ATSDR

October 1993

Case Studies in Environmental Medicine

34

Ionizing Radiation

Environmental ALERT . . .

- ***Everyone is exposed to ionizing radiation. Approximately 82% of this exposure is natural background from cosmic and terrestrial sources, and 18% is due to man-made sources.***
- ***Public exposure to ionizing radiation or contamination of the environment by radioactivity engenders intense fear. The emotional and psychologic stresses resulting from exposure should be recognized and addressed early in a radiation incident.***
- ***Health care providers should understand the physics, chemistry, and biology of radiation to communicate effectively about it.***

This monograph is one in a series of self-instructional publications designed to increase the primary care provider's knowledge of hazardous substances in the environment and to aid in the evaluation of potentially exposed patients. See page 35 for more information about continuing medical education credits and continuing education units.

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U.S. DEPARTMENT OF HEALTH & HUMAN SERVICES
Public Health Service
Agency for Toxic Substances and Disease Registry

ATSDR

How to use this issue...

This issue begins with a composite case study that describes realistic encounters with patients. The case study is followed by a pretest. (Answers to the Pretest questions are on pages 31-32.) The monograph ends with a posttest, which can be submitted to the Agency for Toxic Substances and Disease Registry (ATSDR) for continuing medical education (CME) credit or continuing education units (CEU). See page 35 for further instructions on how to receive these credits.

The objectives of this monograph on ionizing radiation are to help you

- ❑ **Explain why exposure to ionizing radiation is a health concern**
- ❑ **Describe the health effects caused by exposure to ionizing radiation**
- ❑ **Identify evaluation and treatment protocols for radiation-exposed patients**
- ❑ **List sources of information on ionizing radiation**

Contents

This issue is prepared for the U.S. Department of Energy with the assistance of those who share a common concern for physician education, public health, and the environment, including the following organizations: American Academy of Clinical Toxicology, American Academy of Family Physicians, American Academy of Pediatrics, American College of Emergency Physicians, American College of Occupational and Environmental Medicine, American Medical Association, Association of State and Territorial Health Officials, Physicians for Social Responsibility, and the Society of Teachers of Family Medicine. Final responsibility for the contents and views expressed in this monograph resides with ATSDR.

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Case Study

Radiation contamination caused by a transportation accident

You are a physician on duty in the emergency department of a hospital in a community of approximately 40,000 residents. At 7:45 A.M. you receive notification of a vehicular accident about 4 miles northeast of the city. A truck carrying radioactive material struck a guard rail and rolled 200 feet down an embankment. The truck, which came to rest at a point about 15 feet from the river bank, is on fire. The driver of the truck has minor burns on his hands and a deep laceration of the scalp; he is conscious but somewhat confused and incoherent. His assistant, a passenger in the truck, has second-degree burns on his hands and a simple fracture of his lower left leg.

A member of the highway patrol, who was first on scene and noticed the radioactivity placard on the truck, contacted a health physicist from the regional office of the Department of Energy. The health physicist found that the driver of the truck and his assistant are externally contaminated with the radioactive material, which is emitting beta and gamma radiation. The health physicist also detected radioactive contamination along the truck's path as it rolled down the embankment. Three ruptured containers of radioactive material were found near the truck; it is believed that their contents may have entered the river. The community you serve relies on the river for drinking water, as well as for recreational activities.

State police have rerouted traffic and placed road blocks at all points within a 3-mile radius of the accident. However, a young boy whose family is vacationing on a houseboat about 20 yards from the site where the truck came to rest, is known to have approached the scene immediately after the accident occurred. The highway patrol is attempting to locate the boy.

(a) Where could you obtain consultation on treatment and management of persons contaminated with radioactivity?

(b) Describe appropriate initial management of the driver and his assistant.

(c) Is the young boy who has not been located in danger? Explain.
Are the other occupants of the houseboat at risk as a result of the accident?

(d) If the radioactive material entered the river and consisted of aqueous potassium iodide, what steps could be taken to protect the residents of your community who rely on the river for drinking water? Would these steps differ if the radioactive waste consisted of cesium-137 in solution?

Answers to the Pretest can be found on pages 31-32.

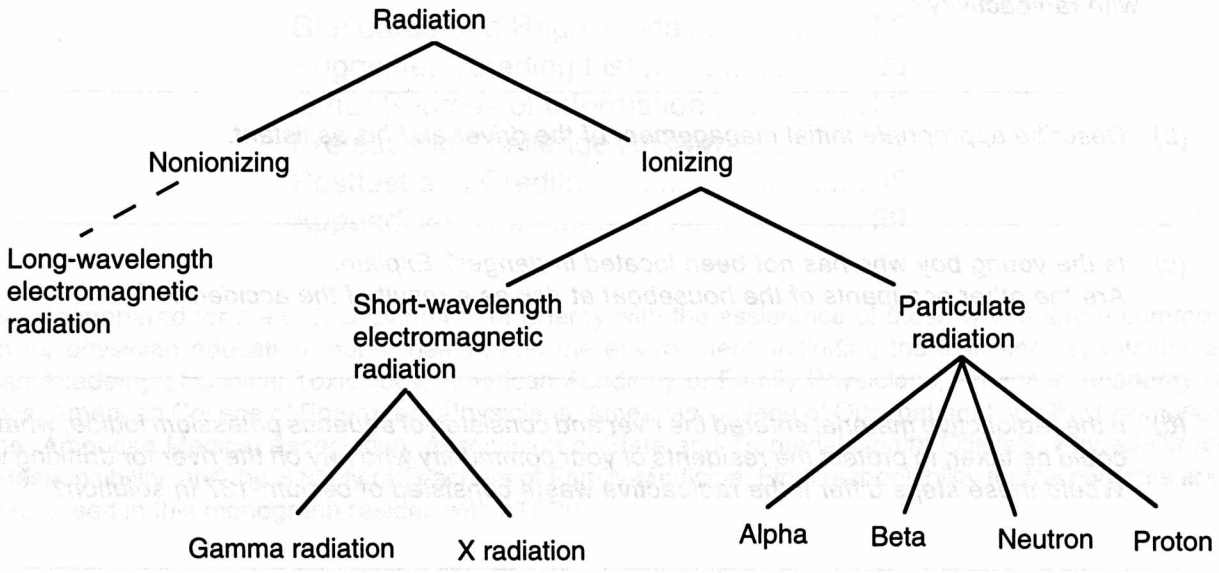
Introduction

- **Radiation is of two types: ionizing and nonionizing.**
- **The nature of ionizing radiation is particulate (e.g., alpha or beta radiation) or wave-like (e.g., X or gamma radiation).**

The nuclear reactor accidents at Three Mile Island in Pennsylvania in 1979 and at Chernobyl in the USSR in 1986 have increased the public's concern about exposure to radiation. Awareness of the potential health effects of elevated levels of radon in homes has intensified that concern. The purpose of this document is to help clinicians answer patients' questions about the early and long-term effects of radiation exposure, the risks of radiation in diagnostic and therapeutic medical procedures, and the potential dangers of radiation to the fetus and future generations.

Events just before the turn of the century, which included Roentgen's discovery of X rays and Becquerel's recognition of natural radioactivity, allowed us to understand how radiation is produced and how it interacts with matter. Radiation may be of two types, ionizing or nonionizing (Figure 1). Ionizing radiation is capable of physically disrupting neutral atoms by dislodging orbital electrons, thus forming an ion pair consisting of the dislodged electron and the residual atom. Ion pairs are chemically reactive and may produce toxic agents in the cell (e.g., free radicals from water), which can interfere with normal life processes. Nonionizing radiation, on the other hand, does not dislodge orbital electrons or destroy the physical integrity of an impacted atom. The health effects of nonionizing radiation are not addressed in this document.

Figure 1. Types of Radiation



Adapted from: Leach-Marshall JM. Analysis of radiation detected from exposed process elements from the krypton-85 fine leak testing system, page 50. Semiconductor Safety Association Journal 1991; 5(2): 48-60.

Ionizing radiation exists as either particles or electromagnetic waves. Particulate radiation (e.g., alpha particles, beta particles, neutrons, and protons) has finite mass and may or may not carry a charge. Electromagnetic radiation, on the other hand, has no mass or charge; it consists of electric and magnetic forces that move at the speed of light in consistent patterns of various wavelengths. The continuum of wavelengths constitutes the electromagnetic spectrum. The shorter wavelengths—gamma radiation and X radiation—have high energies, and like particulate radiation, are capable of ionizing matter. The longer wavelengths of the electromagnetic spectrum, which include radio waves; microwaves; and infrared, visible, and ultraviolet radiation have relatively low energies and are nonionizing.

Not all forms of ionizing radiation have the same biologic effects. Generally speaking, for directly ionizing particles, the ion density along the path of low-energy radiation is greater than that along the path of high-energy radiation; low-energy radiation moves slower and has more time to interact. However, the total pathway of low-energy radiation is usually shorter, so the total number of interactions may well be less than with high-energy radiation. Similarly, the ion density toward the end of the radiation path is greater than at the beginning because the velocity of the radiation is less and the probability of interaction is greater. Alpha particles are capable of producing the highest specific ionization (i.e., greatest number of ion pairs per unit length of path), followed in order by beta particles and electrons. X radiation and gamma radiation interact with matter by transferring energy to electrons. (For more information, see *Appendix I, Forms of Ionizing Radiation.*)

The units that have evolved to measure ionizing radiation are the result of its many facets. Radiation units (Table 1) may characterize the (1) energy, (2) radioactive decay rate, (3) effect in air, (4) ability to be absorbed by matter, or (5) biologic effect. Units may be modified by prefixes such as *milli* (indicating thousandths of the base unit), *micro* (millionths), *pico* (billionths), *kilo* (a thousand times), or *mega* (a million times).

The units used most commonly in this document are rad (radiation absorbed dose) and rem (roentgen equivalent in man or mammal). The rad describes the dose of radiation in terms of the amount of energy absorbed by a given mass, for example, of water or tissue. The absorption of 100 ergs of ionization energy in 1 gram of water has a value of 1 rad.

Use of the rem takes into account the biologic effectiveness of the various types of radiation. The rem is numerically equal to the rad multiplied by a Radiation Weighting Factor (formerly "quality factor"). The Radiation Weighting Factor (RWF) reflects differences in the amount of each type of radiation necessary to produce the same biologic effect. For beta, gamma, and X radiation, RWF is 1.0, making their effect on tissue equivalent. The RWF for alpha particles is 20, indicating its biologic effect is 20 times greater than the effect of beta, gamma, or X radiation.

Table 1. Units of radiation measurement

Characteristic	Unit	Description
Energy	electron volt (eV) (also ergs, joule)	Kinetic energy of an electron as it moves through a potential difference of 1 volt.
Rate of radioactive decay	curie (Ci)	Radioactivity emitted per unit of time (1 Ci = 3.7 x 10^{10} disintegrations per second).
Air exposure	roentgen (R)	Amount of X and gamma radiation that causes ionization in air. One roentgen of exposure will produce about 2 billion ion pairs per cubic centimeter of air.
Absorbed dose	rad	Dose resulting from one roentgen of ionizing radiation deposited in any medium, typically water or tissue. One rad results in the absorption of 100 ergs of ionizing radiation per gram of medium.
Biologic effectiveness	rem	Dose of any form of ionizing radiation that produces the same biological effect as 1 roentgen; 1 rem = 1 rad x Radiation Weighting Factor (RWF), where the value of RWF depends on the type of radiation as follows: X radiation = 1.0 gamma radiation = 1.0 beta =1.0 alpha = 20 neutrons = 5 to 20, depending on their energy

A new System Internationale (SI) nomenclature has been adopted, which is used by international, as well as many domestic, professional organizations and journals (Table 2).

Table 2. Equivalency of international units

Unit	Symbol	Equivalency
Gray	Gy	1 Gy = 100 rad
Sievert	Sv	1 Sv = 100 rem
Becquerel	Bq	1 Bq = 2.7 x 10^{-11} Ci (or 1.0 disintegration per second)

Challenge

(1) A health physicist from the state health department calculates that the young boy at the scene of the accident in the case study potentially received a maximum radiation dose of 50 millirads (mrad). Express this dose in millirems (mrem) and Sieverts (Sv).

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(2) What dose of X radiation would produce the same biologic effect as 50 mrad of gamma or beta radiation? If the radioactive material in the case study had been an alpha-emitter instead of a beta and gamma emitter, would the biologic effects be greater? Explain.

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Exposure Pathways

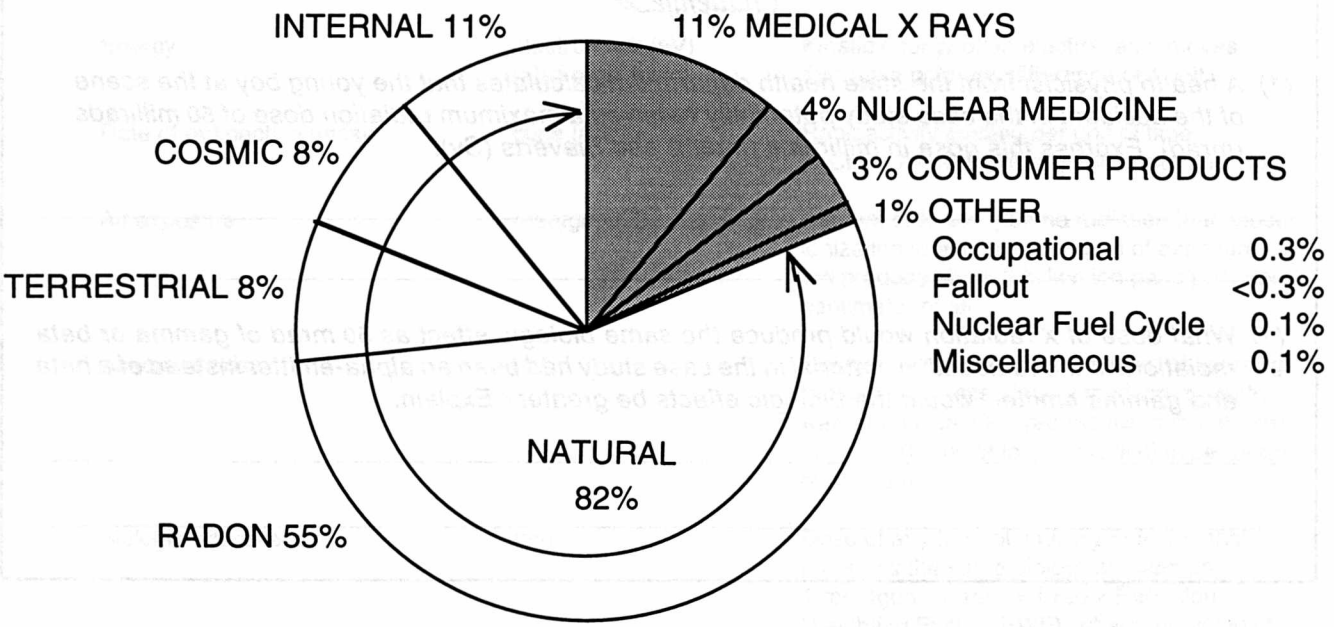
Humans receive an average radiation dose of 300 to 450 mrems per year from both natural (about 82%) and man-made (about 18%) sources. Natural radiation background (Figure 2) is from terrestrial sources and from high-energy particles emanating from stars (including our sun) and other bodies in outer space. Cosmic radiation consists mostly of protons (about 90%), with the remainder being alpha particles, neutrons, and electrons; only about 1/1000 of cosmic radiation penetrates to the earth's surface.

Near sea level, cosmic radiation results in an average dose of ionizing radiation to U.S. residents of about 30 mrem/year. At higher elevations, such as in the Rocky Mountains, where there is less atmosphere to act as a shield, exposures due to cosmic radiation increase by a factor of about two. An even greater increase is experienced during high-altitude air travel; however, passengers of commercial flights are airborne at high altitudes for only a few hours at a time and do not receive significant exposures from this source.

- **Our environment includes continual irradiation from both cosmic and terrestrial sources; this natural radiation background is significantly affected by altitude and geology.**

- **In addition to natural background, an individual's radiation exposure can be increased by factors such as lifestyle (e.g., smoking), geography (e.g., location of residence) and health requirements (e.g., medical diagnosis and therapy).**

Figure 2. Sources of ionizing radiation exposure for the U.S. population (Average annual effective equivalent dose)



Adapted with permission from *Health effects of exposure to low levels of ionizing radiation: BEIR V.* Copyright 1988 by the National Academy of Sciences. Courtesy of the National Academy Press, Washington, DC.

Terrestrial radiation comes from radioactive elements (radionuclides) that were present at the time the earth was formed, and that continue to decay, forming additional radionuclides in the process. Unusual soil composition has increased background radiation twenty-fivefold or more in a few areas in the world. Locations with high background due to naturally occurring radioactive elements in the soil, most of which are derived from the decay of uranium, include the Rocky Mountains (100 mrem/year); Kerala, India (1300 mrem/year); coastal regions of Brazil (500 mrem/year); granite rock areas of France (265 mrem/year); and the northern Nile Delta (350 mrem/year). In the United States, the lowest radiation dose rates are attributed to the sandy soils of the Atlantic and Gulf coastal plains.

One of the products formed during the decay of uranium is radon-222, an alpha-emitting radionuclide. Radon-222 contributes an average equivalent whole-body dose of about 200 mrem/year. Studies of uranium miners and other populations have indicated that inhalation of radon-222 increases the risk of lung cancer, especially in smokers. (See *Case Studies in Environmental Medicine: Radon Toxicity.*) Residents of homes built on abandoned uranium mine and mill tailings or near uranium mines, such as in the Southwest United States (e.g., Mesa County, Colorado) or in areas in Czechoslovakia, have increased internal radiation exposure due to inhalation of radon, as well as increased external radiation exposure due to uranium in the soil.

Construction materials such as wood, granite, and brick bring terrestrial radioactive sources into closer proximity. The dose rate that is attributable to the naturally occurring radionuclides in wood frame buildings is typically less than 10 mrem/year; occupants of masonry structures receive a dose rate of about 13 mrem/year. The dose rate varies not only with the material, but also with ventilation, room size, room location within the structure, season of the year, and other factors.

Potassium is essential to health, and one of its isotopes, potassium-40, is radioactive. Potassium-40 makes its way into the body through foods (e.g., bananas) and through inhaled fossil-fuel combustion products (e.g., fly-ash particulates). Because potassium deposits in muscle tissue, potassium-40 is widely distributed throughout the body. We receive an annual internal dose to all organs of approximately 18 mrem from this radionuclide.

Radiation background from man-made sources includes fallout from aboveground atomic weapon detonations (about 1 mrem/year for U.S. inhabitants), nuclear fuel production and nuclear reactors (less than 1 mrem/year), medical devices (about 50 mrem/year), and various consumer products. Although the United States and the former USSR have stopped aboveground atomic detonations, the dose rate from atomic weapons testing will continue into the next century because of the long-lived isotopes formed during previous tests and the continued aboveground testing carried out by China and France.

As of 1990, 113 nuclear power plants were operating in the United States. In addition, 75 nuclear reactors were being used for training and research, while about 70 reactors were operating at U.S. Department of Energy (DOE) facilities, and at least 100 were used to power military submarines, cruisers, and aircraft carriers. Supporting these reactors are mines, mills, processing plants, and storage sites for spent fuel, all of which are potential sources of radiation exposure. The current deposits of radioactive waste generated by production and use of atomic weapons and nuclear power reactors will remain a potential exposure hazard for 10,000 years or more.

Radiation exposure incurred for medical reasons can contribute the greatest dose from artificial sources. Worldwide, more than 1 billion medical diagnostic X-ray examinations, more than 300 million dental X-ray examinations, and about 4 million radiation therapy procedures or courses of treatment are performed annually. In the United States, over half of the population is exposed to X radiation each year, and more than half of these are diagnostic procedures, including dental diagnosis. The rest experience X radiation during fluoroscopy, radiation therapy (Table 3), and nuclear medicine (Table 4).

Table 3. Common diagnostic X-ray doses*

Examination	Mean KVP	Mean MAS (mrem)	Testes/ Ovaries (mrem)	Embryo/ Fetus
Chest (PA)	80	12	<0.5	<0.5
Skull (lateral)	72	50	<0.5	<0.5
Abdomen (KUB, AP)	78	601	13.7/146	150
Retrograde pyelogram (AP)	77	91	17.2/161	170
Thoracic spine (AP)	75	82	<0.5/0.7	0.9
Cervical spine (AP)	69	48	<0.5	<0.5
Lumbosacral spine (AP)	77	112	13.2/145	150
Pelvis (AP)	100	30	83/79	133
Barium enema (AP)	120	20	68/132	140

* KVP = kilovolt peak; MAS = milliampere second; PA = posteroanterior view; AP = anteroposterior view; mrem = millirem; KUB = kidney, ureter, bladder.

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Table 4. Common radionuclides used in nuclear medicine

Examination	Agent	mCi*	Whole body (mrem)*	Target Organ (mrem)
Lung	Technetium-99†	3	10	Lung—1000
Lung	Xenon-133 gas	15	3	Lung—150
Heart	Thallium-201 chloride	1.5	360	Kidney—2200
Heart	Technetium-99¶	15	200	Blood—300
Liver	Technetium-99§	3	60	Liver—1000
Bone	Technetium-99**	20	200	Bone—450
Kidney	Technetium-99††	10	233	Kidney—500

* mCi = millicurie, mrem = millirem
† Radionuclide delivered in microspheres of human serum albumin
¶ Radionuclide incorporated in red blood cells
§ Radionuclide delivered as sulfur colloid
** Radionuclide incorporated in methylene diphosphonate
†† Radionuclide incorporated in diethylenetriaminepentaacetic acid (DTPA)

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In contrast to environmental exposures, medical procedures usually restrict radiation to local areas. However, during the course of exposing only a small fraction of the body, relatively large doses may be delivered to the bone marrow, which, in comparison to other parts of the body, is very sensitive to radiation. Although the risks due to

radiation exposure are small for patients undergoing medical treatments, the cumulative risk to medical and dental personnel who are present is greater. In addition, staff who are not properly protected may receive whole-body, rather than localized, exposures. Procedures that can be used to protect health care personnel include limiting the time of exposure, maintaining an adequate distance between the X-ray beam and personnel, and providing adequate shielding.

A number of natural and artificially produced radioactive materials are used in consumer products. Of these, tobacco products probably represent the single greatest radiation hazard to smokers. Tobacco smoke contains polonium-210 and lead-210, alpha-emitting radon decay products. These radionuclides may be deposited and retained on the large, sticky leaves of tobacco plants or may derive from the uranium naturally present in the phosphate fertilizers used on the plants. When the tobacco in a cigarette is lit, the radioactive materials are volatilized and enter the lungs. The bronchial lining of the lungs of a person who smokes 1.5 packs of cigarettes per day may receive as much as 16,000 mrem/year (Table 5). The radiation from tobacco smoke may contribute to the carcinogenicity associated with active and passive cigarette smoking.

Although radiation values for dental porcelain and eyeglasses (Table 5) are large, these sources are not a health hazard because the radiation they produce is distributed over a few millionths of an inch in comparatively insensitive tissues; the total contribution of dental porcelain and eyeglasses as an equivalent *whole-body* dose is less than 5 mrem/year. (For more information, see *Appendix II, Radionuclides of Potential Concern in the Environment.*)

Table 5. Background radiation from consumer products

Product	Local Dose (mrem/year)	Portion of Body Considered
Coal combustion (fly ash)	0.03 - 0.3	lungs
Oil combustion (soot)	1.6	lungs
Gas ranges (natural gas)	5	lungs
Tobacco products*	16,000	lungs
Dentures and crowns†	700	superficial layers of tissue in contact with teeth
Ophthalmic glass¶	4,000	cornea
Smoke detectors	0.008	whole body

* Dose for cigarette smokers only; does not include doses experienced by those subjected to passive smoke.
† Due to the uranium present in glazed dental porcelain.
¶ Applies to eyeglasses tinted with uranium or thorium.

Adapted from: National Council on Radiation Protection and Measurements (NCRP). Radiation exposure of the U.S. population from consumer products and miscellaneous sources. Bethesda, Maryland: NCRP, 1988. NCRP Report No. 95.

Challenge

(3) List at least five potential sources of radiation unrelated to the workplace to which the truck driver in the case study may be exposed. Compare the annual dose from each of these sources.

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Who's at Risk

- **Workers in the nuclear energy and defense industries are at greatest risk of exposure to ionizing radiation.**
- **Accidental releases of radiation can occur while producing, using, storing, or transporting radionuclides.**
- **Long-term sequelae of acute high-level or low-level radiation (i.e., cancer and genetic effects) are difficult to assess for a number of reasons.**

Important data about human effects from exposure to ionizing radiation come from survivors of the atomic bomb detonations in Hiroshima and Nagasaki. Additional evidence comes from inhabitants of the Marshall Islands who experienced fallout from thermonuclear testing on Bikini Atoll, radium dial painters, pioneer radiologists, and patients receiving radiation therapy (e.g., patients who were irradiated in the 1950s as treatment for ankylosing spondylitis). Effects of high-level exposure include acute radiation sickness and fatalities. The major long-term health risks of ionizing radiation are cancer, birth abnormalities (from in utero irradiation), infertility, and genetic abnormalities, which are discussed in *Physiologic Effects*, page 13.

Risk of radiation-induced cancer in human populations is difficult to calculate for four reasons: (1) the total number of known radiation-induced cases is too small and the doses too high to allow accurate extrapolation to low doses; (2) cancer from other causes is a prevalent disease (the incidence of cancer morbidity in the U.S. population is 30% to 35%), making incremental incidences due to radiation exposure difficult to detect; (3) radiation-induced cancer cannot be distinguished from cancer due to other causes (although investigators using new molecular biology techniques are attempting to make this distinction possible); and (4) the interval between radiation exposure and cancer appearance may be several decades.

Exposure to low-level ionizing radiation occurs mostly in the workplace. Workers at risk are those involved in the following activities: operating nuclear power plants, other nuclear industrial facilities, or nuclear-powered naval vessels; purifying, enriching, and fabricating uranium for nuclear reactor fuel and for weapons production and use; and working at radionuclide storage sites. In addition,

medical technicians; researchers; uranium miners and other underground miners, cave guides, and spelunkers exposed to radon; industrial radiographers; and geologists using radiologic devices to measure pressure in wells are at risk of radiation exposure.

Criticality accidents (due to uncontrolled nuclear fission) have occurred at Los Alamos, New Mexico, in 1958; Oak Ridge, Tennessee, in 1958; Hanford Works, Richland, Washington, in 1962; and Wood River Junction, Rhode Island, in 1964. In addition, two early experiments (in 1945 and 1946) at the Los Alamos site resulted in uncontrolled nuclear fission. These accidents caused three early fatalities of workers closest to the nuclear reactions; the 22 other workers in the vicinity of the accidents were irradiated at doses less than 465 rem, and all survived for at least 5 years. The radiation from these accidents would have affected a larger area and a greater number of people if conditions during criticality had also resulted in the explosive release of large amounts of energy, which they did not.

The general public can be exposed to radiation through industrial or mining waste streams that contaminate air and drinking water. Releases of iodine-131 to air and water occurred at nuclear power plants in Hanford, Washington, during the period from 1943 to the 1960s and at Three Mile Island in 1978. The release of radioactivity at the Three Mile Island nuclear power plant resulted in an average radiation dose to the surrounding population of about 8 mrem over a radius of 10 miles and about 2 mrem over a radius of 50 miles from the reactor. These doses are conservatively expected to cause an additional 0.7 cancer deaths in the population living within the affected 50-mile radius. (By contrast, the number of cancer deaths estimated to occur from all other causes during the lifetime of this population of 2 million persons is about 390,000.)

Accidental releases of radioactive materials may also occur during transport of radionuclides or at sites storing them. Currently, low-level radioactive waste can be accepted at two commercial storage sites: Barnwell, South Carolina, and Hanford, Washington. The storage site at Beatty, Nevada, no longer accepts shipments of radioactive waste. No repository has yet been designated as a permanent storage site for high-level radioactive waste such as spent fuel from nuclear reactors.

Biologic Fate

- **Depending on their physical state, radionuclides may enter the body by ingestion, inhalation, or by absorption through the skin. They may also enter the body through breaks in the skin.**
- **Distribution, metabolism, and excretion depend on the radionuclide and its chemical form.**
- **Radium and transuranic radionuclides may remain in the liver and bone for years.**

Exposure to ionizing radiation can result from internal sources (i.e., radionuclides deposited within the body), external contamination (i.e., radionuclides deposited on the body surface), and irradiation by an external source. Internally deposited radionuclides frequently produce nonuniform radiation to proximate organs and tissues, depending on the radionuclide's distribution and metabolic characteristics. In many respects, internal contamination can be viewed as chronic exposure.

Radioactive substances can enter the body via inhalation, ingestion, skin absorption or through a contaminated wound. Inhalation is the most common route of internal contamination. Depending on particle size, aerosols may penetrate beyond the self-cleansing mucocilliary system of the central airways. For insoluble aerosols, such as oxides of plutonium and other transuranic elements (elements having an atomic number greater than uranium), the biologic fate usually includes transfer of the radionuclide by macrophages to regional lymph nodes and partial solubilization, with entry into the circulatory system. Heavy nuclides remain in the liver and bone for prolonged periods, typically years.

Hundreds of radioactive nuclides exist, but only a few are extensively used or produced and have the potential to cause significant internal contamination. The radionuclides in the environment of greatest potential concern are cesium-137, iodine-131, plutonium-239, radon-222, strontium-90, tritium, and uranium-238. A brief discussion of the biologic fates of each of these radionuclides can be found in *Appendix II.*

Challenge

Additional information for the case study: The radioactive material has been identified as an aqueous solution of potassium iodide, which was prepared from iodide-131. The cargo was being delivered to a repository for storage of low-level radioactive waste.

(4) Several hours after the accident occurred, a fireman who was first-on-scene is brought to the emergency room complaining of mild chest pain. He asks you if this pain could be caused by radioactivity in the smoke. Considering the biologic fate of iodide-131, is this a likely cause of the patient's chest pain? Explain.

Physiologic Effects

The immediate effect of exposure to high-level ionizing radiation is cytotoxicity, which results in changes in cellular function or direct cell death. Changes in cellular function may include delays in certain phases of the mitotic cycle (mitotic inhibition), disrupted cell growth, permeability changes, and changes in motility.

A suggested mechanism for radiation cytotoxicity involves the formation of ions, which interact with water and create inhibitory toxic chemicals (e.g., hydrogen peroxide) and free radicals that destroy the integrity of proteins, DNA, or other cellular constituents. The body's response to ionizing radiation depends on several factors, including the type and quality of radiation, dose, dose rate, and homogeneity of dose. If a cell receives a sublethal dose of radiation, cellular repair processes may be activated. Repair mechanisms are most likely responsible for the ability of the body to tolerate a higher total dose when exposure occurs over an extended period of time (i.e., at a low dose *rate*).

Cytotoxicity from radiation varies among cell types and tissues. In general, rapidly dividing cells that are poorly differentiated are most radiosensitive. For example, lymphocytes, primitive stem cells of the bone marrow, mucosal crypt cells of the gastrointestinal tract, spermatogonia, and granulosa cells of the ovary are particularly affected by radiation. Endothelial cells of the microcirculation and epithelial cells of many organs have an intermediate sensitivity. Muscle cells, neurons, erythrocytes, and polymorphonuclear granulocytes are relatively resistant to radiation. In most cases, maximum organ damage becomes evident as injured progenitor cells fail to replace the lost mature cells.

- **Rapidly dividing cells are the most sensitive to ionizing radiation.**

- **Hematopoietic changes become observable at exposure levels of about 25 to 100 rem. Changes in the function of most other cells or immediate cell death occurs at exposure levels greater than 100 rem.**

- **DNA repair mechanisms likely influence the effects of radiation exposure that has occurred over an extended period of time.**

Cancer

The largest body of evidence in support of the ability of ionizing radiation to produce cancer derives from studies of the survivors of the atomic detonations during World War II. The increased rates of various cancers in those persons are consistent with the increased rates for comparable cancers in other irradiated populations. A radiation dose of 100 rem causes about a 5% increase in the risk for developing a fatal cancer. Risk of some cancers (e.g., female breast cancer and multiple myeloma) more than doubles with exposure doses greater than 100 rem. A reasonable estimate of additional cancer mortality risk from a one-time whole-body dose of 1 rem is 1 to 5 fatal cancers in 10,000 persons so exposed (0.01% to 0.05%). This risk is in addition to the cancer mortality risk in the general U.S. population of about 1950 fatal cases in 10,000 persons (19.5%).

The first radiation-induced malignancy to appear in the atomic bomb survivors was leukemia. The latent period between radiation exposure and clinical recognition of leukemia ranged from 2 to 15 years.

- **Large doses of ionizing radiation will significantly increase the incidence of cancer in a population. However, at low doses, the incidence of radiation-induced cancer is difficult to detect.**

The risk to the survivors of developing this disease varies with the type of leukemia and the age at the time of exposure. For example, the incidence of chronic lymphocytic leukemia (CLL) is not measurably affected by the radiation level or dose, whereas the incidence of all other types of leukemia has been reported to increase with dose, and the risk is greater to those who were exposed at a younger age.

In the Japanese survivors, increased incidences for solid cancers appeared considerably later than the excess of leukemia. Carcinoma of the thyroid was the first of the solid tumors noted. An increased incidence of multiple myeloma and cancers at the following sites was also found: breast (female), lung, stomach, esophagus, small intestine, colon and rectum, brain and nervous system, ovary, uterus, urinary tract, and salivary glands. In populations irradiated occupationally or primarily for medical reasons, an increased incidence of cancers at these sites has also been reported, as well as at other specific sites including liver [due to internally deposited radionuclides], skeleton, and skin. Current medical reagents and procedures in nuclear medicine are designed to minimize residual radionuclides in the body and adverse side effects.

As with leukemia, the risks for solid tumors in the Japanese survivors are greater in persons who were younger at the time of exposure. The latency period for solid tumors due to radiation exposure is generally one or more decades. Interestingly, an increase in pancreatic cancer, the fourth leading type of fatal cancer in the United States, was not observed in atomic bomb survivors and has been observed inconsistently in other irradiated human populations (i.e., no clear relationship to dose or time after exposure could be identified).

Developmental Effects

❑ **The fetus, with its rapidly dividing cells, is especially radiosensitive.**

Exposure of pregnant women to ionizing radiation has been studied in several populations including survivors of the atomic bomb detonations in Japan. Preimplantation radiation exposure (i.e., within 2 weeks after conception) has not been found to produce anomalies in the fetus. If preimplantation damage occurs, it is likely that spontaneous abortion ensues. In women exposed during pregnancy, increased incidences of miscarriages, stillbirths, and neonatal deaths have been reported. Children exposed in utero have shown an excess of congenital defects.

In children born to survivors of the atomic bomb detonations, a pronounced association exists between gestational age at the time of exposure and the risk of neurodevelopmental effects. Exposure occurring during the first 7 weeks of gestation did not result in increased risks for mental retardation, reduced IQ, or seizure disorders. Exposures greater than 50 rad during gestational weeks 8 to 15, when nerve development and migration are greatest, showed linear dose-effect relationships for each of the above three endpoints and for microcephaly. This gestational period (i.e., 8 to 15 weeks) is recognized

as the most sensitive for the development of fetal neurologic effects (see *Case Studies in Environmental Medicine: Reproductive and Developmental Hazards*). A no-effect threshold for adverse neurodevelopmental effects during this gestational period could not be determined.

Exposures that occurred during 16 to 25 weeks of pregnancy also resulted in an increased risk of adverse neurodevelopmental effects, but to a lesser degree than during the period of peak sensitivity. Irradiation during the 16th to 25th week did not produce a linear relationship between dose and effect. In fact, a threshold for mental retardation appeared to exist. After 25 weeks of gestation, radiation exposures generally cause stunting of growth in the fetus, resulting in a newborn who has reduced physical size but remains normal in other ways.

Genetic Effects

In nonhuman forms of life, the developmental and genetic effects of ionizing radiation are well documented. Radiation exposure in these life forms results in congenital abnormalities and mutations that are transmitted to immediate and remote offspring. In experimental animals, the frequency of genetic effects due to radiation exposure generally increases as a linear-nonthreshold function of dose.

- **Genetic effects due to ionizing radiation are well documented in animals and other nonhuman forms of life.**

An epidemiologic study in Japan compared 38,000 children conceived after one or both parents were exposed to radiation from atomic detonations with 37,000 children whose parents were not exposed. No statistically significant differences were found in stillbirths, birth weight, infant mortality, or sex ratio. Among children of the exposed parents, there was also no effect seen on electrophoretic variants of 28 proteins of blood plasma and erythrocytes. These results may be due to relevant factors that were not controlled in the study. Although this study was negative, it does not prove that humans are exempt from radiation-induced genetic effects.

- **Although inheritable defects have not been evident in atomic bomb survivors, no reason exists to assume that humans are exempt from radiation-induced genetic effects.**

The dose needed to double the mutation rate in humans has been calculated to be higher than 100 rem, which is twice the average gonadal dose received by the atomic bomb survivors. Although the children of the survivors exhibited no inherited chromosomal abnormalities, the survivors themselves showed a dose-dependent increase in chromosomal abnormalities in somatic cells (i.e., circulating blood lymphocytes), which has also been detected in other populations exposed to ionizing radiation.

Some studies involving women who have had medical X-ray exposures suggest an association between maternal preconception exposure to ionizing radiation and the incidence of Down syndrome, while others do not. Thus, the studies are inconclusive. A similar paternal radiation effect has not been noted. Children whose parents

received preconception exposures of greater than 1 rem at Hiroshima and Nagasaki have not exhibited increased incidences of Down syndrome, leukemia, or non-Hodgkin's lymphoma.

Additional information for the case study: The boy is located with friends several hours after the accident and taken to the emergency department of the local hospital. He says he did not come in contact with the radioactive material.

(5) Is the boy a hazard to those with whom he has come in contact since the accident? Explain.

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_____

(6) Is the boy, the truck driver, or his assistant at increased risk of cancer? Explain.

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Clinical Evaluation

Acute Radiation Syndrome

Approximately half of those receiving a radiation dose of 500 rem will die within 30 days if untreated. Below 1000 rem, deaths are attributable to failure of the hematopoietic system. For doses between 1000 and 10,000 rem, death occurs due to ulceration and bleeding in the gastrointestinal tract. Doses above 10,000 rem immediately affect the cells of the nervous system. Depending on the exposure dose, these subsyndromes (i.e., hematopoietic, gastrointestinal, and neurovascular), which make up the acute radiation syndrome, may be discrete or overlapping (Table 6).

- **No immediate symptoms occur from acute doses of whole-body radiation below about 100 rem.**
- **The acute radiation syndrome consists of subsyndromes involving the hematopoietic, gastrointestinal, and neurovascular systems.**

Table 6. Acute effects of whole-body doses of ionizing radiation

rem*	
0 - 25	No detectable clinical effects; small increase in risk of delayed cancer and genetic effects
25 - 100	Temporary reductions in lymphocytes and neutrophils; sickness not common; long-term effects possible
100 - 200	Minimal symptoms; nausea/vomiting/diarrhea/fatigue in a few hours; reduction in lymphocytes and neutrophils, with delayed recovery; possible bone growth retardation in children
200 - 300	Nausea and vomiting on first day; following latent period of up to 2 weeks, symptoms (loss of appetite and general malaise) appear but are not severe; hematopoietic subsyndrome; recovery likely in about 3 months unless complicated by previous poor health
300 - 600	Nausea, vomiting, and diarrhea in first few hours, followed by latent period as long as 1 week with no definite symptoms; loss of appetite, general malaise, and fever during second week, followed by hemorrhage, purpura, inflammation of mouth and throat, diarrhea, and intestine destruction in third week; some deaths in 2–6 weeks; possible eventual death to 50% of those exposed
600 - 1000	Vomiting in 100% of victims within first few hours; diarrhea, hemorrhage, and fever toward end of first week; rapid emaciation; almost certain death
1000 - 5000	Vomiting within 5–30 minutes; 100% incidence of death within 2–4 days
>5000	Vomiting immediately; 100% incidence of death within a few hours to 2 days
Also	
>15	In men yields temporary sterility
>300	In women yields permanent sterility

*rem = rad equivalent in man or mammal

Adapted from: Goldman M. Ionizing radiation and its risks. In: Occupational disease—new vistas for medicine. West J Med 1982;137:540-7.

Acute radiation illness begins with a prodromal period manifesting within hours or a few days. Prodromal symptoms include anorexia, nausea, vomiting, and diarrhea. A latent period of 5 to 7 days then occurs during which the patient appears to have recovered. Within 2 weeks after exposure, the patient will manifest illness that requires aggressive therapy; this critical period may last up to 4 weeks. Generally, the higher the absorbed dose, the shorter the latent period and the more rapid the onset and severity of illness during the critical period.

At levels above 100 rem whole-body dose, radiation-sensitive stem cells in the bone marrow and lymphoid tissues are destroyed or mitotically impaired. The more radio-resistant mature elements normally circulating in the blood cannot be replaced promptly, and fatal hemorrhage can result from platelet loss. Infection from decreased production of granulocytes and other cells can also occur. Recovery has been reported after exposure to 300 to 600 rem when intensive supportive care was provided. Erythrocyte production is also decreased, but in the absence of bleeding, anemia develops only slowly and in modest severity because erythrocytes have a long life span.

Acute radiation doses exceeding 600 rem to the abdomen or whole body usually result in significant damage and reproductive impairment of rapidly proliferating crypt stem cells, thus producing the gastrointestinal tract subsyndrome. The existing mucosa is shed, preventing normal absorption and causing the gut to leak electrolytes and blood. The denuded mucosa becomes a portal of entry for intestinal bacteria; severe diarrhea, shock, and sepsis occur. Although medical therapy may delay death from these causes, the patient usually succumbs.

Acute doses of more than 3000 rem cause damage to capillaries, resulting in a more immediate neurovascular subsyndrome. Within 1 hour after exposure, neurologic symptoms of confusion, prostration, and loss of balance develop. Diarrhea, respiratory distress, intractable hypotension, and central nervous system (CNS) collapse rapidly ensue. Massive damage to the microcirculation probably is responsible for the cerebral edema that causes brain damage. The initial hypotension may be due to release of histamine by the granulated mast cells. At this radiation dose, medical efforts are futile, and death occurs within 48 hours after exposure.

Local Radiation Injury

In a radiation accident, high local exposures may complicate whole-body exposures. Since 1945, about 300 radiation accidents have occurred in the United States, the majority of which have involved industrial devices containing cobalt-60 or iridium-192. Injury to the skin depends on the type of radiation, as well as the strength of the source and duration of the contact. For example, beta radiation typically produces a shallow injury, whereas gamma radiation penetrates more deeply. Both cobalt-60 and iridium-192 are gamma emitters and can produce contact doses that result in immediate and severe third-degree burns. Third-degree contact burns are generally painless and actual skin damage may be worse than is immediately apparent. Most local injuries involve the hand; other common sites are the thighs and buttocks when radioactive sources are carried in pants' pockets. The acute radiation syndrome may also be present in patients who have severe local contact injury.

- **Contact with a radioactive source can result in burns that are worse than is immediately apparent.**

- **Most local radiation injuries involve the hands.**

The intensity of radiation from a source decreases as the distance from the source increases, in accordance with the "inverse square" rule. For example, a dose of 1024 rads at 1 meter from a source is reduced to 256 rads at 2 meters and 64 rads at 4 meters. If the immediate signs and symptoms after a local radiation exposure include erythema of skin and severe pain, the local absorbed dose is probably in excess of 1000 rads. Evidence of transepithelial injury and dry desquamation may follow. At doses above about 2000 rads, blistering and a wet radiodermatitis may ensue. Later, tissue necrosis due to secondary vascular impairment may occur. These injuries are similar to thermal burns in appearance. In radiation cases, erythema may increase during the first week after exposure and fade during the second week but may recur. A feeling of tenderness and itching usually persists.

Laboratory Evaluation

External Indicators

Instruments used to measure radiation levels in the environment are generally of two types: area survey meters and personnel dosimeters. If either dosimetry is available, contact a health physicist for interpretation. These radiation experts are employed at local or state departments of health, universities, and the Radiation Emergency Assistance Center/Training Site (REAC/TS) at Oak Ridge Institute for Science and Education (see *Other Sources of Information*, page 29).

- **An accurate assessment of radiation dose is a useful, though not essential, confirmatory aid to clinical judgment in treating severely affected patients.**

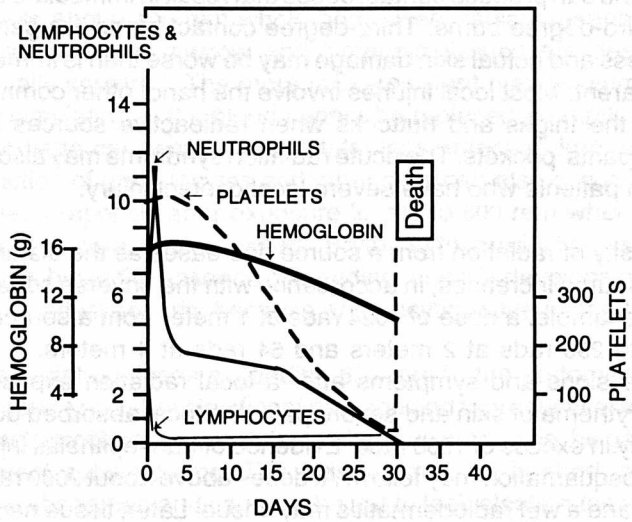
Internal Indicators

If whole-body radiation has occurred, several hematologic parameters can be used to predict biologic effects, as well as to estimate physical dose. The earliest indicator is a fall in the lymphocyte count, which may reach its nadir within 48 hours (Figure 3). At doses

- **Lymphocytes are a biologic marker for radiation exposure.**

up to 300 rad, the rate of fall in circulating lymphocytes is related directly to dose. At doses greater than 300 rad, profound lymphocytopenia occurs, and lymphocyte count becomes unreliable for dose estimation.

Figure 3. Typical hematologic response* to a whole-body radiation dose of 450 rads



* Lymphocyte, neutrophil, and platelet values should be multiplied by 1000. Hemoglobin values are in grams per deciliter.

Adapted from: Goldman M. Ionizing radiation and its risks. In: Occupational disease—new vistas for medicine. West J Med 1982;137:540-7.

Unlike lymphocytes, granulocytes (represented by neutrophils in Figure 3) are not directly lysed by radiation and provide another indication of dose. At whole-body doses of 200 to 500 rads, a brief rise in the peripheral granulocytic count typically occurs in the first few days after exposure. The rise, which is a nonspecific stress response, is followed by a progressive fall, an abortive rise or plateau, and another fall, the true nadir of which is reached within 30 days after exposure. Doses greater than 500 rads cause increasingly earlier and more severe granulocytopenia. The severity of thrombocytopenia (see platelets in Figure 3) is also an indicator of dose.

A useful and sensitive biomarker for dose estimation in acute whole-body radiation exposures, as well as to predict the long-term health risks in large populations exposed to low levels of radiation, is the chromosome aberration assay. Radiation induces several nonspecific but characteristic chromosomal abnormalities, particularly dicentric chromosomes. By scoring the frequency of these abnormalities in lymphocytes in the peripheral blood or bone marrow and comparing the frequency to aberrations produced by irradiating peripheral blood in

vitro, a relatively accurate estimation of radiation dose can be made. Chromosomal aberrations are visible within hours after radiation exposure, and the optimum time to perform the assay is within the first few weeks after exposure. Details of sample preparation and the names of laboratories able to perform cytogenetic assays for radiation exposure can be obtained from REAC/TS (telephone: [615]-576-3131 [day]; [615] 481-1000 [24-hour hotline]).

Indicators of internally deposited radionuclides will depend on the biologic fate and the biologic half-life of the radioactive substance. If the metabolic pathway and biologic and physical half-lives are known, an estimate of dose to the target organ can be made by bioassay. Methods for measuring the amount of radioactivity in the body include urinalysis, fecal analysis, whole body scans, and thyroid scans for exposure to radioactive iodine.

Cytogenetic assays may also be used to detect damage from internally deposited radionuclides. However, these data are not useful in estimating dose to the target organ because internal radionuclides are seldom distributed uniformly within the body. This uneven distribution can affect the radiation received by the circulating lymphocytes and even their survival.

(7) About 36 hours after arriving at the emergency department, the driver in the case study and his assistant experience nausea and vomiting. What is the prognosis for these patients?

(8) In the emergency room you have an opportunity to examine the young boy. What history or other information will help you determine his prognosis?

(9) One month later, the boy's parents ask you to perform a test that will prove the boy was exposed to radiation. Is this possible? Explain.

Treatment and Management

Early Considerations—Decontamination

- **An important consideration in decontamination is to prevent the spread of radioactive materials.**

- **The psychologic effects of actual or potential radiation exposure are often overlooked.**

If radioactive materials are present in a workplace, it is important to have decontamination materials available and a written plan for their utilization. Radiation detection equipment is used to identify a worker contaminated with radioactive liquids or solids (e.g., dusts), as well as the body area that is contaminated.

The first step in decontamination is removal of contaminated clothing, then careful washing of the areas around eyes, nose, and mouth with a washcloth. Showering should be avoided when external contamination is localized because showering can spread radionuclides to clean areas. Mild soap and water are frequently all that is needed to emulsify and remove contamination. Gentle brushing or use of a mildly abrasive soap will help dislodge contamination physically held by skin protein. Harsh abrasives should be used cautiously because they may open a path through the keratinized layer of the skin and allow internal contamination. Addition of a chelating agent to the wash water may help by binding the radionuclide in a complex. Contaminated wash water must be collected and disposed of properly. Instructions for disposal can be obtained from REAC/TS (telephone: [615]-576-3131 [day]; [615] 481-1000 [24-hour hotline]).

Radiation monitoring of the cleaned, dried skin should be done between washings. If repeated washings do not totally remove contamination, the material is probably fixed in skin, which will normally be shed; a frequently changed bandage over the area will prevent spread of contamination via the sloughed skin. In stubborn cases where contamination is localized in the thick horny layers, such as palms and soles of feet, sticky tape or a high-speed abrasive wheel can be used. However, if these techniques are not used properly, they can lead to skin cuts or increased percutaneous absorption. It may be necessary to remove contaminated hair by using clippers or an electric razor. All potentially contaminated material, including hair, debrided tissue, and, if internal contamination has occurred, vomitus and excretion products, must be collected in plastic bags for proper disposal.

If the contaminated worker is physically traumatized, the emergency department plan for management of radiation-accident casualties should be executed. Lifesaving medical care takes precedence over decontamination procedures. After emergency care has been administered, gross decontamination should be conducted on site. Further decontamination can occur at the medical facility. The patient should be wrapped in blankets to prevent the spread of contamination during transport. If the medical facility is not prepared for radiation decontamination and does not have an appropriate decontamination room, the patient should be decontaminated outside or away from areas

where normal activities occur. Care must be taken to prevent the spread of radioactivity within the facility.

The general public perceives the risk of death or injury from radiation as greater than do scientists. Dealing with the fear and mental stress caused by an accident is a significant part of emergency management. Techniques for combatting this anxiety include educating the public before an emergency occurs, efficiently disseminating factual information using a single credible source during the emergency, and presenting evidence that a plan to manage the emergency is in place and working.

Acute Radiation Syndrome

Patients who have received acute total body radiation of 500 rads or more will develop severe pancytopenia and will require aggressive supportive measures. Patients developing aplastic anemia are at risk for systemic bacterial, fungal, and viral infections; infections and bleeding are the major causes of morbidity and mortality. Clinicians are encouraged to consult a hematologist, radiation oncologist, health physicist, or other radiation specialist knowledgeable about acute radiation illness and its treatment. Some referral sources are given in *Other Sources of Information*, page 29. A general treatment scheme for acute radiation injury is presented in Figure 4.

- **Bleeding and infections, which are the primary causes of morbidity and mortality in patients acutely exposed to radiation, should be promptly treated by specialists.**

Local Radiation Injury

Radiation exposures that produce only erythema (300-1000 rad) can be treated as first-degree burns. Burns that result in desquamation (1000-2000 rad) are transepidermal and are similar to second-degree burns. Large surface-area burns may require systemic hydration. Skin grafting may be useful, but success depends on the depth of radiation penetration and the vascular status of the underlying tissues. Third-degree burns are produced by doses greater than 3000 rad. Third-degree burns heal by scarring; as a result, contraction and loss of function may occur, particularly if extremities are involved. Extensive plastic surgery may be required to prevent or limit loss of function. Amputation may be necessary.

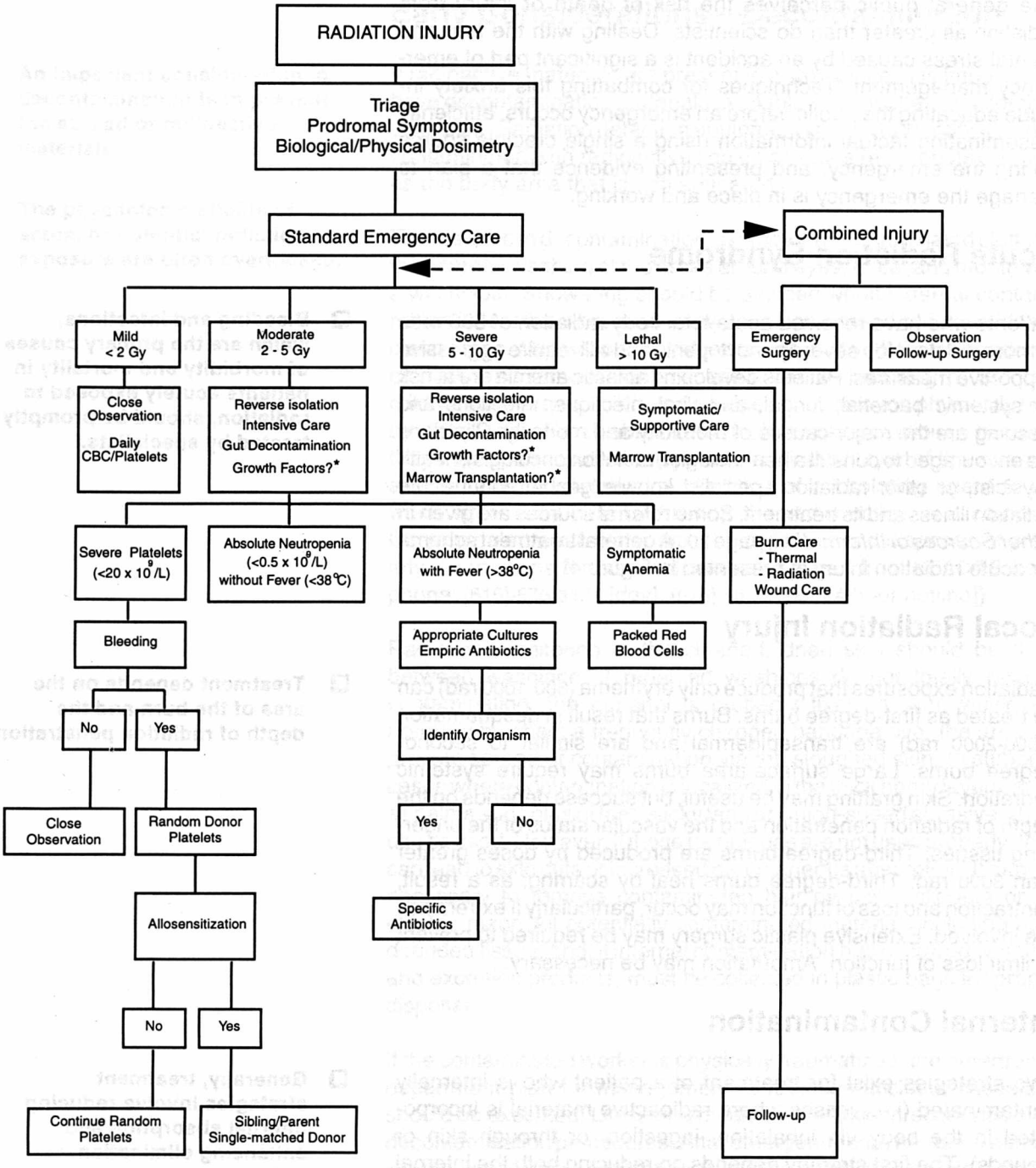
- **Treatment depends on the area of the burn and the depth of radiation penetration.**

Internal Contamination

Two strategies exist for treatment of a patient who is internally contaminated (i.e., cases where radioactive material is incorporated in the body via inhalation, ingestion, or through skin or wounds). The first strategy depends on reducing both the internal absorption and deposition of radioactive material ("blocking"); the second strategy depends on enhancing the elimination and excretion of the radioactive material ("decorporation").

- **Generally, treatment strategies involve reducing internal absorption and enhancing elimination.**

Figure 4. Treatment scheme for patients receiving an acute high-dose radiation exposure



* Whole-body exposures greater than 4 Gy may require bone marrow transplantation or administration of colony-stimulating factors or other hematopoietic growth factors that stimulate proliferation of hematopoietic stem cells. However, few data exist to support firm recommendations about the use of these treatments for radiation victims.

Adapted from: Browne D, Weiss JF, MacVitlie TJ, Pillai MV. Treatment of radiation injuries. New York: Plenum Press, 1990.

In radiation accidents, the identity of the radionuclide contaminant and its chemical and physical state must ultimately be determined. Radionuclides present at a workplace are usually known, and shipping documents and load manifests detail the hazardous contaminantsat transportation accidents. Sometimes it will not be clear whether internal contamination has occurred. Samples collected during external decontamination will provide clues about possible internal contamination. Skin wipes, nasal swabs, urine, and feces should be collected for analysis at a laboratory capable of detecting and identifying radionuclides. Local and whole-body counting can be done at specialized facilities. As mentioned above, gentle mechanical cleansing of wounds and skin and the areas around mouth and nose will prevent further ingestion and absorption of radioactive materials.

Chelation with diethylenetriaminepentaacetic acid (DTPA) accelerates the urinary excretion of some transuranic metals (e.g., plutonium, californium, americium, and curium) and some rare earth ions (e.g., cerium, yttrium, lanthanum, promethium, and scandium). DTPA is an investigational drug available from REAC/TS (see *Other Sources of Information*, page 29). DTPA can be administered intravenously or as an inhaled aerosol according to treatment protocols established by investigators at REAC/TS. In rare cases of massive pulmonary deposition of very hazardous aerosolized radionuclides, lung lavage may be of value. *Appendix III* is a treatment summary for selected elements.

- **Treatment of a patient who is internally contaminated is specific to the contaminating radionuclide and chemical form.**

Challenge

(10) How will you manage and treat the truck driver and his assistant in the case study? Assuming the young boy has experienced no immediate effects from the irradiation, what follow-up is appropriate for him?

_____

Additional information for the case study: An hour after the accident, the concentration of radioactivity at the point where the material entered the river was measured at 20 picoCuries per liter (pCi/L) of river water. The town switched to an alternate source of drinking water. Two weeks later, the state public health department declared the river water safe, and the town resumed using the river as its source of drinking water.

(11) You continue to receive calls from your patients, expressing fear and concern about exposure to radioactivity. One of these patients insists that a rash that developed on his arm yesterday is caused by showering with "radioactive water." A patient who is pregnant fears that her unborn child will be malformed or have cancer as a result of her drinking water from the river. How will you respond?

_____

Standards and Regulations

During the period 1900 to 1930, standards for radiation protection were informal and set quite high (approximately 60 R/year). They reflected concern for acute effects of exposure. When concerns over the long-term effects of radiation exposure began to develop (1930 to 1950), protection standards were formalized. The recommendation in 1934 of the U.S. Advisory Committee on X-Ray and Radium Protection (now the National Council on Radiation Protection and Measurements [NCRP]) was to restrict whole-body exposures to less than 0.1 R/day. From 1950 to 1960, attention centered on genetic effects of radiation exposure, and recommendations were proposed to limit exposure to the equivalent of 5 rem/year, which applied to both the general public and workers. Because any amount of radiation exposure poses some risk, all standards now employ a philosophy that radiation exposures should be limited to levels that are as low as reasonably achievable (ALARA) and consistent with the benefits of radiation to society.

Regulatory agencies in the United States that are involved in radiation control include the Nuclear Regulatory Commission, Department of Transportation, Food and Drug Administration, Occupational Safety and Health Administration, and the General Accounting Office. EPA has also established a standard for drinking water of 5 pCi/L, which applies to radioactivity from radium-226 and radium-228 combined. A new drinking water standard of 20 pCi/L each for radium-226 and radium-228 has been proposed.

Many states and cities also have regulations concerning the use of and protection from radiation. NCRP, established in 1964 to advise Congress on issues related to radiation, and the International Commission on Radiological Protection (ICRP) recommend the standards in Table 7.

Table 7. Summary of recommendations for ionizing radiation

Dose Limits for Workers*	**ICRP, 1991†**	**NCRP, 1993¶**
Based on stochastic effects§ (e.g., cancer and genetic damage)	5 rem (50 mSv) annual effective dose limit and 10 rem (100 mSv) as 5-year cumulative effective dose limit	5 rem (50 mSv) annual effective dose limit and 1 rem (10 mSv) times age in years cumulative effective dose limit
Based on nonstochastic effects§ (e.g., lens cataracts and fertility impairment)	15 rem (150 mSv) equivalent dose limit to lens of eye and 50 rem (500 mSv) annual equivalent dose limit to skin, hands, and feet	15 rem (150 mSv) annual equivalent dose limit to lens of eye and 50 rem (500 mSv) annual equivalent dose limit to skin, hands, and feet
Dose Limits for the Public*	**ICRP, 1991**	**NCRP, 1993**
Based on stochastic effects	0.1 rem (1 mSv) annual effective dose limit, and, if needed, higher values provided that the annual average over 5 years does not exceed 0.1 rem	0.1 rem (1 mSv) annual effective dose limit for continuous exposure and 0.5 rem (5 mSv) annual dose limit for infrequent exposure
Based on nonstochastic effects	1.5 rem (15 mSv) annual equivalent to lens of eye and 5 rem (50 mSv) annual equivalent dose limit to skin, hands, and feet	5 rem (50 mSv) annual equivalent dose limit to lens of eye, skin, and extremities
Embryo-fetus	0.2 rem (2 mSv) equivalent dose to the woman's abdomen once pregnancy has been declared	0.05 rem (0.5 mSv) equivalent dose limit in a month once pregnancy is known

* The dose limits for both workers and the public exclude medical and natural background exposures. Note that the dose limits for the public are lower, in general, than those for workers. Workers, by virtue of the ability to work, tend to be a healthier population than the public, which includes susceptible populations, the elderly, and children.

† International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Annals of the ICRP 21. Elmsford, New York: Pergamon Press, 1991.

¶ National Council on Radiation Protection and Measurements (NCRP). Limitation of exposure to ionizing radiation. Bethesda, Maryland: NCRP, 1993. NCRP Report No. 116.

§ Stochastic effects are those effects for which the probability of occurrence, rather than the magnitude of the effect, is proportional to dose. Not all irradiated persons show such effects; however, the probability that they will can be described by a dose-response curve that extends to zero with no threshold. Nonstochastic effects are proportional in severity to the magnitude of the absorbed dose; they probably have a threshold below which no effect will be observed because simultaneous injury to many cells is required.

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Other Sources of Information

More information on the adverse effects of ionizing radiation and the treatment and management of radiation-exposed persons can be obtained from ATSDR, your state and local health departments, and university medical centers. For clinical consultation and assistance, physicians and other health care providers are urged to contact

> Radiation Emergency Assistance Center/Training Site (REAC/TS)
> Telephone: (615)-576-3131 (day); (615) 481-1000 (24-hour hotline)
> c/o Oak Ridge Institute for Science and Education, P.O. Box 117,
> Oak Ridge, Tennessee, 37831-0117.

Information and assistance may also be obtained from the Nuclear Regulatory Commission (202) 492-7000 and CHEMTREC ([800] 424-9300; 24-hour hotline) or from the offices listed below.

The United States Department of Energy (DOE) regional coordinating offices should be notified for radiological assistance as soon as possible. At the request of a patient or the attending physician, a DOE radiologic assistance team physician may give advice regarding hospitalization and further definitive treatment. The physician may also make available special DOE medical facilities for the diagnosis and treatment of radiation injury. DOE's geographical areas of responsibility are listed below. Through this single contact, the resources of thirteen federal agencies will be made available.

Department of Energy Regional Offices

Region 1 (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont)

Brookhaven Area Office	Upton, Long Island
(516) 345-2200	New York, NY 11973

Region 2 (Arkansas, Kentucky, Louisiana, Mississippi, Missouri, Puerto Rico, Tennessee, Virginia, Virgin Islands, and West Virginia)

Oak Ridge Operations Office	PO Box E
(615) 576-6833 or (615) 525-7885	Oak Ridge, TN 37831

Region 3 (Alabama, Canal Zone, Florida, Georgia, North Carolina, and South Carolina)

Savannah River Operations Office	PO Box A
(803) 824-6331, ext. 3333	Aiken, SC 29802

Region 4 (Arizona, Kansas, New Mexico, Oklahoma, and Texas)

Albuquerque Operations Office	PO Box 5400
(505) 844-4667	Albuquerque, NM 87115

Region 5 (Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin)

Chicago Operations Office	9800 S Cass Avenue
(312) 972-5731 or (312) 972-4800	Argonne, IL 60439

Region 6 (Colorado, Idaho, Montana, Utah, and Wyoming)

Idaho Operations Office	PO Box 2108
(208) 526-1515	Idaho Falls, ID 83401

Region 7 (California, Hawaii, and Nevada)

San Francisco Operations Office	333 Broadway
(510) 273-4237	Oakland, CA 94612

Region 8 (Alaska, Oregon, and Washington)

Richland Operations Office	PO Box 550
(509) 842-7381	Richland, WA 99352

Answers to Pretest and Challenge Questions

Pretest questions are on page 1. Challenge questions begin on page 5.

Pretest

(a) Consultation for treatment of persons exposed to radiation may be obtained from REAC/TS at (615) 576-3131 (day) or (615) 481-1000 (24-hour hotline) or from other sources listed on page 29.

(b) Ideally, decontamination should be performed immediately at the site of the accident. Attending personnel must be properly protected to prevent secondary contamination. After emergency care for life-threatening trauma has been administered, the patients' contaminated clothing should be removed and double-bagged. The patients' skin and hair should be flushed with water, and the contaminated water should be caught in a child's play pool or other device for later disposal. A mild soap may be used to remove oily or adherent material. Monitoring the clean, dried skin with a beta-gamma counter between flushings will indicate the effectiveness of the decontamination procedure.

If the accident occurs in inclement weather or at a site where washing facilities are unavailable or if the patient is in need of immediate medical care, decontamination may have to be delayed. In that case, care must be taken to prevent the spread of contamination during transport by wrapping the patient in blankets. If the hospital or other medical facility is not prepared to handle a patient who is externally contaminated with radioactivity, a temporary decontamination station can be set up at the medical care facility. It should be located outside, but if that is not feasible, it should be far removed from normal activity and other patient care areas. If decontamination is performed indoors, ventilation should be suspended so that no radioactivity escapes the room. Butcher paper taped to the floor and other surfaces is an effective barrier. All potentially contaminated material, including debrided tissue, must be collected in plastic bags for proper disposal. Attending personnel must be properly attired with disposable jumpsuits, gloves, or other protective equipment to avoid contamination through contact.

(c) The potential health consequences will depend on the boy's interaction with the radioactive material. For example, it is not known whether the boy contacted the material and subsequently ingested radioactive material through hand-to-mouth activity, which would result in an internal contamination hazard. An external radiation hazard could exist if the boy contacted the material and is carrying radionuclides on his skin. Finally, the boy may have only approached the source, but may have been close enough to be exposed to beta and gamma radiation.

Assuming no contact occurred and the boy's proximity to the source were known, a radioactivity counter could provide dosimetric information that would aid in estimating his exposure. Maximum potential dose can also be calculated based on the characteristics of the source and the presumed location of the boy. The intensity of radiation decreases as the distance from the source increases, in accordance with the "inverse square" rule.

It is unlikely that the occupants of the houseboat would be affected by beta radiation, which has a relatively short range and can usually be stopped by a few feet of air. Gamma radiation has greater penetration than beta radiation; therefore, gamma radiation could have reached the houseboat about 20 yards from the source. However, shielding by the houseboat or other structures could reduce the radiation. A gamma counter might be used to obtain direct dosimetric information inside the houseboat.

(d) In this case, it is unlikely that any steps will be required to protect the members of the community who rely on the river for drinking water; however, a public health official will make that determination. Iodide-131 has a radiation half-life of 8 days. In just 32 days (4 half-lives) the amount of radioactivity will be one-sixteenth of what it was originally. Dilution by the river will also reduce the concentration of radioactivity.

Should the radioactivity level be of concern, an alternate source of water can be supplied to the community during the time required for the radioactive material to decay to a level that is considered to be safe by a health physicist. The antidote for radioactive iodide is early administration (within about 2 hours of ingestion of radioactive iodine) of SSKI (supersaturated potassium iodide [KI] solution) or iodide tablets. Stable iodide blocks absorption of iodide-131 in the thyroid. Oral administration of stable iodide is an effective and relatively inexpensive means to protect exposed residents of a community.

Cesium-137 has a 30-year radiologic half-life. It would take 120 years for the radioactivity from this source to decay to one-sixteenth of its original value. The water could remain unusable for a prolonged period depending on the concentration of cesium-137 and the characteristics of the river (e.g., volume and flow rate).

Cesium is distributed uniformly throughout the body and is rapidly eliminated by the kidneys. The experimental antidote for cesium is oral administration of ferric cyanoferrate (II). Commonly referred to as Prussian blue, this antidote binds the cesium ions that are enterically cycled and prevents their reabsorption from the gastrointestinal tract. The effectiveness of the antidote depends on the length of treatment and how soon after exposure it is started. However, Prussian blue is not approved by the Food and Drug Administration for general use or as an antidote for radioactive cesium. A radiation specialist at REAC/TS should be consulted before the antidote is administered.

Challenge

(1) The RWF for beta or gamma radiation is one; therefore, a dose of 50 mrads of beta or gamma radiation is equivalent to 50 mrem or 0.05 rem. One Sievert equals 100 rem; therefore, 0.05 rem equals 0.0005 (5×10^{-4}) Sv.

(2) The RWF for X radiation is also one; therefore, a dose of 50 mrads of X radiation would produce the same biologic effect as 50 mrads of gamma or beta radiation.

Iodide-131 is not an alpha-emitter; however, if the radioactive material was emitting alpha particles and the material was ingested, the biologic effectiveness would be greater. The RWF for alpha particles is 20, which indicates a given dose of alpha radiation is twenty times more biologically effective than the same dose of beta or gamma radiation.

(3) Potential sources of radiation for the truck driver, as well as the general public, are as follows:

- Cosmic radiation and terrestrial radiation each produce an average dose rate of 30 mrem/year. Radon exposure provides an additional dose of about 200 mrem/year.
- Potassium-40 naturally present in human tissue contributes an average dose rate of about 65 mrem/year.
- Building and construction materials contribute variable dose rates. Occupants of wood frame buildings typically receive less than 10 mrem/year; occupants of masonry structures receive about 13 mrem/year.
- Atmospheric fallout provides an exposure dose rate of about 5 mrem/year.
- Consumer products, including tobacco, contribute a dose rate of less than 5 mrem/year when expressed as whole-body exposure.
- Medical diagnostic and therapeutic radiation is variable and generally applied locally; the average dose rate due to medical procedures is estimated to be 100 mrem/year.

(4) It is not likely that the radioactivity is the direct cause of the chest pain. If the iodide-131 vaporized and was inhaled, it would be absorbed from the lungs into the bloodstream and concentrated in the thyroid. However, this action would cause the patient no immediate discomfort. The cause of the chest pain must be sought elsewhere.

(5) If the boy had no physical contact with the radioactive material and was only irradiated by the gamma and beta energy, he is not a radiation hazard to others. Had the boy contacted the waste and radioactive material was transferred to his skin or clothing, then he would be a hazard because the residue would continue to emit radiation and irradiate those nearby, or he could secondarily contaminate others through contact.

(6) All three of these persons are at increased risk of cancer, and the risk increases in proportion to the dose of radiation received. If the boy did not contact the radioactive material, he presumably received less radiation than the driver and his assistant, and therefore, would be at much less risk. A small proportion of persons exposed to radiation will develop cancer as a result; if exposed persons do develop cancer, it may never be certain whether the cancer was the result of radiation exposure or other causes. (A carcinoma induced by radiation is histologically indistinguishable from other carcinomas).

(7) Acute radiation syndrome is characterized by nausea and vomiting, which begins within 1 to 4 hours after exposure and may last as long as 48 hours, with the extent of symptoms related to the severity of exposure. The onset of vomiting for these patients is delayed, occurring about 36 hours after exposure; therefore, it is unlikely that these symptoms are directly due to radiation exposure. The cause must be sought elsewhere (e.g., anxiety). If the onset of nausea and vomiting was as late as 4 hours after exposure, the hematopoietic subsyndrome would likely ensue, and illness due to bleeding and infection could develop. In either case, with appropriate supportive care, the driver and his assistant should recover.

(8) Pertinent clinical history includes proximity to the source and duration of the exposure. Whether gastrointestinal symptoms (nausea, vomiting, and diarrhea) have occurred is important because the time of onset of these symptoms can be inversely correlated with the severity of exposure. A complete blood count, including a lymphocyte count, can also help to estimate the severity of exposure; these tests should be repeated several times during the first few days after exposure.

(9) A useful and sensitive biomarker for radiation exposure in general is the chromosome aberration assay. Radiation induces several characteristic but nonspecific chromosomal abnormalities, particularly dicentric chromosomes, in peripheral blood lymphocytes. The optimum time to perform the assay is within hours to a few weeks after exposure. Only a few laboratories are prepared to perform and interpret this radiation cytogenetic assay; call REAC/TS at (615)-576-3131 (day) or (615) 481-1000 (24-hour hotline) for further information.

(10) Assuming the truck driver and his assistant experienced no internal contamination, treatment is supportive and symptomatic. See page 24 for a treatment scheme that is based on the degree of irradiation.

During the next week, the boy's lymphocyte count should be periodically checked; no other immediate follow-up is required. An ongoing medical surveillance program is unwarranted unless the clinical evidence contradicts the health physicist's original estimate of maximum radiation exposure indicated in Challenge question 1. A whole-body dose of 50 mrads is similar to doses received in some medical diagnostic procedures.

(11) Fear is a natural reaction when people feel they may have been exposed to radiation. Reassurance is needed to alleviate the emotional and psychologic stresses that are caused when an accident involving radioactivity occurs. (See Ricks et al., 1991, in *Suggested Reading List*, page 29, for a discussion of the psychologic aspects of radiation exposure.)

You could point out that the levels of radioactivity initially found in the river soon after the accident were low (i.e., 20 pCi/L). Depending on the dynamics of the river, the radioactivity level is likely to be even lower now. The proposed drinking water standard for iodine-131 is 108 pCi/L.

To further reassure these patients, you could suggest that they have their water tested for radioactivity. You or the health physicist could also calculate the potential maximum amount of radiation exposure and compare this to information in the literature (e.g., Table 6, page 17). No immediate clinical symptoms have been associated with the amount of radiation these patients were likely to have received by ingesting or contacting the contaminated water, and the additional long-term risk of cancer at these radiation levels is negligible.

Posttest and Credits

Continuing education credit is available to health professionals who use this monograph and complete the posttest. The criterion for awarding continuing medical education (CME) credits and continuing education units (CEU) is a posttest score of 70% or better.

The Centers for Disease Control and Prevention (CDC) is accredited by the Accreditation Council for Continuing Medical Education (ACCME) to sponsor continuing medical education for physicians, and by the International Association for Continuing Education and Training (IACET) to sponsor continuing education units for other health professionals.

The Agency for Toxic Substances and Disease Registry, in joint sponsorship with CDC, is offering 1 hour of CME credit in Category 1 of the Physician's Recognition Award of the American Medical Association and 0.1 hour of CEU for other health professionals upon completion of this monograph.

In addition, the series *Case Studies in Environmental Medicine* has been reviewed and is acceptable for credit by the following organizations:

The **American Academy of Family Physicians (AAFP).** This program has been reviewed and is acceptable for 1 prescribed hour by the American Academy of Family Physicians (term of approval: beginning January 1992). For specific information, please consult the AAFP Office of Continuing Medical Education.

The **American College of Emergency Physicians (ACEP).** Approved by the American College of Emergency Physicians for 1 hour per issue of ACEP Category 1 credit.

The **American Osteopathic Association (AOA).** AOA has approved this issue for 1 credit hour of Category 2-B credit.

The **American Association of Occupational Health Nurses (AAOHN).** This independent study offering has been approved for 1.4 contact hours (term of approval beginning July 19,1996) by AAOHN, which is accredited as an approver of continuing education in nursing by the American Nurses Credentialing Center's Commission on Accreditation. For current approval status, contact AAOHN at 404-262-1162.

The **American Board of Industrial Hygiene (ABIH).** ABIH has approved this program for 0.5 certification maintenance (CM) point per 3 case studies. The CM approval number is 2817.

To receive continuing education credit (CME or CEU), complete the Posttest on page 36 in the manner shown in the sample question below. **Circle all correct answers.**

Which of the following is known to precipitate migraine headaches?

(a) fatigue
(b) alcohol
c. grapefruit
(d) sunlight
e. sleep

After you have finished the Posttest, please record your answers on page 37 and complete the evaluation on the lower half of that page. Fold, staple, and mail that page to Continuing Education Coordinator, Agency for Toxic Substances and Disease Registry, Division of Health Education, E33, 1600 Clifton Road, NE, Atlanta, GA 30333. Your confidential test score will be returned with an indication of where the correct answers can be found in the text. Validation of earned CME credit and CEU will also be forwarded to participants, and their names, if requested, will be placed on the mailing list to receive other issues in the *Case Studies in Environmental Medicine* series.

POSTTEST: IONIZING RADIATION

Circle **all** correct responses and record your answers on page 37.

1. Potential sources of radiation exposure include
   a. isotopes inside the body
   b. nuclear reactors
   c. rocks and soil
   d. automobile repair shops
   e. medical radiation therapy facilities

2. Whole-body radiation exposures of 10 rem
   a. double the risk of cancer.
   b. produce small head size in most exposed fetuses.
   c. cause erythema of the skin.
   d. depress lymphocyte count within 48 hours.
   e. cause no immediate clinical symptoms.

3. Patients irradiated by an external source of ionizing radiation
   a. may be at risk for the acute radiation subsyndromes.
   b. will require decontamination.
   c. are a danger to emergency department personnel.
   d. should have serial CBCs performed.
   e. should be asked about nausea, vomiting, and diarrhea.

4. The hematopoietic radiation subsyndrome
   a. may accompany the gastrointestinal subsyndrome.
   b. is always lethal.
   c. significantly depletes circulating red blood cells in 30 days.
   d. has little effect on platelet levels.
   e. causes a rapid drop in the lymphocyte count.

5. Local radiation burns
   a. can be caused by beta radiation.
   b. can be caused by alpha radiation.
   c. can be caused by gamma radiation.
   d. may require skin grafting.
   e. begin with an immediate burning sensation.

6. Which of the following statement(s) is (are) true?
   a. No treatment is available for patients who have inhaled plutonium-239.
   b. Ingested iodide-131 can be treated with SSKI.
   c. Persons who have been exposed to a cesium radiologic source may be treated with DTPA.
   d. Persons who have ingested strontium-90 may be treated with barium sulfate.
   e. Persons who have inhaled tritium may be treated with a saline infusion and furosemide.

7. Early external decontamination of a radiation accident victim
   a. takes precedence over medical care.
   b. includes removing the patient's clothing.
   c. must be carried out at a hospital.
   d. should include careful cleaning of face and wounds.
   e. ideally is continued until no radioactivity remains on skin.

8. Whole body acute radiation exposures greater than 1000 rem
   a. produce nausea and vomiting that begins 48 hours after exposure.
   b. cause only temporary reductions in lymphocytes and neutrophils.
   c. double the dominant inheritable mutations in humans.
   d. can cause death in less than 60 days.
   e. are necessarily uniform in nature.

CASE STUDIES IN ENVIRONMENTAL MEDICINE: IONIZING RADIATION

If you wish CME credits or CEU, please indicate your answers to the Posttest questions on page 36 by circling the letters below for the correct answers. Complete the evaluation questionnaire and fill in the information requested on the reverse side. Tear off this last page, fold, staple, and mail to Continuing Education Coordinator, Agency for Toxic Substances and Disease Registry, Division of Health Education, E33, 1600 Clifton Road, NE, Atlanta, GA 30333.

1. a b c d e
2. a b c d e
3. a b c d e
4. a b c d e
5. a b c d e
6. a b c d e
7. a b c d e
8. a b c d e

Evaluation Questionnaire

Please complete the following evaluation by circling the appropriate number.

	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
1. As a result of completing this monograph, I will be able to:					
Explain why ionizing radiation is a health concern.	1	2	3	4	5
Describe the health effects caused by exposure to ionizing radiation.	1	2	3	4	5
Identify evaluation and treatment protocols for persons exposed to ionizing radiation.	1	2	3	4	5
List sources of information on ionizing radiation.	1	2	3	4	5
2. The monograph addressed the objectives printed on the inside front cover.	1	2	3	4	5
3. I am more likely to ask patients questions regarding possible environmental exposures as a result of reading this issue.	1	2	3	4	5
4. Independent study was an effective teaching method for the content.	1	2	3	4	5
5. How much time (in minutes) was required to read this monograph and complete the posttest?	40	60	80	100	120

Comments:_____

To obtain credit, provide the information requested below.

Name _____

Address _____

_____

_____ Zip _____

Check one:

☐ CME-AMA ☐ CME-AAFP ☐ CME-ACEP ☐ CME-AOA

☐ CEU ☐ Contact Hours-AAOHN ☐ CM-ABIH

Specialty _____

To be placed on mailing list, check here. ☐

fold here first

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PLEASE PLACE STAMP HERE

Continuing Education Coordinator
Agency for Toxic Substances and Disease Registry
Division of Health Education, E33
1600 Clifton Road, NE
Atlanta, GA 30333

fold here second

Please send me the following *Case Studies in Environmental Medicine*:

- ☐ Arsenic
- ☐ Asbestos
- ☐ Benzene
- ☐ Beryllium
- ☐ Cadmium
- ☐ Carbon Tetrachloride
- ☐ Chlordane
- ☐ Cholinesterase Inhibitors
- ☐ Chromium
- ☐ Cyanide
- ☐ Dioxins
- ☐ Ethylene/Propylene Glycols
- ☐ Exposure History
- ☐ Gasoline
- ☐ Jet Fuel
- ☐ Lead
- ☐ Mercury
- ☐ Methanol
- ☐ Methylene Chloride
- ☐ Nitrates/Nitrites
- ☐ Pentachlorophenol
- ☐ Polyaromatic Hydrocarbons (PAHs)
- ☐ Polychlorinated Biphenyls (PCBs)
- ☐ Radiation
- ☐ Radon
- ☐ Reproductive and Developmental Hazards
- ☐ Skin Lesions
- ☐ Stoddard Solvent
- ☐ Tetrachloroethylene
- ☐ 1,1,1-Trichloroethane
- ☐ Trichloroethylene
- ☐ Toluene
- ☐ Vinyl Chloride

staple or tape

ML0993

Appendix I

Forms of Ionizing Radiation

Alpha particles, which are charged helium nuclei (i.e., 2 protons and 2 neutrons with an electrical charge of +2), have energies in the range of 4 to 8 million electron volts (MeV). Because of their mass and charge, alpha particles travel only a few centimeters in air and can be stopped by a piece of paper or intact skin. However, they cause intense ionization when they interact with matter and can result in significant local damage if emitted in body tissues by radionuclides incorporated through inhalation, ingestion, or through an open wound. Alpha particles are formed typically during the radioactive decay of radium-226 and transuranic elements such as plutonium and americium.

Beta particles originate in the disintegrating nucleus of radioactive elements (radionuclides). A beta particle is an electron that may be charged positively (positron) or negatively (negatron); it has a mass that is about 1/7500 of an alpha particle. Beta particles are emitted from the nuclei of radionuclides at velocities approaching the speed of light and have peak energies ranging from about 0.010 to 4 MeV. They can travel several feet in air, but are typically stopped by a thin sheet of aluminum or 1 to 2 centimeters of plastic or paper. Effects of a beta-emitting radionuclide that is deposited in the body depend on whether the emitter is excreted or stored in tissue. Beta emitters commonly used in research include tritium, carbon-14, and iodine-131. Conversion and Auger electrons originate in the outer structure of the atom. They are monoenergetic with energies ranging from less than 0.001 to 1 MeV and interact with matter in the same way as beta particles. An example of a radionuclide that emits such electrons is iodine-125.

Neutrons are emitted from the atomic nuclei of heavy elements when the elements are bombarded by high-speed particles. A neutron has a mass approximately equal to a proton (i.e., 1 atomic mass unit [amu]), but has no electrical charge. Neutrons do not interact with the orbital electrons of atoms as do most other forms of radiation. Instead, neutrons interact with atomic nuclei. The disruption of the atomic nucleus may cause alpha, beta, or gamma radiation to be emitted. In addition, nuclear contact with either fast or slow (thermal) neutrons can cause acceleration of the target atom, resulting in dense ionizations along its path. Neutron radiation is produced in devices such as particle accelerators (high-energy neutrons) and nuclear reactors (low-energy neutrons). Neutrons can interact with water in the body; the proton making up the nucleus of a hydrogen atom in a molecule of water and nitrogen nuclei are the neutron's major targets in living tissue.

Gamma radiation is high-energy electromagnetic waves spontaneously emitted by the nucleus of radioactive atoms. Unlike the emission of alpha or beta radiation, the emission of gamma radiation results in a nucleus whose physical integrity is unaffected and whose energy state is more stable. X radiation differs from gamma radiation only in origin. X rays do not come from the nucleus; they are emitted when electron transitions occur in the atom's orbital shells. Both X and gamma radiations are highly penetrating and can be detected even after passing through several inches of steel. The energies of gamma and X rays are in the range of thousands of electron volts (keV) to MeV. In contrast to the dense ionization caused by particulate (e.g., alpha or neutron) radiation as it penetrates matter, gamma and X radiation create sparse ion pairs separated by relatively large distances. Alpha radiation generates 20,000 to 50,000 ion pairs/centimeter; beta, 50 to 500; and gamma, 5 to 8. Table 8 summarizes the characteristics of the various types of ionizing radiation.

Table 8. Types of ionizing radiation

Type	Charge	Atomic Mass (amu)	Source*	Shielding†
alpha	+2	4	Radium-226 Polonium-210 Uranium-238	Sheet of paper; intact skin
beta	±1	.0005	Carbon-14 Strontium-90 Tritium Iodine-131	Lead; aluminum foil; a few centimeters of plastic
neutron	0	1	Particle accelerator Nuclear reactor	High energy=paraffin Low energy=water
proton	+1	1	Cosmic radiation Particle accelerator	Air
gamma	0	0	Cobalt-60 Uranium-238 Iodine-131	A few centimeters of lead; many inches of steel
X	0	0	Diagnostic and therapeutic medicine	A few centimeters of lead; many inches of steel

* Familiar examples of originating source.
† In any given situation, the type and thickness of shielding is dependent on the energy and intensity of the radiation.

Appendix II

Radionuclides in the Environment of Potential Concern

Cesium-137

Cesium is an alkali metal that has 21 radioactive isotopes. The isotope most likely to be encountered is cesium-137 because it is an important fission fragment produced during fissioning of either uranium or plutonium fuels. It is long-lived (radiation half-life of 30 years) and is found in the environment as a result of worldwide fallout associated with atmospheric weapons tests. It is used in industry as a sealed gamma source for measuring the thickness of materials and in medicine as a sealed source for therapy and as a tracer substance.

Cesium and potassium have similar chemical and biologic behavior, including distribution and metabolism in the body. Because of its water solubility, cesium is distributed almost uniformly throughout body fluids and is rapidly eliminated by the kidneys. The biologic half-life of cesium-137 ranges from 68 to 165 days; about 10% of the amount ingested is excreted within the first 2 days. The biologic half-life is much shorter in children, ranging from 12 days in infants to 57 days in older children, and somewhat shorter in women (up to 111 days reported).

Iodine-131

Radioactive iodines (especially iodine-131, -132, and -129) are important fission products from nuclear weapons tests and nuclear reactors. They are volatile substances and were an early concern in the accident at Three Mile Island in 1979. Once released to the atmosphere, radioactive iodine may return via precipitation to land used for pasture, thereby contaminating vegetation and, ultimately, the food and milk supply. Fallout from atmospheric nuclear weapons testing exposed residents of the Marshall Islands to radioactive iodine by ingestion, as well as external radiation. Iodine-131, which has a radiation half-life of 8.05 days, emits several medium-energy beta particles and mostly low-energy gamma rays. Because of the selective uptake of iodine by the thyroid, iodine-131 is used for medical examination and treatment of some thyroid conditions.

If iodine-131 is administered in the form of sodium iodide, it will distribute throughout the body. As the blood passes through the thyroid, about 20% of plasma iodide is removed per passage; in normal patients, 0.5% to 6.8% of the iodide in the circulating pool is removed per hour. About 30% of injected radioactivity may accumulate in the thyroid, where the iodine is rapidly bound to protein. It is released from the thyroid only slowly. Beta and gamma radiation from absorbed iodine-131 bound to circulating protein contributes to irradiation of the blood and bone marrow. Iodine also concentrates in the salivary glands and gastric mucosa. Excretion of iodine is almost entirely via urine.

The effective biologic half-life (radiation half-life combined with biologic half-life) of iodine-131 in humans is 7.6 days. In infants, about 90% of the total beta energy from resident iodine-131 is absorbed by the thyroid gland, and in adults, about 95% of the total beta energy is absorbed. An increased frequency of nodules and cancers have been reported in persons exposed to radioactive iodine, and some patients treated for hyperthyroidism have developed hypothyroidism up to 17 years later.

Exposures to radioactive iodine usually result from inhalation, but ingestion and absorption through the skin also occur. In cases of environmental contamination with radioactive iodine (e.g., after a nuclear reactor accident), the clinician may be asked about the safety of drinking milk. In general, iodine-131 has an effective half-life on vegetation of about 5 days. An infant who drinks 1 liter of milk per day containing 1 microcurie per liter (μCi/L) will receive a total cumulative dose to the thyroid of about 16 rem. The maximum permissible organ burden for continuous exposure to iodine-131 is a thyroid dose of 15 rem per year. Emergency reference levels (0.25 μCi/L as a peak level in milk and 1.5 μCi per square meter on pasture) should trigger protective actions, which

include changing the cow forage, withholding milk from consumption, and diverting contaminated milk from direct use to milk products such as cheese, condensed milk, or powdered milk. Preparation time for these milk products would allow the iodine-131, with its relatively short half-life, to decay significantly, and the amount of emitted radiation would be of little consequence.

Plutonium-239

Plutonium is a man-made element. It is readily fissionable by neutrons and is used as fuel in nuclear power reactors and as a "trigger" device in explosive nuclear weapons. Reactor-grade plutonium is about 70% plutonium-239, and weapons-grade plutonium, about 93% plutonium-239. Plutonium-239 emits two high-energy alpha particles and has a radiation half-life of 24,390 years.

The most common route of entry to the body of plutonium-239 is through inhalation, usually of plutonium oxide (PuO_2). As with all inhaled particulates, the particle size of the oxide will determine its deposition and location within the respiratory system. Small-diameter particles of PuO_2 will remain in the lower respiratory tract and lungs for an average of 2 years, emitting very intense alpha radiation that can destroy small local masses of lung tissue and may result in lung cancer. Of the amount of PuO_2 inhaled, 15% reaches the thoracic lymph nodes (10% of this amount is retained permanently), 5% is found in the blood, and the remainder either stays in the respiratory tract or reaches the mouth and is swallowed. Workers may also be exposed to plutonium-239 through puncture wounds that occur via contaminated metal splinters or glass chips formed while processing the metal. Very little ingested PuO_2 (about 0.003%) is absorbed through the gastrointestinal tract.

Plutonium in the blood is eventually equally distributed between liver and bone; a small amount settles in the abdominal lymph nodes, and an even smaller amount settles in the gonads. Retention half-time of plutonium-239 in the whole body has been estimated to be 200 years in man, and the half-times in skeleton and liver are estimated to be 100 years and 40 years, respectively. Excretion is via the kidneys.

Nuclear weapons testing programs have placed more than 5000 kilograms of plutonium (representing 320 kCi) into the stratosphere, mostly as insoluble particles of oxide. In addition, 1 kg of plutonium-238 (17 kCi) that had been used as fuel for a power pack vaporized into the atmosphere from burn-up of a U.S. satellite. These releases have resulted in worldwide deposition. Plutonium-239 accumulation is uneven; areas having greater rainfall generally experience greater fallout. Increased amounts of radioactive plutonium have been found in soil near nuclear weapons testing, processing, and storage facilities. Wind action can resuspend the contaminated soil, carrying radioactive particles away from the site and increasing the hazard to nearby residents.

Radon-222

Radon results from the radioactive decay of radium, a ubiquitous element in rock and soil derived from the decay of uranium. Radon gas is odorless, colorless, tasteless, and cannot be detected, except by empirical measurement. It seeps from soil into buildings primarily through sump holes, dirt floors, floor drains, cinder-block walls, and cracks in foundations and concrete floors. When trapped indoors, it can accumulate to significant levels.

Radon's half-life, 3.8 days, provides sufficient time for it to diffuse into homes, where further decay produces more chemically and radiologically active progeny ("radon daughters"). The progeny, which include four isotopes with half-lives of less than 30 minutes, are a major source of human exposure to alpha radiation. The alpha radiation from radon and its progeny deposited in the lungs may contribute to cellular transformations in the respiratory tract that result in lung cancer. For further information, see *Case Studies in Environmental Medicine: Radon Toxicity.*

Strontium-90

Strontium has 16 radioisotopes, six of which are direct fission products of uranium. The most important of these isotopes is strontium-90 because of its long radiation half-life of 28 years. Strontium-90 emits a relatively high-energy beta particle, giving rise to yttrium-90, which then emits a beta particle of higher energy. In medicine, strontium-90 is used to treat cutaneous lesions that are only a few millimeters in depth; in industry, it is used in thickness gauges, as a source for static dust elimination by air ionization, a compact heat source, and a thermoelectric source in buoys and other devices where a long-lived, independent power source is needed.

Because of the risks posed by strontium-90 from nuclear fallout during atmospheric weapons tests and from the possible escape of strontium into the environment during and after reprocessing of used fuel elements, the metabolism of strontium-90 has been well studied. After ingestion, about 25% of strontium-90 is absorbed into extracellular fluid; after inhalation, about 35% is absorbed into the extracellular fluid. In the body, strontium acts much like calcium. About one-half of the amount absorbed is deposited in bone, where the high-energy beta particles emitted irradiate both calcified bone and adjacent bone marrow.

The biologic half-life of strontium-90 depends on the route of exposure. It was found to be less than 250 days after a single ingestion, about 500 days after inhalation, and 843 days when used as an intravenous tracer dose. The average long-term biologic retention is estimated to be 50 years for bone and 36 years for other tissues. Strontium-90 is eliminated in the urine and feces. By measuring concentrations of strontium-90 and calcium in a 24-hour urine collection, one can estimate the amount of strontium-90 that has accidentally entered the body.

Tritium

Tritium (1 proton and 2 neutrons) is a hydrogen atom that has captured a neutron, resulting in an atomic mass of 3. This unstable nucleus emits a beta particle of low energy and has a radiation half-life of 12.3 years. Tritium is most familiar in the form of tritiated water (^3H_2O), formed when normal water (H_2O) absorbs neutrons during the process of moderating nuclear fission in a reactor. Tritiated water has also been produced in the atmosphere as a result of the release of tritium gas from nuclear reactors.

Tritiated water can enter the body by inhalation of water vapor, diffusion through the skin, breaks in the skin, or ingestion. The beta particles from tritium are stopped by only 6 millimeters of air or about 5 micrometers of water. These beta particles cannot penetrate the outermost layer of skin, and so present no hazard when they originate outside the body. However, when they emanate from tritium inside the body, they can produce injury.

Once ingested, tritiated water is completely absorbed and mixes freely with body water. It distributes uniformly throughout the body, permeating all tissues. The normal biologic half-life of tritiated water is about 12 days, with a small fraction of the radionuclide being excreted at a much slower rate. The complex excretion curve suggests that some of the tritium may exchange with organically bound normal water. On the 415th day after a worker accidentally ingested tritiated water, the concentration of tritium in urine was still significantly elevated

Uranium-238

Naturally occurring uranium consists of uranium-238 (99.27%), uranium-235 (0.72%) and uranium-234 (0.0054%). Uranium-235 is extracted or concentrated from natural uranium for use in nuclear weapons or nuclear power reactors. The uranium remaining after uranium-235 has been removed is referred to as depleted or spent uranium; however, this uranium continues to be a radiation hazard, as well as a chemical hazard.

Together the members of the uranium decay series are responsible for significant alpha radioactivity contamination in the environment. Initially, uranium-238 decays by emitting high-energy alpha particles. The alpha emissions are followed by two beta decays (producing thorium-234 and metastable [short-lived] protactinium-234, in succession), which, in turn, are followed by additional alpha emissions from several

progeny; uranium-234, thorium-230, radium-226, and radon-222. The physical half-life of uranium-238 is 4.5 billion years; however, its specific activity (radioactivity per given weight), 3.34 microcuries per milligram, is low.

The amount of natural uranium that is absorbed by the body depends on its physical state, chemical form, and the route of exposure. Based on studies in experimental animals, about 20% of the uranium in blood is retained with an effective half-life of 20 days, and about 2.3% is retained with an effective half-life of 5000 days. Most of the retained uranium is stored in bone and kidney. Uranium is excreted in urine. Intake of natural uranium in soluble form is limited by uranium's chemical toxicity to the kidneys, rather than by its radiation dose.

Appendix III

Treatment Summary for Internal Contamination, by Selected Radioactive Elements

The benefit from therapy recommendations in the Immediate Actions to Consider (column 2) and Drugs to Consider (column 3) will be influenced by the route of exposure: ingestion, inhalation, skin absorption, injection, or contaminated wounds. The chemical form and solubility of the radionuclide will also change markedly the efficacy of the recommended treatment. The table below lists therapeutic procedures or drug therapy that may be helpful for the listed elements in favorable circumstances.

Element	Immediate Actions to Consider	Drugs to Consider	Information and Comment
Americium (Am)	DTPA*	DTPA	Chelation should be started as soon as treatment decision can be made. CaEDTA† may be used if CaDTPA is not immediately available.
Arsenic (As)	Lavage	Dimercaprol	Short-lived isotopes. Use of dimercaprol is not indicated except in massive exposures.
Barium (Ba)	Lavage, purgatives	See column 4	Use of sodium or magnesium sulfate with and after stomach lavage will precipitate insoluble barium sulfate.
Calcium (Ca)	Lavage, purgatives, calcium	Calcium, furosemide	Massive exposure may warrant use of the sodium salt of EDTA , but with caution over a 3- to 4-hour period to avoid tetany. Furosemide enhances urinary excretion.
Californium (Cf)	DTPA, lavage, purgatives	DTPA	Same as for Americium.
Carbon (C)	(None listed)	No treatment	Low-energy beta rays of carbon-14 available are not detected by survey instruments; collect samples and smears for special low-energy beta counting in laboratory.
Cerium (Ce)	DTPA, lavage purgatives	DTPA	Same as for Americium.
Cesium (Cs)	Prussian blue, lavage, purgatives	Prussian blue	Ion exchange resins should be as effective as Prussian blue, but have not been used in humans.

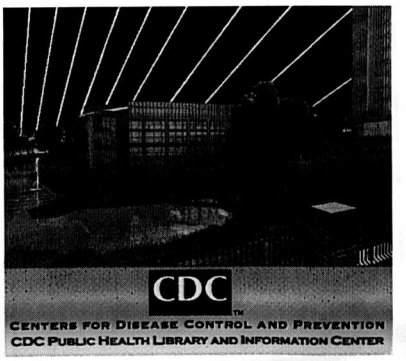
Chromium (Cr)	Lavage, purgatives	No treatment available for anionic forms; DTPA or DFOA** for cationic forms.	Antacids are contraindicated. Adsorbents, such as charcoal, may reduce intestinal tract absorption.
Cobalt (Co)	Lavage, purgatives	See column 4	Penicillamine may be considered for therapeutic trial in large exposures.
Curium (Cm)	DTPA, lavage, purgatives	DTPA	Same as for Americium.
Europium (Eu)	Lavage, purgatives	DTPA	None.
Fission Products	Lavage, purgatives	††	Gamma-ray spectroscopy of air or swipe samples may identify prominent radionuclides (mixed). Check also for possible alpha emitters.
Fluorine (F)	Aluminum hydroxide gel	See column 4	Very short half-life. Oral aluminum hydroxide gel will reduce absorption in the gastrointestinal (GI) tract.
Gallium (Ga)	See column 4	See column 4	Short half-life. Penicillamine can be considered for therapeutic trial.
Gold (Au)	None	Dimercaprol and penicillamine are possible therapeutic agents.	No known therapy for colloidal gold.
Iodine (I)	Potassium iodide, lavage	Potassium iodide	Success of stable iodine depends on early administration.
Iron (Fe)	Lavage	DFOA	Materials that reduce GI absorption include egg yolk or adsorbents. Oral penicillamine also chelates iron.
Lanthanum (La)	Lavage, purgatives	DTPA	CaEDTA may be used if CaDTPA is not immediately available.
Lead (Pb)	Lavage	EDTA	Dimercaprol and penicillamine are less satisfactory alternative drugs.
Mercury (Hg)	Lavage	Penicillamine	Dimercaprol may be considered for alternative therapy. Gastric lavage with egg white solution or 5% sodium formaldehyde sulfoxide; if unavailable, use a 2% to 5% solution of sodium bicarbonate.

Phosphorus (P)	Lavage, aluminum hydroxide	Phosphates	Severe overdosage may be treated with parathyroid extract (intramuscular) in addition to oral phosphates.
Plutonium (Pu)	DTPA	DTPA	DFOA may be used initially if DTPA is not available. CaEDTA may also be used, but is less effective.
Polonium (Po)	Lavage, purgatives	Dimercaprol	Consider toxicity of dimercaprol before using in cases of low-level exposure. Penicillamine is an alternative treatment.
Potassium (K)	Purgatives, diuretics, aluminum hydroxide	Diuretics	Use aluminum hydroxide antacids first to reduce GI tract absorption. Use oral liquid potassium supplements for dilution.
Promethium (Pm)	DTPA	DTPA	Chelation treatment should be started as soon as possible.
Radium (Ra)	Magnesium sulfate, lavage, purgatives	See column 4	Use 10% magnesium sulfate solution for gastric lavage and as saline cathartic. Oral sulfates reduce intestinal absorption. No effective therapy after absorption.
Rubidium (Rb)	Prussian blue	Prussian blue	Chemical properties are similar to potassium, but efficacy of similar treatments is unknown.
Ruthenium (Ru)	Lavage, purgatives	See column 4	Chlorthalidone causes enhanced urinary excretion. DTPA has variable effectiveness.
Scandium (Sc)	Lavage, purgatives	DTPA	EDTA may be used in place of DTPA.
Sodium (Na)	Lavage	Diuretic	Isotopic dilution (1 liter of 0.9% sodium chloride) by intravenous route, followed by furosemide or other diuretic agent.
Strontium (Sr)	Aluminum phosphate, lavage	Strontium or calcium intravenously	Corticosteroid may be considered, but adverse reactions should be balanced against probable limited effectiveness.
Technetium (Tc)	(None listed)	(None listed)	Potassium perchlorate has been used effectively to reduce thyroid dose.
Thorium (Th)	(None listed)	DTPA or DFOA for soluble compounds	Treatment not effective for thorotrast (ThO_2).
Tritium (^3H)	Forced water	Forced water	Low-energy beta rays of ^3H are not detectable by survey instruments; requires samples for special low-energy beta counting in laboratory.

Uranium (U)	DTPA	(None listed)	DTPA must be given within 4 hours to be effective. Sodium bicarbonate protects the kidneys from damage.
Yttrium (Y)	(None listed)	DTPA	CaEDTA may be used if CaDTPA is not immediately available.
Zinc (Zn)	Lavage	DTPA	Zinc sulfate or CaEDTA may be used as a diluting agent if CaDTPA is not immediately available. Penicillamine is another alternative.

* DTPA = diethylenetriaminepentaacetic acid
† CaEDTA = calcium salt of ethylenediaminetetraacetic acid
¶ CaDTPA = calcium diethylenetriaminepentaacetic acid
§ EDTA = ethylenediaminetetraacetic acid
** DFOA = deferoxamine or desferrioxamine
†† Depends on major isotope(s) in mixture, which varies with age of the isotope mixture.

Adapted from: National Council on Radiation Protection and Measurements. Management of persons accidentally contaminated with radionuclides. Washington, DC: National Council on Radiation Protection and Measurements, 1980. NCRP Report No. 65.



The state of knowledge regarding the treatment of patients potentially exposed to hazardous substances in the environment is constantly evolving and is often uncertain. In this monograph, the Agency for Toxic Substances and Disease Registry (ATSDR) has made a diligent effort to ensure the accuracy and currency of the information presented but makes no claim that the document comprehensively addresses all possible situations related to this substance. This monograph is intended as an additional resource for physicians and other health professionals in assessing the condition and managing the treatment of patients potentially exposed to hazardous substances. It is not, however, a substitute for the professional judgment of a health care provider and must be interpreted in light of specific information regarding the patient available to such a professional and in conjunction with other sources of authority.

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