape, gunpowder, lead, and poisons that are important to criminal investigations. Samples of

materials are placed in a nuclear reactor and bombarded with neutrons. The induced radiation produces a "fingerprint" of the elements in the sample.

In addition, activation analysis can prove the authenticity of old paintings by detecting whether certain modern materials are present. Museums routinely use this and other techniques that rely on radioisotopes to spot forgeries.

Radioisotopes are used to detect pollution in the air, water, and soil. Sources of acid rain and greenhouse gases that may be causing global warming can be traced using radioisotopes. In addition, electron beam radiation can be used to remove gaseous pollutants such as sulphur dioxide or nitrogen oxide, both harmful gases emitted from coal-fired power plants and other industries.

## Conclusion

When used properly, radioisotopes are a productive part of today's world. The NRC and the Agreement States remain committed to protecting public health and safety in the use of these nuclear materials by inspecting medical, academic, and industrial applications carefully, and monitoring users to ensure safe practices.

# Appendix: Some of the Major Uses of Radioisotopes in the United States.

### Americum-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 expolsives...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.

## The regulation and use of radioisotopes in today's world

### 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 coffeemakers...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.

## The regulation and use of radioisotopes in today's world

### 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 lighting 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.

### Strontium-90

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

### Sulphur-35

Used in genetics and molecular biology research.

### Technetium-99m

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.

*Courtesy of Management Information Systems, Inc.*

## Notes

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