Radiation Benefit and Risk Assessment

How much radiation does it take to cause our risk for an observable health effect to increase? Is there a level of radiation that is safe? How is radiation beneficial?

The question of an effect occurring because of radiation exposure and the question of whether low-level radiation is safe are much-debated topics. There are many thoughts on the answers to these questions, and suggested answers lie along a continuum, especially when the topic is low-level radiation. Answers range from “radiation is good for you” (this is the hormesis hypothesis) to “low levels of radiation are safe” (they do not measurably increase your risk of disease) to “any amount of radiation exposure carries some risk” (this is the linear no-threshold hypothesis).

According to the American Cancer Society, the average natural incidence of cancer in the United States is 42 percent (42 out of 100 people will get cancer in their lifetime). Diagnostic medical radiation exposures may or may not increase this risk. It is important to note that radiation exposure does not create a unique cancer risk situation, nor is the risk directly measurable or distinguishable from the cancer risk caused by other sources (environmental, chemical, biological, etc.).

When we discuss radiation risks, the effects are probabilistic in nature—like the odds of getting a heads when we flip a coin. First, we lack the scientific data to determine a precise risk of cancer in the future from radiation exposure today, but we estimate the increase in the cancer incidence rate is about 0.17 percent per rem of radiation dose; this is based on the effects we see with high doses.

However, it is impossible to say with certainty that any single person will get a radiation-induced cancer. Second, it may be impossible to even demonstrate that additional cancers have occurred, since the normal incident rate of cancer is about 42 percent plus or minus some natural variation. What this means is that out of a group of 100 people, it is estimated that about 42 will get a cancer in their lifetime. If we expose each of them to one rem of radiation, still about 42 out of 100 will get a cancer in their lifetime.

If we expose each to five rem of radiation, we estimate now that about 43 out of 100 will get a cancer in their lifetime. What we cannot tell, though, is whether the estimated one additional cancer is just a natural variation or whether it is due to the radiation exposure.

According to the conclusions of the National Research Council in its report on health effects of exposure to radiation, it takes significant doses (>10 rem) to measurably increase the risk. This is above the doses normally received in diagnostic medical exams that involve exposure to radiation. As for radiation exposure to the reproductive organs (testes or ovaries), genetic effects have not been observed in human populations exposed to ionizing radiation.

Radiation exposure can have many benefits for individuals and society. Medical imaging exams that involve radiation are beneficial in determining whether organs are functioning properly or bones are broken and in cancer therapy. Low levels of radiation exposure are used for most medical exams involving radiation, although when we are using radiation to treat a disease (e.g., cancer), we use very high doses to actually kill the cancer cells. Like so many things in our society that have benefits, some also have risks. For instance, aspirin is extremely effective in many indications but, taken in large quantities, can be harmful and even cause death. With radiation it is similar—the small radiation doses used to conduct medical exams carry little or no risk, while exposure to high levels may cause observable health effects.

Tissues of the body that are actually exposed and the amount of radiation they receive depends on the type of exam and the techniques used to do the imaging (for an x ray, this includes the kilovoltage, milliamperes, distance between the patient and the tube, etc.; for a nuclear medicine study, this includes the radionuclide, activity administered, etc.). Our current medical knowledge does not allow us to identify the exact "cause" of a cancer, so a radiation-induced cancer doesn't look any different than the same cancer caused by any of the other possible causes. We know that radiation-induced cancers do not appear until at least 10 years after exposure (for tumors) or 2 years after exposure (for leukemia). The time after exposure until possible cancer formation is called the "latent period." The risk of cancer after exposure can extend beyond this latent period for the rest of your life for tumors or about 30 years for leukemia.

It is also important to realize that equating dose for all x-ray procedures is like comparing apples to oranges. The radiation dose received by the head during dental x rays is not the same as x rays to the wrist, and neither is the same as x rays of the abdomen or chest. Risk from radiation dose is typically based on calculations of the actual effect of the radiation dose that is delivered based on the type of radiation, the energy that it leaves in the body, and where in the body it leaves its energy. Radiation exposure to a nonsensitive area of the body (like the wrist) really has no actual effect. Radiation exposure to a sensitive area of the body (like blood-forming organs) can have an effect if the amount of energy left is high enough.

A medical procedure involving radiation should be done only when there is a question to be answered—is something broken, why the pounding headaches, could there be cancer? This is what we call justification; i.e., there should be appropriate medical reason for the x ray to be performed. The issue of medical radiation exposure is not only a matter of safety; it's a matter of benefit compared with risk. The question should be, "In regard to the medical condition of this person, are these x rays necessary for proper medical care?" That decision can only be made by someone who is familiar with the medical condition and the care that is necessary to properly manage it.

The x-ray exam should only include the affected area and use the most dose-effective settings on the equipment. This assures the best picture with the lowest radiation dose to the patient—what we call optimization. There are several reasons we don't want needless x rays performed: it is unnecessary radiation exposure (no justification), it increases cost to the patient and the institution, and some procedures have inherent risks other than the radiation exposure (like a catheter being placed in the heart).

The decision to have a medical test performed that involves radiation must be made collectively between the patient and his or her physician. Any diagnostic test should be justified by the risks of not having the test performed; there must be some benefit. This should be the basis for decisions made by physicians and their patients. Patients can refuse tests at any time or get a second opinion. Patients should feel free to express to their physician any concerns they might have, particularly regarding radiation exposure, and to seek assurance from the physician that this procedure is necessary and that the procedure will be performed in such a way as to reasonably minimize the radiation dose without compromising the diagnostic information being sought. The patient should also ask if there are alternative diagnostic procedures and about the limitations and potential risks of any alternative procedures.

In any situation, radiation exposure must be clearly identified and explained. It is especially important that the risks are not only explained, but also *understood* by the individual so that he/she can make an informed decision regarding whether or not to accept the benefit in light of any risks. Medical uses of radiation must be prescribed by a physician and must be for justified purposes (e.g., to determine whether a bone is broken).

For some information about general radiation doses and expected effects, click here .
To see a table of commonly encountered radiation doses, click here.
For a list of resources used to write this summary: Resources
For a list of references used to write this summary: References

General radiation doses and expected effects (radiation doses are to the entire body).

- 0-5 rem received in a short period or over a long period is safe—we don't expect observable health effects.
- 5-10 rem received in a short time or over a long period is safe—we don't expect observable health effects. At this level, an effect is either nonexistent or too small to observe.
- 10-50 rem received in a short time or over a long period—we don't expect observable health effects, although at above 10 rem your chances of getting cancer are slightly increased. We may also see short-term blood cell decreases for doses of about 50 rem received in a matter of minutes.
- 50-100 rem received in a short time will likely cause some observable health effects and received over a long period will increase your chances of getting cancer. Above 50 rem we may see some changes in blood cells, but the blood system quickly recovers.
- 100-200 rem received in a short time will cause nausea and fatigue. 100-200 rem received over a long period will increase your chances of getting cancer.
- 200-300 rem received in a short time will cause nausea and vomiting within 24-48 hours. Medical attention should be sought.
- 300-500 rem received in a short time will cause nausea, vomiting, and diarrhea within hours. Loss of hair and appetite occurs within a week. Medical attention must be sought for survival; half of the people exposed to radiation at this high level will die if they receive no medical attention.
- 500-1,200 rem in a short time will likely lead to death within a few days.
- >10,000 rem in a short time will lead to death within a few hours.

Commonly encountered radiation doses.

Effective Dose	Radiation Source
Less than (<) or equal to (=) 0.01 rem	annual dose living at nuclear power plant perimeter
	bitewing, panoramic, or full-mouth dental x rays
	skull x ray
	chest x ray
<=0.1 rem	single spine x ray
	abdominal x ray
	pelvic x ray
	hip x ray
	mammogram
<=0.5 rem	kidney series of x rays
	most barium-related x rays
	head CT*
	any spine x-ray series
	annual natural background radiation dose
	most nuclear medicine brain, liver, kidney, bone, or lung scans
<=1.0 rem	barium enema (x rays of the large intestine)
	chest, abdomen, or pelvic CT*
<=5.0 rem	cardiac catheterization (heart x rays)
	coronary angiogram (heart x rays)
	other heart x-ray studies
	most nuclear medicine heart scans

*CT = computerized tomography; a specialized x-ray exam.

Resources

- Health Physics Society Position Statement on Risk Assessment
- ICRP 60: International Commission on Radiological Protection. 1990 recommendations of the International Commission on Radiological Protection. Oxford: Pergamon Press; ICRP Publication 60; Ann ICRP 21(1-3):1-201; 1991.
- ICRP 62: International Commission on Radiological Protection. Radiological protection in biomedical research. Oxford: Pergamon Press; ICRP Publication 62, Ann ICRP 22/3, 1993.
- The University of Michigan's Radiation and Health Physics Page—this link is the cover page for a book titled *What You Need to Know about Radiation to Protect Yourself, to Protect Your Family, to Make Reasonable Social and Political Choices*. On this cover page, you'll find titles and links to each section.
- An excellent review of radiation health effects can be found in the Executive Summary of "Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2" (2006).

References

- Committee on the Biological Effects of Ionizing Radiations (BEIR Committee). Health effects of exposure to low levels of ionizing radiation (BEIR VII). Washington, DC: National Academy Press; 175; 2006.
- Kereiakes JG, Rosenstein M. Handbook of radiation doses in nuclear medicine and diagnostic x-ray. Boca Raton, FL: CRC Press; 212-213; 1980.
- National Research Council. Health effects of exposure to low levels of ionizing radiation (BEIR V). Washington, DC: National Academies Press; 1990.
- HPS Position Statement. Radiation risk in perspective. Position of the Health Physics Society; March 2001.

Linear No-Threshold Hypothesis (LNT)

Experts agree that high doses of radiation cause harmful effects. Even as early as the 1950s, when scientific groups were creating radiation protection guidelines, no one really knew what the effects of radiation at low doses were or if there were any. For many reasons, some political, it was decided to assume that the radiation dose and the effect of the dose were linear and proportional—this means for a given dose of radiation to a person, that person has some possibility of a radiation effect; if the dose of radiation is doubled, that person has twice the possibility and so on. It was also decided that at any dose, no matter how small, there could be an effect (or no threshold). We really had only the knowledge that a lot of radiation was harmful, so assumptions were made about low doses of radiation so protection standards could be set. Setting radiation protection standards required "erring" in these assumptions on the "safe" side, i.e., setting a standard lower than it may have to be if the real level of hazard were known. This was and still is the basis for the LNT.

Even though LNT was intended for scientists to set radiation protection standards and not for general use, most people applied it as "fact" because it was easy to use and explain rather than saying we do not know the effects of low doses of radiation or that low doses of radiation are safe. So, for several decades now, we have simply been assuming that low doses of radiation carry a risk. That still works well when setting radiation protection standards. However, since no activity is risk free, we really need to ask ourselves what dose of radiation is safe—not risk-free, but safe.

Hormesis

Hormesis, by definition, is a generally favorable biological response to low exposures to toxins or stressors that would give an unfavorable response at high exposures. There have been some studies of worker populations, plants, animals, and cells that have shown favorable health outcomes at low exposures of radiation as compared to adverse outcomes at high exposures. However, these studies have not been accepted as proof of a hormetic effect from radiation. As one example, there have been some studies in which the authors report that cells exposed to a small amount of radiation (called a conditioning dose) can actually produce what they refer to as an adaptive response that makes cells more resistant to another dose of radiation. Some potential issues with this are (1) that many of the results cannot be reproduced (meaning that other scientists have tried to do the same testing and get the same results, but haven't been able to; this suggests that the initial results might have been just due to chance), (2) that not every type of cell has this capacity for an adaptive response, and (3) that the adaptive response does not appear to last long (so the second radiation dose would have to occur soon after the conditioning dose). So, is it real or not? Scientists can't agree because the results of studies are so inconsistent.

Glossary

absorbed dose: Absorbed dose is used for purposes of radiation protection and assessing dose or risk to humans in general terms. Absorbed dose is the amount of radiation absorbed in an organ or tissue (i.e., the amount of radiation energy that has been left in cells, tissues, or organs). Absorbed dose is usually defined as energy deposited (joule) per unit of mass (kilogram). See gray and rad.

alpha particle: An alpha particle is a particle with weight (it is made up of two protons and two neutrons) and charge (it is positively charged because protons have a positive charge). Alpha particles do not travel very far and are not considered an exposure hazard unless the radioactive material that emits them gets inside the body.

background radiation: Background radiation includes radiation from cosmic sources, naturally occurring radioactive materials (including radon), and global fallout (from the testing of nuclear explosive devices). The typically quoted average individual exposure from background radiation is 0.30 rem per year.

becquerel: The becquerel (Bq) is the unit in the International System of Units to replace the curie (see curie).

beta particle: A beta particle is an energetic electron given off by atoms when the atoms have too much energy. Beta particles do not travel very far, but travel farther than alpha particles. Beta particles are typically stopped by a few millimeters or about an eighth (1/8) of an inch of tissue; higher-energy beta particles will be stopped by approximately a centimeter or about a third (1/3) of an inch of tissue. Beta particles do have a charge—those that are negatively charged are essentially electrons and those that are positively charged are called positrons.

cosmic radiation: Cosmic radiation is penetrating ionizing radiation comprised of particles and electromagnetic energy that comes from outer space. Cosmic radiation accounts for about half of the natural background radiation we receive each year.

curie: The curie (Ci) is the original term used to describe the amount of radioactive material present or strength of the source. It is based upon the radioactive decay rate of the radionuclide. One curie is equal to 3.7×10^{10} disintegrations (37 trillion decays) per second (dps); one becquerel is equal to 1 dps. The most common activity levels used in laboratories are the millicurie (mCi) and microcurie (μCi). A millicurie (mCi) is $1/1{,}000^{th}$ of a curie and a microcurie (μCi) is $1/1{,}000{,}000^{th}$ of a curie. In the International System of Units, the becquerel (Bq) describes the amount of radioactive material present. One curie is equal to 3.7×10^9 Bq.

diagnostic: In medicine, diagnosis or diagnostics is the process of identifying a medical condition or disease by its signs and symptoms and from the results of various procedures. As used when referring to medical exams involving radiation, it is the use of x rays or radioactive materials to identify the medical condition.

dose: Dose is a general term used to express (quantify) how much radiation exposure something (a person or other material) has received. The exposure can subsequently be expressed in terms of the absorbed, equivalent, committed, and/or effective dose based on the amount of energy absorbed and in what tissues.
effective dose: Radiation exposures to the human body, whether from external or internal sources, can involve all or a portion of the body. The health effects of one unit of dose to the entire body are more harmful than the same dose to only a portion of the body, e.g., the hand or the foot. To enable radiation protection specialists to express partial-body exposures (and the accompanying doses) to portions of the body in terms of an equal dose to the whole body, the concept of effective dose was developed. Effective dose, then, is the dose to the whole body that carries with it the same risk as a higher dose to a portion of the body. As an example, 8 rem (80 mSv) to the lungs is roughly the same potential detriment as 1 rem (10 mSv) to the whole body based on this idea.

equivalent dose: Equivalent dose is a dose quantity used for radiation protection purposes that takes into account the chance that a type of radiation will cause an effect. Different types of radiation (alpha, beta, gamma) interact with human tissues differently, with some leaving a lot of energy in the tissue and others leaving very little energy in the tissue, and the energy that is left is what partially determines whether an effect will occur or not. Because of this, different types of radiation are assigned numbers based on how effective each type of radiation is at leaving its energy in the tissue, thus having more potential to cause an effect. By using equivalent dose we are provided an indication of the potential for biological effects. From this, risk comparisons can be made between the different types of radiation.

exposure: Exposure is commonly used to refer to being around a radiation source, e.g., if you have a chest x ray, you are exposed to radiation. By definition, exposure is a measure of the amount of ionizations produced in air by photon radiation.

exposure rate: Exposure rate is the amount of exposure or dose you are receiving per unit time (e.g., 1 mrem/hour).

gamma rays: Gamma rays are high-energy electromagnetic radiation (photons) emitted in an attempt by the radionuclide to become stable, i.e., radioactive decay. Gamma rays have moderate-to-high penetrating power, are often able to penetrate deep into the body, and generally require some form of shielding, such as lead or concrete. Visible light is also in the form of photons. Gamma photons behave similarly to light, but they are invisible.

genetic effect: A genetic effect resulting from radiation exposure is an effect that can be passed from parent to child because of changes to reproductive cells.

gray: Gray (Gy) is the unit in the International System of Units to replace the rad (see rad).

high-level radiation: High-level radiation refers to radiation doses >10 rem to a human body.

low-level radiation: Low-level radiation refers to radiation doses <=10 rem to a human body.

observable health effect: An observable health effect is a change in physical health that can be detected medically. Observable health effects may include changes in blood cell counts, skin reddening, cataracts, etc. Whether or not it is an observable *harmful* health effect depends on whether damage to the body has occurred and whether that damage impairs how the body is able to function.

rad: Rad is the term used to describe absorbed radiation dose. It describes a specific amount of energy absorbed in a medium (human tissue, for example). In the International System of Units, the gray (Gy) describes absorbed radiation dose. One gray is equal to 100 rad.

radiation: Radiation is a term commonly used to describe ionizing radiation (i.e., x and gamma rays, alpha and beta particles, neutrons). Ionizing radiation is radiation that is capable of producing ions by passing through matter.

radioactive material: Radioactive material is material that contains radioactivity and thus emits ionizing radiation. It may be material that contains natural radioactivity from the environment or a material that has been made radioactive (see radioactivity).

radioactivity: Radioactivity is the property of a nucleus in unstable atoms causing the atoms to spontaneously release energy in the form of photons (e.g., gamma rays) or subatomic particles (e.g., alpha or beta particles).

radionuclide: A radionuclide is a radioactive element, man-made or from natural sources, with a specific atomic weight.

rem: Rem is the term used to describe equivalent or effective radiation dose. In the International System of Units, the sievert (Sv) describes equivalent or effective radiation dose. One sievert is equal to 100 rem.

risk: Risk is defined in most health-related fields as the probability or odds of incurring injury, disease, or death.

roentgen: The roentgen (R) is the term used to describe radiation exposure. This term for exposure only describes the amount of ionization in air. In the International System of Units, the coulomb/kilogram (C/kg) describes radiation exposure. One roentgen is equal to 2.58×10^{-4} C/kg.

safe: Safe, as it is being used in the information on this Web site, is defined as an activity that is generally considered acceptable to us. This is not to say there is absolutely no risk with an activity that is considered safe; there may be a risk from the activity or the exposure to radiation, but it is the same as or lower than the risks from everyday actions. At a level of radiation that is considered safe, an effect is either nonexistent or too small to observe.

sievert: Sievert (Sv) is the unit in the International System of Units to replace the rem (see rem).

stochastic effects: Stochastic effects are chance effects—like rolling the dice. Radiation, like many other things, has the ability to cause cancer in cells and the chance of cancer increases as radiation exposure increases.

therapy: Therapy is the medical treatment of disease or disorders. With respect to radiation therapy, therapeutic doses (e.g., external beam treatments for tumors, radioiodine treatment for thyroid disorders) are significantly greater than those received from diagnostic procedures (e.g., chest x-rays, CT scans, nuclear medicine procedures, etc).

threshold: Threshold is the point at which radiation first produces an observable effect (response) from acute exposures.

x rays: X rays are electromagnetic radiation (photons) that can be emitted from radionuclides or from certain types of devices. Generally, x rays have lower energies than gamma rays, but like gamma rays, x rays can penetrate into the body. Sometimes lead or concrete may be used as shielding for x rays.