Radiation Injury

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Radiation injury is damage to tissues caused by exposure to radiation.

In general, radiation refers to high-energy electromagnetic waves (x-rays, gamma rays) or particles (alpha particles, beta particles, neutrons). Radiation is emitted by radioactive substances (radioisotopes), such as uranium, radon, and plutonium. Radiation is also produced by man-made sources, such as x-ray and radiation therapy machines.

Radiation dose is measured in several different units, but all relate to the amount of energy deposited. The units include the roentgen (R), the gray (Gy), and the sievert (Sv). The sievert and gray are similar, except the sievert takes into account the biologic effects of different types of radiation.

The two main types of radiation exposure are irradiation and contamination. Many radiation accidents expose a person to both.

Irradiation is exposure to radiation waves that pass directly through the body from outside the body. Irradiation can make a person sick immediately (acute radiation illness). Additionally, irradiation, particularly in high doses, can damage a person's genetic material (DNA), causing chronic (delayed) disorders, such as cancer and birth defects. However, irradiation does not make the person or his tissues radioactive.

Contamination is contact with and retention of radioactive material, typically in the form of a dust or liquid. The radioactive material may stay on the skin, where it can fall or be rubbed off, contaminating other people and objects. The material also may be absorbed by the body through the lungs, digestive tract, or breaks in the skin. The absorbed material is transported to various sites in the body, such as the bone marrow, where it continues to release radiation. This internalized radiation does not cause acute radiation illness but may produce chronic disorders such as cancer.

Annual Radiation Exposure in the United States

Source	Average Dose (millisieverts)
Naturally occurring sources	
Radon gas	2.00
Other terrestrial sources	0.28
Radiation from outer space	0.27

Natural internal radioactive elements	0.39
Subtotal	2.94
Man-made sources	
Diagnostic x-rays (for average person)	0.39
Nuclear medicine	0.14
Consumer products	0.10
Fallout from weapons testing	less than 0.01
Nuclear industry	less than 0.01
Subtotal	0.63
Total annual exposure	**3.6**
Other sources of exposure	
Airline travel	0.005 mSv/hour of flight
Dental x-rays	0.09
Chest x-ray	0.10
Barium enema	8.75

Causes

People are constantly exposed to low levels of natural radiation (background radiation). Radiation comes from outer space (cosmic radiation), although much of it is blocked by the earth's atmosphere. Exposure to cosmic radiation is greater for people living at high altitudes. Radioactive elements, particularly radon gas, also are present in many rocks and minerals. These elements end up in a variety of substances, including food and construction materials. Radon exposure is a greater risk in basements because of their proximity to the ground. In addition, people are exposed to radiation from man-made sources, including the environmental radiation that results from nuclear weapons testing and radiation from various medical tests and treatments. The average person receives a total of about 3 to 4 mSv (1 mSv = $^{1}/_{1000}$ Sv) per year from natural radiation and man-made sources. People who work with radioactive materials and with x-ray sources are at risk of exposure to higher levels of radiation. People who are receiving radiation treatments for cancer may receive very high levels of radiation.

Rarely, radiation has been released from nuclear power plants, including the Three Mile Island plant in Pennsylvania in 1979 and the Chernobyl plant in the Ukraine in 1986. The Three Mile Island accident did not result in major radiation exposure; in fact, anyone living within 1 mile of the plant received only about 0.08 mSv additional radiation. However, people living near the Chernobyl plant were exposed to about 430 mSv of radiation. More than 30 people died, many

more were injured, and radiation from that accident reached other parts of Europe, Asia, and the United States. In total, radiation exposure from reactors in the first 40 years of nuclear energy use, excluding Chernobyl, has resulted in 35 serious exposures with 10 deaths, but none were associated with power plants.

Nuclear weapons release massive amounts of radiation. These weapons have not been used against people since 1945. However, a number of nations now possess nuclear weapons, and several terrorist groups have also tried to obtain them, raising the possibility that these weapons could once again be used.

The damaging effects of radiation depend on several factors, including the amount (dose) and duration of exposure. A single, rapid dose of radiation to the entire body can be fatal, but the same total dose given over a period of weeks or months may have much less effect. For a given dose, genetic damage is more likely with rapid exposure. The effects of radiation also depend on how much of the body is exposed. For example, more than 6 Gy generally causes death when the radiation is distributed over the entire body; however, when concentrated in a small area, as in radiation therapy for cancer, 3 or 4 times this amount can be given without serious harm.

The distribution of radiation is also important, because certain parts of the body are more sensitive to radiation. Organs and tissues in which cells are multiplying quickly, such as the intestines and bone marrow, are harmed more easily by radiation than those in which cells multiply more slowly, such as muscles and tendons. The genetic material of sperm and egg cells can be damaged by radiation. During radiation therapy for cancer, therefore, every attempt is made to shield the more vulnerable parts of the body from radiation so that high doses can be delivered primarily to the cancer.

Symptoms

Radiation exposure produces two types of injury: acute (immediate) and chronic (delayed). Radiation therapy for cancer mainly produces symptoms in the part of the body that receives radiation. For example, in radiation therapy for rectal cancer, abdominal cramping and diarrhea are common because of the effects of radiation on the small intestine.

Acute Radiation Illness: Acute radiation illness generally occurs in people whose entire body has been exposed to radiation. Acute radiation illness progresses through several stages, beginning with early symptoms (prodrome) and followed by a symptom-free period (latent stage). Various syndromes (patterns of symptoms) follow, depending on the amount of radiation the person received. The greater the amount of radiation, the more severe the symptoms and the quicker the progression from the early symptoms to the actual syndrome. The symptoms and time course are consistent from person to person for a given amount of radiation exposure. Doctors can predict a person's radiation exposure

from the timing and nature of the symptoms. Doctors divide acute radiation syndromes into three groups based on the main organ system affected, although there is overlap among these groups.

The **hematopoietic syndrome** is caused by the effects of radiation on the bone marrow, spleen, and lymph nodes—the primary sites of blood cell production (hematopoiesis). Loss of appetite (anorexia), lethargy, nausea, and vomiting begin 2 to 12 hours after exposure to 2 Gy or more of radiation. These symptoms resolve within 24 to 36 hours after exposure, and the person feels well for a week or more. During this symptom-free period, the blood-producing cells in the bone marrow, spleen, and lymph nodes begin to waste away and are not replaced, leading to a severe shortage of white blood cells, followed by a shortage of platelets and then red blood cells. The shortage of white blood cells can lead to severe infections. The shortage of platelets may cause uncontrolled bleeding. The shortage of red blood cells (anemia) causes fatigue, weakness, paleness, and difficulty breathing with physical exertion. After 4 to 5 weeks, if the person survives, blood cells begin to be produced once more, but the person feels weak and tired for months.

The **gastrointestinal syndrome** is due to the effects of radiation on the cells lining the digestive tract. Severe nausea, vomiting, and diarrhea begin 2 to 12 hours after exposure to 4 Gy or more of radiation. The symptoms may lead to severe dehydration, but they resolve after 2 days. During the next 4 or 5 days, the person feels well, but the cells lining the digestive tract, which normally act as a protective barrier, die and are shed. After this time, severe diarrhea—often bloody—returns, once more resulting in dehydration. Bacteria from the digestive tract invade the body, producing severe infections. People who have received this much radiation also develop the hematopoietic syndrome, which results in bleeding and infection and increases their risk of death.

The **cerebrovascular (brain) syndrome** occurs when the total dose of radiation exceeds 20 to 30 Gy. A person rapidly develops confusion, nausea, vomiting, bloody diarrhea, and shock. Within hours, blood pressure falls, accompanied by seizures and coma. The cerebrovascular syndrome is always fatal.

Chronic Effects of Radiation: Chronic effects of radiation result from damage to the genetic material in dividing cells. These alterations may cause abnormalities of cell growth, such as cancer. In severely irradiated animals, damage to reproductive cells has been shown to lead to defective offspring (birth defects). However, no deformities resulting from irradiation have been observed in the offspring of survivors of the nuclear blasts in Japan. It may be that radiation exposure below a certain (unknown) level does not alter genetic material enough to cause birth defects.

Radiation Therapy for Cancer: Radiation therapy for cancer can be either internal or external. In internal therapy, small pellets of radioactive material are

implanted directly into the cancer. In external therapy, a beam of radiation is transmitted through the person's body into the cancer.

External radiation therapy for cancer produces a number of symptoms, depending on the amount of radiation and the area of the body treated. Nausea, vomiting, and loss of appetite may occur during or shortly after irradiation of the brain or abdomen. Large amounts of radiation to a limited area of the body often damage the skin over that area. Skin changes include hair loss, redness, peeling, sores, and, eventually, thinning of the skin and dilated blood vessels just beneath the skin's surface (spider veins). These changes increase the likelihood of skin cancer years later. Radiation to the mouth and jaw can cause permanent dry mouth, resulting in an increased number of dental caries and damage to the jawbone. Pus-filled pockets of infection (abscesses) may then develop. Radiation to the lungs can cause lung inflammation (radiation pneumonitis), and large amounts may cause severe scarring (fibrosis) of lung tissue, which can be fatal. The heart and its protective sac (pericardium) can become inflamed after extensive radiation to the breastbone and chest. High accumulated doses of radiation to the spinal cord can cause catastrophic damage, leading to paralysis. Extensive radiation to the abdomen (for lymph node, testicular, or ovarian cancer) can lead to chronic ulcers, scarring, and narrowing or perforation of the intestines.

Prolonged or repeated exposure to low doses of radiation from radioactive implants or because of job-related duties (as occurs with some health care professionals) may cause cessation of menstrual periods (amenorrhea) in women, decreased fertility or sterility, and decreased sex drive (libido).

Occasionally, severe injuries develop long after the completion of radiation therapy. Kidney function may decline 6 months to a year after a person has received extremely large amounts of radiation, resulting in anemia and high blood pressure. High accumulated doses of radiation to muscles may cause a painful condition that includes muscle wasting (atrophy) and calcium deposits in the irradiated muscle. Very rarely, these changes result in a cancerous (malignant) muscle tumor. Radiation-induced cancers typically occur 10 or more years after exposure.

Diagnosis

Exposure to radiation is usually obvious from the history.

Irradiation injury is suspected when a person becomes ill after receiving radiation therapy or being exposed to radiation in an accident. No specific tests are available to diagnose the condition, although certain tests may be used to detect infection, low blood count, or organ malfunction. To determine the severity of radiation exposure, doctors measure the number of lymphocytes (a type of white blood cell) in the blood. The lower the lymphocyte count 48 hours

after exposure, the worse the radiation exposure.

Radioactive contamination, unlike irradiation, can be determined by surveying a person's body with a Geiger counter, a device that detects radiation. Swabs from the nose, throat, and any wounds also are checked for radioactivity.

Prognosis and Treatment

The outcome depends on the dose, dose rate (how quickly the exposure has occurred), and distribution over the body as well as on the person's underlying state of health. In general, most people who have received more than 6 Gy of radiation at once die. Because doctors are unlikely to know the measured amount of radiation a person has received, they usually judge outcome by the person's symptoms. The cerebrovascular syndrome is fatal within hours to a few days. The gastrointestinal syndrome generally is fatal within 3 to 10 days, although some people survive for a few weeks. Many people who receive proper medical care survive the hematopoietic syndrome, depending on their total amount of radiation; those who do not survive typically die after 8 to 50 days.

Irradiation has no emergency treatment, but doctors closely monitor the person for the development of the various syndromes and treat the symptoms as they arise.

Contamination requires immediate removal of the radioactive material to prevent it from being taken up by the body. Skin contaminated by radioactive materials should be scrubbed immediately with large amounts of soap and water or with a solution designed for this purpose, when available. Small puncture wounds should be cleaned vigorously to remove all radioactive particles, even though scrubbing may cause pain. Contaminated hair is clipped off, not shaved—shaving may abrade the skin and allow contamination to enter the body. Scrubbing continues until the Geiger counter shows that the radioactivity is gone. If a person has recently swallowed radioactive material, vomiting is induced. Some radioactive materials have specific antidotes that can prevent absorption of swallowed material. Most such antidotes are given only to people exposed to significant radioactive contamination, such as from a major reactor accident or nuclear explosion. Potassium iodideSome Trade Names
SSKI
PIMA
prevents the thyroid gland from absorbing radioactive iodine and lowers the risk of thyroid cancer. Other drugs, such as pentetic acid (DTPA), ethylenediaminetetraacetic acid (EDTA), and penicillamineSome Trade Names
CUPRIMINE
, can be given intravenously to remove certain radioactive elements after they have been absorbed.

When contamination is not suspected, nausea and vomiting can be reduced by

taking drugs to prevent vomiting (antiemetics); such drugs are routinely given to people undergoing radiation therapy. Dehydration is treated with fluids given intravenously.

People with the gastrointestinal or hematopoietic syndrome are kept isolated so that they do not contact infectious microorganisms. Blood transfusions and injections of growth factors (such as erythropoietinSome Trade Names
EPOGEN
PROCRIT
and colony-stimulating factor) that stimulate blood cell production are given to decrease bleeding and increase blood counts. If the bone marrow is severely damaged, these growth factors are ineffective, and sometimes a bone marrow transplantation is performed, although the success rate is low.

People with the gastrointestinal syndrome require antiemetics, fluids given intravenously, and sedatives. Some people may be able to eat a bland diet. Antibiotics, such as neomycin, are given by mouth to kill bacteria in the intestine that may invade the body. Antibiotics as well as antifungal and antiviral drugs also are given intravenously when necessary.

Treatment for the cerebrovascular syndrome is geared toward providing comfort by relieving pain, anxiety, and breathing difficulties. Drugs are given to control seizures.

People with chronic effects of radiation or disorders caused by radiation therapy receive treatment directed at their symptoms. Sores or ulcers can be removed or repaired surgically and can be helped to heal with the use of high-pressure (hyperbaric) oxygen therapy. Radiation-induced leukemia is treated with chemotherapy. Blood cells can be replaced through transfusions. No treatment can reverse sterility, but low levels of sex hormones as a result of abnormal ovarian and testicular functioning can be treated with replacement hormones. Investigators are currently exploring ways to prevent or reduce radiation-induced normal tissue injury using cytokines, growth factors, and various other therapies. Amifostine has been shown to decrease the severity of dry mouth (xerostomia) in people with head and neck cancer treated with radiation therapy.