AIHA™

Protecting Worker Health

Should I Be Worried About Ionizing Radiation?

Ionizing Radiation

The very word "radiation" conjures up scary images – nuclear weapons, cancer therapy, perhaps a science fiction movie scenario with giant mutant ants. In fact, radiation in one form or another is a part of our daily lives. Understanding what radiation, or specifically, ionizing radiation, is can help you understand what risks you face. Although ionizing radiation is a broad topic, we will examine several of the most common sources. We hope to give you a greater understanding of the risks and rewards of radiation in everyday life. You may be surprised to find that whereas exposure to some forms of ionizing radiation is indeed harmful, many forms are either beneficial or health neutral.

Must I Be Exposed to Radiation?

Radiation is known to occur naturally and no one lives radiation free. Naturally occurring radiation surrounds us. There is cosmic radiation from the sun and earthly radiation from uranium and other elements in the rocks and soil. Life on earth always has been exposed to radiation, and it’s known to cause cellular damage that ultimately can lead to injury or disease in the irradiated individual or the individual’s progeny.

Most people think about radiation and safety issues at some time in their lives. This pamphlet outlines some basic concepts about what radioactivity is, how it works, and when it can become hazardous.

The AIHA Ionizing Radiation Committee comprises industrial hygienists who specialize in the recognition, evaluation, and control of potential radiation hazards. We work for government agencies, hospitals, research labs, universities, consulting firms, and manufacturers.

Just Exactly What Is Ionizing Radiation?

Go back to high school science class where we learned that everything is composed of atoms. An atom consists of a positively charged nucleus (protons with positive charges and neutrons with no charge) surrounded by a cloud of negatively charged electrons. As long as the proton-to-neutron ratio in the nucleus is properly balanced, the atom is “stable”; however, when the proton-to-neutron ratio is out of balance, the atom is “unstable,” that is, radioactive, and it emits particulate, or radiant energy, in an attempt to regain stability. The energy emitted from the nucleus is the ionizing radiation. The process of emitting energy from a radioactive atom is referred to as disintegration or decay, and it causes the atom to change from one element to another, which is transformation.

Ionizing radiation is energetic charged particles, such as alpha particles and beta particles; uncharged particles, such as neutrons; and nonparticulate radiation, such as gamma rays or X-rays. Basically, it is the emission of energy just as sunlight is the emission of energy in the form of light; infrared radiation is the emission of energy in the form of heat and musical instruments emit energy in the form of sound. The difference between sunlight or sound and radiation is the ability to ionize things it passes through. This implies that energy from ionizing radiation is emitted with greater energy than light waves, infrared waves, sound waves, radio waves, and other forms of electromagnetic (EM) radiation. Because of its ability to disrupt atomic bonds, ionizing radiation has the potential to alter more complex molecules than it encounters, including biological molecules important for the maintenance of an organism’s structure or function.

Ionizing radiation can be emitted as either pure energy or as a stream of particles. Alpha radiation, which is the same as a helium atom without any electrons, and beta radiation, which is the same as electrons, are considered particles. Gamma rays or X-rays are called photons, waves of pure EM energy that deposit their energy into the matter through which they pass in discrete packets called quanta.

Should I Be Worried About Ionizing Radiation?

The extent of radioactiveness of a substance can be measured in terms of its activity, which refers to the number of transformations, disintegrations, or decays per second. There are two systems of units that describe activity. In the classical system of nomenclature, the Curie (Ci) is used as the unit of measure and is defined as 3.7x1010 disintegrations per second (DPS). There are 1,000 millicuries (mCi) in one Ci and 1,000,000 microcuries (µCi) in one Ci; in the international system of nomenclature (now preferred), the unit of activity is the becquerel (Bq) and is defined as one disintegration per second (DPS). Because the becquerel is such a small unit, we typically deal with megabecquerels (MBq), which are 106 Bq or gigabecquerels (GBq), corresponding to 109 Bq. One may be required to convert from one system of units to the other, and the best way to do this is to remember that 1 Ci = 3.7x1010 Bq (or 37 mBq = 1 mCi).

Radioactive materials are unusual in that they gradually become less radioactive over time, that is, they have a physical “half-life.” Every radioactive substance has its own unique half-life, defined as the time it takes for half of the substance to decay and transform into a new substance (which sometimes is still radioactive and sometimes is not). Consider the following example: Take a piece of paper and tear it in half and toss away one piece. The paper has just gone through one half-life. Take the remaining half and tear in half again tossing away one piece. The paper has just gone through a second half-life. If you continue this process until the paper is too small to tear in half, you should have a basic understanding of what a half-life is. The radioactive decay process follows what mathematicians and physicists call a decay curve, which shows how much of the material is left after a given time period. If a radioactive material undergoes 10 half-lives, less than 0.01% of the original substance remains.

The ubiquity of radioactive materials in the environment and our understanding of the decay process and half-lives has allowed, for example, the dating of artifacts from prehistoric times based on an analysis of the proportion of carbon 14 (radioactive) to carbon 12 (stable) in organic matter. This is made possible because every living thing, or former living thing, including humans, contains small amounts of radioactive variants of common elements called isotopes.

In determining the potential to cause harm to living organisms, both the total dose of radiation the organism receives and the dose rate (how much of the dose is delivered per unit of total exposure time) are important considerations because biological effects vary both with the dose and its “intensity.” Different terminology is used to describe the total amount of ionizing radiation capable of interacting with matter (“exposure,” in units of Roentgen); the total amount of energy actually deposited in matter (“dose” in units of rad or Gray); and a measure of the relative biological effectiveness of the energy deposited in terms of producing injury (“dose equivalent,” in units of rem or Sievert). These factors not only take into consideration the radiation source's intensity but also the rate at which the radiation is being delivered and the amount of time a living organism is exposed to it. Because these units refer to large amounts of energy, we usually talk in terms of mR (milliroentgen), mrad (millirads), and mrem (millirems). Rads and rems are the classical units of dose and dose equivalent, whereas the corresponding international units are Grays (Gy) and Sieverts (Sv). One Gy equals 100 rads, and 1 Sv equals 100 rems.

Recently, the National Academy of Sciences (NAS) completed a comprehensive evaluation of the radiobiological literature relevant to the risks of radiation exposure(BEIR VII. [2005]) and, in particular, to exposures in the low-dose range more typical of the types of radiation exposures received by occupational workers who use radioactive materials and by the general public. The committee concluded that since, in the low-dose range of interest, the difference between risks predicted by different possible models of dose response is small relative to the 95% confidence intervals for risk extrapolated from data at higher doses, the linear, no-threshold dose-response relationship is consistent with the data. One important implication of this model is that there is no absolutely safe level of exposure to ionizing radiation, that is, that even very low doses have some probability of causing untoward health effects, including injuries to normal tissue and possibly carcinogenesis. This being the case, even exposure to background radiation has the potential to cause cancer, although the individual risk is quite small and decreases further with decreasing dose (but never reaches zero risk). It should be noted, however, that in human populations known to receive several times the average annual natural background radiation dose, radiation is thought to be responsible for only a tiny fraction of the cases of cancer and other adverse health effects observed, attesting to the low risks involved with such small doses. Of course, additional exposures cause additional risks that may or may not be cumulative, depending on the type of radiation, its dose rate, and the type(s) of tissue being irradiated.

The committee also concluded that radiation can cause other health effects, such as heart disease and stroke, and that further study is needed to predict the doses that result in these noncancer health effects. It is also possible that children born to parents who have been exposed to radiation could be affected by those exposures because radiation-induced damage to genetic material contained in the parents' sperm or egg cells can and does occur.

Finally, the National Academy of Sciences BEIR VII committee reviewed some novel ways that radiation causes responses in cells – processes that had not yet been recognized at the time of the last committee report – that could have radiation safety and protection implications. Among these responses are:

The "bystander effect," a recently described mechanism by which radiation produces changes in cells that did not receive a direct energy deposition but, rather, were in the vicinity of those that did. The changes include (but are not limited to) increased intercellular communication; increased levels of DNA or chromosomal damage followed by the appearance of DNA repair-related proteins; and increased apoptosis, a unique and rapid type of cell death different from that most commonly noted for lethally irradiated cells, and which is thought to represent a cellular defense mechanism against the propagation of damaged cells that could present a risk to the entire organism. Some of these changes are overt manifestations of molecular damage to the cell, while others probably are biochemical responses by the cell in an attempt to mitigate the damage. It appears that both direct communication from cell to cell through physical contact, and indirect communication through release of signaling compounds into the extracellular environment are important. It is known that reactive oxygen species (ROS) such as OH- and H2O2 are involved, but it is not clear if they are themselves the signaling compounds or if they are produced by the cells in response to the signal.

A related phenomenon (in terms of the ability of cells to modify their behavior and that of their neighbors in response to irradiation) is termed the "adaptive response." This describes one or more poorly understood processes by which cells that have been exposed to a low, "priming" dose of radiation become more resistant to the toxic and mutagenic effects of subsequent doses. The priming dose needed to produce the adaptive response is typically less than 20 rad/cGy.

Another novel, radiation-induced phenomenon is called "genomic instability," which is the tendency of cells that survive radiation exposure seemingly intact, yet become especially susceptible to accruing more and more DNA damage over time at rates orders of magnitude higher than might occur in a previously unirradiated cell. This is thought to be an early, if not the initial, step in the process of carcinogenesis and likely explains why ionizing radiation can act as a carcinogen as well as a frank toxin. According to the BEIR report, this might contribute significantly to radiation-induced cancer risk.

Uses of Ionizing Radiation

When considering uses of radioactive materials, most people immediately think of nuclear reactors used for research or electricity generation and that are likely to become increasingly common in the future. However, nuclear power is certainly not the only use of radioactive materials or ionizing radiation in general. Industry uses radiation to determine a tank is full or empty, if a pipe contains the correct makeup or consistency of material, or even if the right amount of material is flowing. Gauges are used to assess the correct thickness of products, such as paper or plastic sheeting, and are used at construction sites to determine the soil moisture content and density. In addition, radiation is used to assess the quality of welding join during construction. Further, radioactive materials (and newer X-ray devices) are used to determine the composition of materials and the amount of lead-based paint present on painted surfaces.   And, let's not forget that trace amounts of radioactive materials are used commonly in smoke detectors and some exit signs.

Academic and commercial research and development laboratories use radioactive materials as tracers and markers during the search for and testing of new pharmaceuticals. In addition, basic science laboratories use radioisotopes to aid in their studies of fundamental molecular and cellular processes in both normal and diseased states.

The medical uses of ionizing radiation are many. The medical subspecialty of nuclear medicine uses small amounts of radioactive materials to assess the structure and function of internal organs such as the thyroid or liver. In addition, the specialty of medical imaging (i.e., diagnostic radiology) makes use of X-rays (radiographic and fluoroscopic), CT scans, PET scans, and mammography to look into the human body for structural or functional evidence of disease. (Note that magnetic resonance imaging [MRI] and diagnostic ultrasound, although themselves imaging modalities, are not a source of ionizing radiation.) The medical specialty of radiation oncology uses highly focused X-rays, electrons, or heavier, accelerated particles for cancer therapy, taking advantage of the toxic properties of ionizing radiation in eradicating malignant cells. Finally, the field of dentistry also makes use of X-rays and is beginning to use CT scans to image the teeth and jaws.

One concept to keep in mind is the difference between contamination and irradiation. Let’s consider an illustrative example. When you do a painting project you probably lay out newspaper to prevent paint splatters from getting on the floor or nearby furniture. When you open the paint you can smell it, and as you use it you most probably will get paint on your hands and clothing. Irradiation would be similar to smelling the paint, but getting the paint on you would be considered contamination. Hence, once the radiation beam is shut down (or the paint can is sealed) the irradiation stops, but you have to scrub and wash off the contamination. Contamination can be thought of as “dirt” in a place you don’t want it. Usually, washing the surface or removing the contaminated clothing will remove the contamination.

So are there reasons you should fear exposures to such uses of low-level radiation? Compared with the minimal exposure you'll receive when getting an X-ray or taking a standard diagnostic test, it's much more important for you to worry about wearing your seatbelt on the way to the doctor's office. As with all artificial radiation, common sense should prevail. For instance, although you may get dental X-rays every one to two years, dental technicians shield themselves from the (minimal) exposure because otherwise they would be exposed to the radiation daily. Likewise, pregnant woman are urged to avoid diagnostic X-rays because of the possibility of harming the unborn child.

Low-Level Radioactive Waste

Radioactive waste consists of normal trash with the exception that it’s contaminated with or contains radioactive materials. There are several classes of radioactive waste: high-level waste consisting of spent nuclear reactor fuel rods; transuranics, which are radionuclides higher than uranium on the periodic table; and low-level radioactive waste (LLRW), which is everything else that doesn’t fit the other categories. Ninety-five persent of radioactive waste is low-level radioactive waste generated by industry, research and development laboratories (academic and commercial), and medical institutions.

Low-level radioactive waste consists of R&D waste contaminated with radioactive materials used during the course of a research project. In addition, the sample vials that contained the radioactive materials, together with materials used to prevent spills or in cleanup following the experiment, are included in the waste. LLRW may consist of solids as well as liquids. Be very careful not to combine radioactive waste with hazardous chemical waste; because this creates mixed waste, which is very difficult to dispose of.

Industrial radioactive waste includes used gauges and devices when the radioactive material has decayed below a usable activity but is still radioactive.

Most medical uses of radioactive materials use those with short half-lives that will decay in a few hours to days. However, the small quantities that remain in the vials and syringes are considered radioactive waste, although most of the radioactivity is gone by the time this material arrives at the site. (You may have seen bins in a hospital or doctor's office marked with the universal radiation symbol.) This kind of waste is low intensity and typically does not present a significant hazard. This waste is safely used by direct introduction into patients' bodies. Health care workers who administer and dispose of medical radiation materials are required to follow standard procedures for handling radioactive materials.

The LLRW is placed in proper containers and transported to the waste disposal site where it may be incinerated or compacted then placed into the proper licensed disposal facility. The disposal facilities are constructed in such a way that any leakage is minimized and the site is constantly monitored to detect any leakage should it occur. Any leakage from a waste site would provide much, much less radiation than we get from natural background or cosmic radiation from space.

Irradiated Food

In the grocery store, you may have seen food labeled as irradiated. Although not yet standard procedure throughout the country, the next several years it maybe more likely to find more radiation-treated foods on grocery store shelves everywhere. If that is the case, you may wonder whether it is necessary to irradiate food and is it safe to eat.

For the first question, there are two answers: (1) food safety and (2) longer shelf life. Despite our best efforts, the U.S. food supply is not safe from contamination from various sources, such as Escherichia coli and Salmonella typhimurium bacteria. Although no one knows for sure how many illnesses are caused by these two bacteria, it is conservatively estimated that millions of people are adversely affected every year, with symptoms ranging from mild nausea to death – possibly as many as 10,000 fatalities per year. Scientists cite radiation's ability to kill the E. coli bacteria found in undercooked meat and the salmonella bacteria that plague our nation's poultry supply as the best reason to irradiate food. Greatly reducing, if not eliminating, these toxins from our food would be a major step forward in public health. It has ramifications outside the United States, especially since bacterial diarrhea from ingestion of tainted food is a major killer in developing nations.

Studies show that in addition to E. coli and Salmonella, radiation can destroy a variety of other bacteria, spores, and mold and fungi, although not necessarily the toxins they produce (nor can radiation destroy the deadly Clostridium botulinum bacteria, which is responsible for botulism). By ridding food of these microscopic organisms, the shelf life of irradiated food also is increased considerably. This is not only a boon economically but could prove extremely beneficial for the global distribution of food to third world or famine-stricken countries.

The Federal Drug Administration (FDA) strictly regulates how and what food can be irradiated. The country's first commercial irradiation, or ionizing, facility was founded in Tampa, Florida, in 1992 for the treatment of certain fruits and vegetables and poultry. Though ionized spices have been sold in the United States since the 1980s, the Tampa plant was the first in this country to provide large-scale irradiation of food. Foods such as strawberries and chicken parts are bombarded with gamma rays to severely limit microbe growth.

Once the process is complete, all ionized food must be labeled as such before being released for sale to the public. Tests have shown that most consumers find no difference in the taste of irradiated food largely because laboratory testing is used to determine which foods are least likely to suffer loss of flavor or texture after irradiation. Foods with high water content, such as lettuce, can become mushy when irradiated and, consequently, are not candidates for treatment.

But are irradiated foods safe to eat? Yes, according to a long-term study by the World Health Organization (WHO). The study, Safety and Nutritional Adequacy of Irradiated Food, states that as long as requirements for "good manufacturing practice are implemented, food irradiation is safe and effective." Good manufacturing, in this case, means practicing the same procedures that are used to ensure safe canning, freezing, and other processing methods commonly implemented in food production.

With the WHO's report (based on more than 500 scientific studies conducted throughout 40 years), many public health experts have called for the increased use of irradiation, particularly for safeguarding our meat supply, including beef, pork, poultry, and shellfish.

There are vocal critics of food irradiation, although their main concern is nutrient loss during the processing. (Studies do not show any measurable increase in residual radioactivity in previously irradiated foods, so that seems to be of little concern.) Some food is indeed more sensitive to nutrient and vitamin loss than others.

According to the WHO study, this can be corrected by irradiating foods at lower temperatures or in the presence of oxygen.

Despite food irradiation’s critics, many physicians and scientists are increasing the call for carefully regulated food irradiation. Following the highly publicized 1993 West Coast incident of E. coli poisoning from undercooked fast-food hamburgers – where several hundred people became ill and four children died – the American Gastroenterological Association Foundation petitioned the FDA to allow irradiation to be used to treat beef and poultry. In addition, some 40 other countries have approved food irradiation to some extent.

If there is general consensus that food irradiation is not only safe but contributes greatly to the general safety of our food supply and the public health, does this mean that you'll be seeing food with the international radiation symbol popping up in your local grocery store any day soon? Yes, but probably only in a gradual fashion. Some experts have likened the initial resistance to irradiated food to that of pasteurized milk; after a period of education and public discussion, consumers will accept and eventually expect the sale of treated meat, fruit, and vegetables. But don't forget: You still need to fully cook your chicken.

It’s interesting to note that spices have been sterilized by irradiation for years and are not required to be labeled if they are used in other commercial products, such as spaghetti sauces. In addition, medical equipment and supplies have been sterilized by irradiation for decades and do not need to be labeled.

Danger in the Basement? The Radon Question

One of the open questions of radiation safety is household radon exposure. Radon gas is a naturally occurring substance found throughout the world. As uranium in rocks and soil decays, it transforms into several additional radioactive isotopes, including radon.

Radon has been a "hot button" issue in radiation protection for many years. Since the 1980s, the Environmental Protection Agency (EPA) has warned homeowners about the potential dangers of radon gas in the home, specifically, that it can cause lung cancer at sufficiently high concentrations or throughout long exposure times. For years the EPA ran a public information campaign warning that buildup of radon in the home was a major cause of lung cancer (second only to smoking), and that homeowners should have their houses tested for the gas. Newer houses in particular, because of their superior insulation, held the gas inside much more efficiently than older, draftier houses. Commercially available test kits costing between $10 and $20 now allow homeowners to determine for themselves whether the indoor air of their houses is contaminated with unacceptable levels of radon. The EPA safety standard is 4 pCi/l, above which one should consider some form of remediation.

It has been shown that high levels of inhaled radon gas leave alpha-emitting radioactive isotopes in the lungs that over time may cause lung damage and cancer. It is not as clear whether the radon concentration found in the typical "contaminated" house is sufficient to cause a statistically measurable increase in lung cancer incidence in the house's occupants. The original studies (from the 1980s) that the EPA quotes in its risk estimates were based on much higher level radon exposures such as the exposures, that are found in deep mines. Miners in fact do have higher incidences of lung cancer than the general population, and radon inhalation is thought to be a contributing factor. Using these studies as their basis, and on the advice of many experts, the EPA issued reports stating that approximately 10 percent (or 15,000) of all lung cancer deaths in the United States annually are caused by radon exposure in the home. The EPA encourages all homeowners to test their indoor air. If the test measures radon levels above the recommended limit (which was extrapolated from the data on miners), the agency urges homeowners to install vents and fans, retrofitting procedures that often cost $2,000 or more. The retrofits do work, however, with radon effectively dispersed outdoors by the improved ventilation.

Newer data, however, reveal that the link between the amount of radon found in a contaminated home may have been exaggerated unknowingly. In particular, a long-term study from Finland showed little, if any, correlation between low-level radon exposure and measurable increases in lung cancer.

Other smaller studies conducted in Canada, Missouri, and China have come to the same conclusion as the Finnish study, whereas a study in Sweden did find a correlation between radon exposure and cancer. Given the uncertainty, the EPA is awaiting the results of an ongoing international study before deciding whether to change its current safety recommendations. The National Cancer Institute has praised the Finnish study but admits that at this time the jury is still out on radon exposure, that is, if high-level radon exposure can cause cancer, then what low-level exposure is considered safe? Unfortunately, unlike the other types of radiation discussed in this brochure, the issue of risk associated with radon in the home remains unresolved.

For current information on radon, contact the National Safety Council's radon hotline at 1-800-SOS-RADON. They will send you a brochure and tell you how to contact the agency in your region that is responsible for radon abatement.

The Bottom Line – Should You Be Worried?

We hope this has given you an overview of some of the ways you are most likely to encounter ionizing radiation in your daily life. Should you be concerned? If you are dealing with high-intensity radiation sources with long half-lives and high exposure rates, the answer is certainly yes. But for most sources of common radiation exposures, the answer is probably no, with the caveat that there is always some risk even if very small. In fact, as previously discussed, radiation can be beneficial when controlled and used judiciously. As with all powerful things – from automobiles to weed killer – common sense, coupled with up-to-date information, should be the hallmark of any interaction.

There is no doubt that radiation is a powerful entity; no single answer fits all concerns about radiation exposures. If you have a question about a specific radiation situation, contact your state office of radiation protection or call AIHA at (703) 849-8888 for more information.