In everyday life we are surrounded by radiation, but this issue is never considered. However, when radiation does become a focus, people don’t really know a great deal about it and sometimes what is known is not always complete or it turns out to be completely untrue. Given all these factors, this and next month’s issue of Health and Safety News will be dedicated to this important topic. The areas of focus for this month include the following: radiation basics, health effects of radiation, and a glossary of pertinent terms.

The information for this issue was taken directly from the U. S. Environmental Protection Agency’s website (http://www.epa.gov/radiation/all.html). To read more about any topic in the newsletter or anything related to this area, please visit the EPA’s site. Also, for items in blue, right mouse click and select Open Hyperlink for more details.

General Information

Understanding Radiation

• Radiation Basics

Radiation: Non-Ionizing and Ionizing

Radiation has a wide range of energies that form the electromagnetic spectrum (illustrated...
below). The spectrum has two major divisions:

- non-ionizing radiation
- ionizing radiation

Radiation that has enough energy to move around atoms in a molecule or cause them to vibrate, but not enough to remove electrons, is referred to as "non-ionizing radiation." Examples of this kind of radiation include visible light and microwaves.

Radiation that falls within the "ionizing radiation" range has enough energy to remove tightly bound electrons from atoms, thus creating ions. This is the type of radiation that people usually think of as 'radiation.' We take advantage of its properties to generate electric power, to kill cancer cells, and in many manufacturing processes.

The energy of the radiation shown on the spectrum below increases from left to right as the frequency rises.

Types of Radiation in the Electromagnetic Spectrum

Nonionizing Radiation
We take advantage of the properties of non-ionizing radiation for common tasks:

- microwave radiation telecommunications and heating food
- infrared radiation infrared lamps to keep food warm in restaurants
- radio waves broadcasting

Non-ionizing radiation ranges from extremely low frequency radiation, shown on the far left through the audible, microwave, and visible portions of the spectrum into the ultraviolet range.

Extremely low-frequency radiation has very long wave lengths (on the order of a million meters...
or more) and frequencies in the range of 100 Hertz (cycles per second) or less. Radio frequencies have wavelengths of between one and 100 meters and frequencies in the range of one million to 100 million Hertz. Microwaves that we use to heat food have wavelengths that are about one hundredth of a meter and have frequencies of about 2.5 billion Hertz.

**Ionizing Radiation**

Higher frequency ultraviolet radiation begins to have enough energy to break chemical bonds. X-ray and gamma ray radiation, which are at the upper end of magnetic radiation, have very high frequencies (in the range of 100 billion billion Hertz) and very short wavelengths of about 1 picometer (1 trillionth of a meter). Radiation in this range has extremely high energy. It has enough energy to strip off electrons or, in the case of very high-energy radiation, break up the nucleus of atoms.

Ionization is the process in which a charged portion of a molecule (usually an electron) is given enough energy to break away from the atom. This process results in the formation of two charged particles or ions: the molecule with a net positive charge and the free electron with a negative charge.

Each ionization releases approximately 33 electron volts (eV) of energy. Material surrounding the atom absorbs the energy. Compared to other types of radiation that may be absorbed, ionizing radiation deposits a large amount of energy into a small area. In fact, the 33 eV from one ionization is more than enough energy to disrupt the chemical bond between two carbon atoms. All ionizing radiation is capable, directly or indirectly, of removing electrons from most molecules.

There are three main kinds of ionizing radiation:

- **alpha particles**, which include two protons and two neutrons
- **beta particles**, which are essentially high-speed electrons
- **gamma rays** and x-rays, which are pure energy (photons).

**Health Effects of Radiation**

**Radiation and Health**

*How does radiation cause health effects?*

Radioactive materials that decay spontaneously produce ionizing radiation, which has sufficient energy to strip away electrons from atoms (creating two charged ions) or to break some chemical bonds. Any living tissue in the human body can be damaged by ionizing radiation in a unique manner. The body attempts to repair the damage, but sometimes the damage is of a nature that cannot be repaired or it is too severe or widespread to be repaired. Also mistakes made in the natural repair process can lead to cancerous cells. The most common forms of ionizing radiation are alpha and beta particles, or gamma and X-rays.

*What kinds of health effects does exposure to radiation cause?*
In general, the amount and duration of radiation exposure affects the severity or type of health effect. There are two broad categories of health effects: stochastic and non-stochastic.

**Stochastic Health Effects**

Stochastic effects are associated with long-term, low-level (chronic) exposure to radiation. (“Stochastic” refers to the likelihood that something will happen.) Increased levels of exposure make these health effects more likely to occur, but do not influence the type or severity of the effect.

Cancer is considered by most people the primary health effect from radiation exposure. Simply put, cancer is the uncontrolled growth of cells. Ordinarily, natural processes control the rate at which cells grow and replace themselves. They also control the body's processes for repairing or replacing damaged tissue. Damage occurring at the cellular or molecular level, can disrupt the control processes, permitting the uncontrolled growth of cells cancer. This is why ionizing radiation's ability to break chemical bonds in atoms and molecules makes it such a potent carcinogen.

Other stochastic effects also occur. Radiation can cause changes in DNA, the "blueprints" that ensure cell repair and replacement produces a perfect copy of the original cell. Changes in DNA are called mutations.

Sometimes the body fails to repair these mutations or even creates mutations during repair. The mutations can be teratogenic or genetic. Teratogenic mutations are caused by exposure of the fetus in the uterus and affect only the individual who was exposed. Genetic mutations are passed on to offspring.

**Non-Stochastic Health Effects**

Non-stochastic effects appear in cases of exposure to high levels of radiation, and become more severe as the exposure increases. Short-term, high-level exposure is referred to as 'acute' exposure.

Many non-cancerous health effects of radiation are non-stochastic. Unlike cancer, health effects from 'acute' exposure to radiation usually appear quickly. Acute health effects include burns and radiation sickness. Radiation sickness is also called 'radiation poisoning.' It can cause premature aging or even death. If the dose is fatal, death usually occurs within two months. The symptoms of radiation sickness include: nausea, weakness, hair loss, skin burns or diminished organ function.

Medical patients receiving radiation treatments often experience acute effects, because they are receiving relatively high "bursts" of radiation during treatment.

**Is any amount of radiation safe?**

There is no firm basis for setting a "safe" level of exposure above background for stochastic effects. Many sources emit radiation that is well below natural background levels. This makes it extremely difficult to isolate its stochastic effects. In setting limits, EPA makes the conservative
(cautious) assumption that any increase in radiation exposure is accompanied by an increased risk of stochastic effects.

Some scientists assert that low levels of radiation are beneficial to health (this idea is known as hormesis).

However, there do appear to be threshold exposures for the various non-stochastic effects. (Please note that the acute affects in the following table are cumulative. For example, a dose that produces damage to bone marrow will have produced changes in blood chemistry and be accompanied by nausea.)

<table>
<thead>
<tr>
<th>Exposure (rem)</th>
<th>Health Effect</th>
<th>Time to Onset (without treatment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-10</td>
<td>changes in blood chemistry</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>nausea</td>
<td>hours</td>
</tr>
<tr>
<td>55</td>
<td>fatigue</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>vomiting</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>hair loss</td>
<td>2-3 weeks</td>
</tr>
<tr>
<td>90</td>
<td>diarrhea</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>hemorrhage</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>possible death</td>
<td>within 2 months</td>
</tr>
<tr>
<td>1,000</td>
<td>destruction of intestinal lining</td>
<td></td>
</tr>
<tr>
<td></td>
<td>internal bleeding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and death</td>
<td>1-2 weeks</td>
</tr>
<tr>
<td>2,000</td>
<td>damage to central nervous system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>loss of consciousness;</td>
<td>minutes</td>
</tr>
<tr>
<td></td>
<td>and death</td>
<td>hours to days</td>
</tr>
</tbody>
</table>

How do we know radiation causes cancer?

Basically, we have learned through observation. When people first began working with radioactive materials, scientists didn't understand radioactive decay, and reports of illness were scattered.

As the use of radioactive materials and reports of illness became more frequent, scientists began to notice patterns in the illnesses. People working with radioactive materials and x-rays developed particular types of uncommon medical conditions. For example, scientists recognized as early as 1910 that radiation caused skin cancer. Scientists began to keep track of the health effects, and soon set up careful scientific studies of groups of people who had been exposed.

Among the best known long-term studies are those of Japanese atomic bomb blast survivors, other populations exposed to nuclear testing fallout (for example, natives of the Marshall Islands), and uranium miners.
Aren’t children more sensitive to radiation than adults?

Yes, because children are growing more rapidly, there are more cells dividing and a greater opportunity for radiation to disrupt the process. EPA’s radiation protection standards take into account the differences in the sensitivity due to age and gender.

Fetuses are also highly sensitive to radiation. The resulting effects depend on which systems are developing at the time of exposure.

Effects of Radiation Type and Exposure Pathway

Both the type of radiation to which the person is exposed and the pathway by which they are exposed influence health effects. Different types of radiation vary in their ability to damage different kinds of tissue. Radiation and radiation emitters (radionuclides) can expose the whole body (direct exposure) or expose tissues inside the body when inhaled or ingested.

All kinds of ionizing radiation can cause cancer and other health effects. The main difference in the ability of alpha and beta particles and gamma and x-rays to cause health effects is the amount of energy they can deposit in a given space. Their energy determines how far they can penetrate into tissue. It also determines how much energy they are able to transmit directly or indirectly to tissues and the resulting damage.

Although an alpha particle and a gamma ray may have the same amount of energy, inside the body the alpha particle will deposit all of its energy in a very small volume of tissue. The gamma radiation will spread energy over a much larger volume. This occurs because alpha particles have a mass that carries the energy, while gamma rays do not.

Non-Radiation Health Effects of Radionuclides

Radioactive elements and compounds behave chemically exactly like their non-radioactive forms. For example, radioactive lead has the same chemical properties as non-radioactive lead. The public health protection question that EPA's scientists must answer is, "How do we best manage all the hazards a pollutant presents?" (See Protecting Against Exposure)

Do chemical properties of radionuclides contribute to radiation health effects?

The chemical properties of a radionuclide can determine where health effects occur. To function properly many organs require certain elements. They cannot distinguish between radioactive and non-radioactive forms of the element and accumulate one as quickly as the other.

- Radioactive iodine concentrates in the thyroid. The thyroid needs iodine to function normally, and cannot tell the difference between stable and radioactive isotopes. As a result, radioactive iodine contributes to thyroid cancer more than other types of cancer.
- Calcium, strontium-90 and radium-226 have similar chemical properties. The result is that strontium and radium in the body tend to collect in calcium rich areas, such as bones and teeth. They contribute to bone cancer.

Estimating Health Effects
What is the cancer risk from radiation? How does it compare to the risk of cancer from other sources?

Each radionuclide represents a somewhat different health risk. However, health physicists currently estimate that overall, if each person in a group of 10,000 people exposed to 1 rem of ionizing radiation, in small doses over a life time, we would expect 5 or 6 more people to die of cancer than would otherwise.

In this group of 10,000 people, we can expect about 2,000 to die of cancer from all non-radiation causes. The accumulated exposure to 1 rem of radiation, would increase that number to about 2005 or 2006.

To give you an idea of the usual rate of exposure, most people receive about 3 tenths of a rem (300 mrem) every year from natural background sources of radiation (mostly radon).

What are the risks of other long-term health effects?

Other than cancer, the most prominent long-term health effects are teratogenic and genetic mutations.

Teratogenic mutations result from the exposure of fetuses (unborn children) to radiation. They can include smaller head or brain size, poorly formed eyes, abnormally slow growth, and mental retardation. Studies indicate that fetuses are most sensitive between about eight to fifteen weeks after conception. They remain somewhat less sensitive between six and twenty-five weeks old.

The relationship between dose and mental retardation is not known exactly. However, scientists estimate that if 1,000 fetuses that were between eight and fifteen weeks old were exposed to one rem, four fetuses would become mentally retarded. If the fetuses were between sixteen and twenty-five weeks old, it is estimated that one of them would be mentally retarded.

Genetic effects are those that can be passed from parent to child. Health physicists estimate that about fifty severe hereditary effects will occur in a group of one million live-born children whose parents were both exposed to one rem. About one hundred twenty severe hereditary effects would occur in all descendants.

In comparison, all other causes of genetic effects result in as many as 100,000 severe hereditary effects in one million live-born children. These genetic effects include those that occur spontaneously ("just happen") as well as those that have non-radioactive causes.

Protecting Against Exposure

What limits does EPA set on exposure to radiation?

Health physicists generally agree on limiting a person's exposure beyond background radiation to about 100 mrem per year from all sources. Exceptions are occupational, medical or accidental exposures. (Medical X-rays generally deliver less than 10 mrem). EPA and other regulatory agencies generally limit exposures from specific source to the public to levels well under 100
mrem. This is far below the exposure levels that cause acute health effects.

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**How does EPA protect against radionuclides that are also toxic?**

In most cases, the radiation hazard is much greater than the chemical (toxic) hazard. Radiation protection limits are lower than the chemical hazard protection limits would be. By issuing radiation protection regulations, EPA can protect people from both the radiation and the chemical hazard. However, deciding which hazard is greater is not always straightforward. Several factors can tip the balance:

- toxicity of the radionuclide
- strength of the ionizing radiation
- how quickly the radionuclide emits radiation (half-life)
- relative abundance of the radioactive and non-radioactive forms

For example:

- **Uranium-238** is both radioactive and very toxic. Its half-life of 4.5 billion years means that only a few atoms emit radiation at a time. A sample containing enough atoms to pose a radiation hazard contains enough atoms to pose a chemical hazard. As a result, EPA regulates uranium-238 as both a chemical and a radiation hazard.
- **Radioactive isotopes of lead** are both radioactive and toxic. In spite of the severe effects of lead on the brain and the nervous system, the radiation hazard is greater. However, the radioactive forms of lead are so uncommon that paint or other lead containing products do not contain enough radioactive lead to present a radiation hazard. As a result, EPA regulates lead as a chemical hazard.

**Resources**

*Possible Health Effects of Radiation Exposure on Unborn Babies*
Centers for Disease Control and Prevention (CDC)
This fact sheet was developed to help you understand the possible health effects to your unborn baby from exposure to radiation.

**Radiation Glossary A-C**

**A**

Acute Exposure

a single exposure that results in biological harm or death; usually characterized by a brief exposure lasting no more than 7 days, as compared to longer, continuing exposure over a period of time

**Agreement State**
a state that has signed an agreement with the Nuclear Regulatory Commission allowing the state to regulate the use of by-product radioactive material within the state.

**Alpha Particle**

a positively charged particle made up of two neutrons and two protons emitted by certain radioactive nuclei. Alpha particles can be stopped by thin layers of light materials, such as a sheet of paper, and pose no direct or external radiation threat; however, they can pose a serious health threat if ingested or inhaled.

**Ambient Air**

the air that surrounds us

**Americium**

a silvery metal; it is a man-made element whose isotopes americium-237 through -246 are all radioactive. Americium-241 is formed spontaneously by the beta decay of plutonium-241. Trace quantities of americium are widely used in smoke detectors, and as neutron sources in neutron moisture gauges.

**Advanced Notice of Proposed Rulemaking (ANPRM)**

an official notice by a government agency that it is preparing regulations on a specific topic. An ANPRM frequently describes the approach the agency is taking in general terms, and may invite public comment.

**Applicable or Relevant and Appropriate Requirement (ARAR)**

Under the Comprehensive Environmental Responsibility, Cleanup and Liability Act (Superfund), cleanups must follow two kinds of requirements:

- applicable requirements meaning those that directly apply to the situation
- relevant or appropriate requirements meaning those that apply to contaminants that are present at the site or apply to a contaminated medium, such as water, at the site

For example, the standards for cleaning up uranium and thorium processing facility sites are frequently considered "relevant and appropriate" for radiologically contaminated sites that did not conduct such processing. ARARs can be federal, state, or local requirements.

**Area**

a general term referring to any portion of a site, up to and including the entire site.

**Area of Elevated Activity**
an area over which residual radioactivity exceeds a specified value DCGL(sub-EMC).

**Atomic Mass number**

the number of protons and neutrons in the nucleus of a nuclide. (The atomic mass number is not the same as the chemical atomic weight, which is the average of all the naturally occurring isotopes of an element weighted according to their relative abundances.)

**Atomic Mass Unit (AMU)**

AMU is equal to the mass of one-twelfth of a carbon-12 atom.

**Atoms for Peace**

President Eisenhower's 1954 initiative to allow the peaceful uses of atomic energy to be available to other nations.

**Authorities**

the Presidential and legislative powers transferred to federal agencies through laws, Executive Orders, and Presidential Decision Directives

**B**

**Beneficiation**

a set of processes used to reduce the particle size of mined ore to allow the desired mineral to be separated from wastes and either used or further processed

**Biological Effects of Ionizing Radiation (BEIR) Reports**

reports of the National Research Council's committee on the Biological Effects of Ionizing Radiation

**Becquerel (Bq)**

a unit used to measure radioactivity. One Becquerel is the amount of a radioactive material that will undergo one transformation in one second.

Often radioactivity is expressed in larger units like: thousands (Kq), or millions (MBq) of becquerels.

As a result of having one Becquerel being equal to one transformation per second, there are $3.7 \times 10^{10}$ (37 billion) Bq in one curie.

**Beta Particle**
an electron or positron emitted by certain radioactive nuclei. Beta particles can be stopped by aluminum. They can pose a serious direct or external radiation threat and can be lethal depending on the amount received. They also pose a serious internal radiation threat if inhaled or ingested.

**Binding Energy (cosmic glue)**

the amount of energy required to break up a nucleus into its constituent parts, or conversely, the energy released upon formation of the nucleus

**By-Product Material**

radioactive materials left over from the production or use of special nuclear material

the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content

Regulatory definition: "(1) Any radioactive material (except special nuclear material) yielded in, or made radioactive by, exposure incident to the process of producing or utilizing special nuclear material, and (2) The tailings or wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source material content, including discrete surface wastes resulting from uranium solution extraction processes. Underground ore bodies depleted by these solution extraction operations do not constitute "by-product material" within this definition (10 CFR 20.1003)."

**C**

Carcinogen

a cancer-causing substance

**Cerium**

an iron-gray, lustrous metal. It is malleable, and oxidizes very readily at room temperature, especially in moist air. The pure metal may ignite when scratched with a knife. Cerium-141, -143, and -144 are radioisotopes of cerium. They emit beta particles during radioactive decay.

**Cesium**

a metal that may be stable (non radioactive) or unstable (radioactive). The most common radioactive form of cesium is cesium-137. Another fairly common radioisotope is cesium-134. Cesium-137 is much more significant as an environmental contaminant than cesium-134. It is also very useful in industry for its strong radioactivity.

**Chain Reaction**

a reaction that initiates its own repetition. In a fission chain reaction, a fissionable nucleus absorbs
a neutron and fissions (splits) spontaneously, releasing additional neutrons. These, in turn, can be absorbed by other fissionable nuclei, releasing still more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in non-fissionable material or by escape from the system.

**Characterize**

to describe the characteristics of something, such as a waste or a waste site. For example, characterizing a waste from mining or processing a naturally occurring radioactive material typically includes finding the following types of information:

- chemical and radionuclide content
- level of radiation
- physical description (is it liquid or solid; in big chunks or a fine powder, etc.)
- amount
- pH (is it an acid or a base)

**Chronic Exposure**

exposure to a substance over a long period of time, possibly resulting in adverse health effects.

**Class I Survey**

a type of final status survey that applies to areas with the highest potential for contamination, and meet the following criteria: (1) impacted; (2) potential for delivering a dose above the release criterion; (3) potential for small areas of elevated activity; and (4) insufficient evidence to support classification as Class 2 or Class 3.

**Class 2 Survey**

a type of final status survey survey that applies to areas that meet the following criteria: (1) impacted; (2) low potential for delivering a dose above the release criterion; and (3) little or no potential for small areas of elevated activity.

**Class 3 Survey**

a type of final status survey that applies to areas meeting the following criteria: (1) impacted; (2) little or no potential of delivering a dose above the release criterion; and (3) little or no potential for small areas of elevated activity.

**Cobalt**

a gray, hard, magnetic, ductile, and somewhat malleable metal, cobalt is relatively rare and generally obtained as a byproduct of other metals, such as copper. Its most common radioactive isotope is cobalt-60, which emits beta particles during radioactive decay.

**Compact**
a group of two or more states formed to dispose of low-level radioactive waste on a regional basis. The Low-Level Radioactive Waste Policy Act of 1980 encouraged states to form compacts to ensure continuing low-level waste disposal capacity. As of December 2000, forty-four states have formed ten compacts. No compact has successfully sited and constructed a disposal facility.

Conference of Radiation Control Program Directors (CRCPD)

an organization whose members represent state radiation protection programs

Contamination

the deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or people. It may also be airborne, external, or internal (inside components or people).

Continuity of Operations

planning to ensure that the essential functions of an organization, such as an agency or the federal government, can continue during a wide range of potential emergencies.

Cooling Tower

a heat exchanger designed to aid in the cooling of water that was used to cool exhaust steam exiting the turbines of a power plant. Cooling towers transfer exhaust heat into the air instead of into a body of water.

Coordinating Agency

the agency responsible for the radiological facility or activity involved in the incident. Coordinating agencies have primary responsibilities for federal activities related to the nuclear/radiological aspects of the incident.

Cooperating Agency

agencies that provide support to the Coordinating Agency during the federal response to a radiological emergency.

Criticality

a term used to describe the state of a fission reaction when the number of neutrons released by fission is exactly balanced by the neutrons being absorbed and escaping. For example, reactor is said to be "critical" when it achieves a self-sustaining nuclear chain reaction, as it does when the reactor is operating.

Cumulative Dose

the total dose resulting from repeated exposures of ionizing radiation to an occupationally
exposed worker to the same portion of the body, or to the whole body, over a period of time.

**Curie**

a measure of radioactivity based on the observed decay rate of approximately one gram of radium. The Curie was named in honor of Pierre and Marie Curie, pioneers in the study of radiation. One curie of radioactive material will have 37 billion atomic transformations (disintegrations) in one second.