Radiation at Fukushima: Basic Issues and Concepts

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Tracking, assessing, and understanding the developments at Japan's severely damaged Fukushima Daiichi nuclear power plant is challenging: conditions are fluctuating daily, as is the quality of information available about them, and the vocabulary and concepts at play in a nuclear crisis are complicated. It also has been many years since the U.S. public, press, and even most U.S. officials have had to be conversant in the language of nuclear radiation risks. The release of radiation in Japan, therefore, has caused great concern and confusion among the general public and the media alike, especially regarding the extent of the potential health risks that could occur as a result of the damaged Fukushima reactor. This brief is intended to help explain and put into context for a nonexpert audience some of the often unfamiliar terminology and concepts associated with nuclear radiation.

Radioactive Isotopes and Nuclear Reactors

Nuclear radiation refers to the subatomic particles or electromagnetic waves that are emitted by certain naturally occurring and inherently unstable isotopes (variants of certain elements with differing numbers of neutrons) that emit such particles or electromagnetic waves in the process of becoming more stable. The isotopes are said to be radioactive. Radioactive isotopes are also called radionuclides.

Before the crisis began, the Fukushima reactors (as is the case with all nuclear reactors) were harnessing the radioactive process to generate heat to produce electricity. In the normal operation of a nuclear reactor, concentrated sources of radioactive isotopes of uranium or plutonium (nuclear fuel) are brought into close proximity to each other. In so doing, neutron particles emitted from one atom—the smallest particle of an element that can exist independently—of the nuclear fuel elements (neutron radiation) causes a neighboring atom to split. This is referred to as fission. In turn, each fission event will release more neutrons, resulting in a cascading chain reaction of rapidly multiplying fissions. The chain reaction of nuclear fissions is controlled in a reactor by insertable control rods that absorb neutrons and reduce this reaction. These fissions release a great deal of energy in the form of heat and also create new elements (fission products) that are themselves radioactive. Each atom of a radioactive isotope emits radiation only once, so over time the source becomes less radioactive. This radioactive decay occurs at a predictable rate (half-life) that is specific to the isotope.

Four Major Forms of Radiation in a Nuclear Reactor

Four types of nuclear radiation exist within a reactor: alpha, beta, gamma, and neutron. For the most part, neutrons are not a concern outside the reactor unless enough fissionable radioactive material is present (for example, in radioactive fuel processing) to permit a chain reaction to occur, which is referred to as a criticality event. This has not happened at Fukushima. The 3 other forms of radiation can be dangerous if there is a release of radioactive material from a reactor or from spent nuclear fuel. At Fukushima, alpha, beta, and gamma radioactivity have been released outside the reactor, though the only immediate danger of this radiation has been at very close proximity to the reactors.

Alpha radiation consists of a proton and a neutron. This type of radiation does not travel far in the air and can be stopped by a sheet of paper. It cannot penetrate skin; therefore, it is of concern only if ingested or inhaled. If sufficient alpha-radiation occurs inside the body (eg, in someone who consumed polonium-210), it can cause severe damage resulting in illness or death. At Fukushima, low levels of the alpha-emitter plutonium have been discovered in soil samples near the reactor, the result of radioactive dust settling in the soil. If dust particles are inhaled, potential alpha radiation damage could occur in humans. Plutonium can disperse widely; most of the current plutonium found in the soil worldwide is the result of prior nuclear weapons testing.

Beta radiation consists of high-energy electrons. They are a somewhat more penetrating form of radiation, but they can be stopped by aluminum foil or wood shielding. External beta radiation can cause a radiation burn to the skin, which may appear as a slower healing form of sunburn. Beta-radiation can also be inhaled or ingested. At Fukushima, radioactive iodine and cesium—both beta-emitters—have been detected in vegetables, the result of radioactive dust settling on leaves. Trace levels of radioactive iodine and cesium have been detected as far away as California and Massachusetts.
Gamma radiation, the most concerning kind of radiation from a health risk standpoint, consists of high-energy photons, which can penetrate body tissues from an external source and cause damage to cells and their genetic material. Such radiation can be attenuated by using a shield such as lead or concrete, or by sufficient distance from the radiation source.

The Most Important Radionuclides Involved in a Nuclear Reactor

Many different radioactive isotopes are used in or are produced by nuclear reactors. The most important of these are described below:

1. **Uranium 235 (U-235)** is the active component of most nuclear reactor fuel.

2. **Plutonium (Pu-239)** is a key nuclear material used in modern nuclear weapons and is also present as a byproduct in certain reprocessed fuels used in some nuclear reactors. Pu-239 is also produced in uranium reactors as a byproduct of fission of U-235.

3. **Cesium (Cs-137)** is a fission product of U-235. It emits beta and gamma radiation and can cause radiation sickness and death if exposures are high enough. Absorbed cesium is rapidly excreted by the body, and exposure to low levels of Cs-137 has not been linked definitively to long-term health effects (eg, cancer) in humans. Its half-life, the time required for half the amount of a substance to be eliminated by natural processes, is 31 years.

4. **Iodine 131 (I-131)**, also a fission product of U-235, emits beta and gamma radiation. After inhalation or ingestion, it is absorbed by and concentrated in the thyroid gland, where its beta radiation damages nearby thyroid tissue. When administered therapeutically in relatively high doses, it is used as a treatment for overactive thyroid glands. However, in lower doses, I-131 is known to cause thyroid cancer, primarily in children. The uptake of I-131 by the thyroid can be effectively blocked by pretreatment with potassium iodide. The half-life of I-131 is only 8 days. Therefore, environments (and food chains) contaminated by I-131, even if very heavily contaminated, will be mostly free of radiation in a matter of weeks.

At this point, the important radionuclides that have been publicly reported to have been detected outside the Fukushima reactor complex are I-131, Cs-137, and plutonium. The plutonium was found in soil samples around the reactor site in low levels that do not exceed background plutonium rates in other areas of Japan.

Health Effects of Radiation

One of the great challenges to public understanding of the risks posed to the population living closest to the Fukushima reactors has been interpreting the language of radiation dose. Radiation can be expressed in several different units that quantify the amount of energy that is absorbed from radiation or its effects on living organisms. The currently accepted unit of dose measurement is the Sievert (Sv), which replaced an older term, the rem (1 Sv = 100 rem). A Sievert is a unit of measurement of the biological activity of radiation and is the most accurate way of quantifying the effect of radiation on the human body.

The dose of radiation absorbed by a person depends on the strength of the radiation source, the individual’s distance from the source, the amount of protective shielding, and the duration of the exposure. The health effects of radiation depend on the type of radiation, the dose of radiation absorbed, the time over which the exposure occurs, the exposure pathway (e.g., ingestion, inhalation, external), and the specific parts and percentage of the body exposed.

There are several other factors that influence health effects as well. Certain tissues are especially sensitive to the effects of radiation (e.g., bone marrow and gastrointestinal tract tissue). Some radionuclides are more or less harmful depending on the exposure pathway. For example, as stated above, alpha emitters are a problem, for the most part, only if they are ingested or inhaled. Environmental contamination from, for example, I-131 can result in consumption of radionuclides by livestock, such as cows, and then incorporation into foods consumed by humans, which can be another route of exposure for humans. At Fukushima, the principal environmental contamination has been with I-131 and Cs-137, which have been detected primarily in Japan and in lower, nondangerous amounts elsewhere. In contrast, at Chernobyl a massive explosion and fire propelled radioactive isotopes high into the atmosphere, facilitating widespread distribution of the radioactive material.
Exposure to high doses of radiation over large parts of the body can cause severe illness and death (acute radiation sickness). The threshold for acute symptoms is approximately 1 Sv of total body dose over a short period of time. Typically, doses in excess of 3-5 Sv are needed to cause death from acute exposure (see Table 1). Exposure to the same radiation source, if limited to only a relatively small part of the body—the feet, for example—may cause nothing more than superficial burns of the skin.

Table 1: Radiation Dose and Acute illness

<table>
<thead>
<tr>
<th>Est’d whole body radiation dose</th>
<th>Acute illness</th>
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<tbody>
<tr>
<td>1 Sv</td>
<td>Threshold for acute radiation symptoms</td>
</tr>
<tr>
<td>3-4 Sv</td>
<td>Threshold for possible death without treatment</td>
</tr>
<tr>
<td>5-6 Sv</td>
<td>Threshold for possible death with treatment</td>
</tr>
<tr>
<td>&gt;8 Sv</td>
<td>Death likely, even with treatment</td>
</tr>
</tbody>
</table>

For more information: See David McCandless’s graphic radiation dosage chart (InformationIsBeautiful.net) and the New York Times’ interactive Map of the Damage from the Japanese Earthquake, which shows radiation levels around the Fukushima plant (as recently as March 28) and compares them with doses from daily life.

Exposure to approximately 100 milliSievert (100 mSv) may be associated with a discernible—albeit small—increased risk of cancer over a lifetime. The magnitude of this risk and the types of cancer associated vary with the dose, the type of radiation, the route of exposure (eg, ingestion vs. external), and the time over which the exposure occurred. The American Cancer Society estimates that the whole lifetime risk of developing a cancer for each individual is approximately 42%. Exposure to 100 mSv could increase that risk by approximately 1 more percentage point. There remains scientific debate over this issue, as very small increases in cancer risk that might be associated with very low radiation doses cannot easily be distinguished from the normal risk of cancer. In fact, in some studies summarized in the scientific journal Human and Environmental Toxicology, low levels of radiation have been found to be associated with lower risks of cancer. Due in part to the uncertainty of the science, U.S. regulatory agencies have set policy based on the “linear non-threshold hypothesis,” which assumes that no level of radiation is safe and that any dose of radiation would theoretically translate to an increased cancer risk.

Low-Level Radiation Exposure Is Part of Normal Life

In considering the doses of radiation exposure related to Fukushima, it is important to understand that low levels of naturally occurring radiation permeate our environment, primarily from the sun and the soil. Everyone is exposed to low levels of radiation from a variety of sources every day. Table 2 summarizes levels of radiation experienced with various activities.

Table 2: Levels of Radiation Exposure Associated with Daily Activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Radiation level</th>
</tr>
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<tbody>
<tr>
<td>Daily life</td>
<td>2 milli-Sieverts/ year</td>
</tr>
<tr>
<td>Chest X-ray</td>
<td>0.1 milli-Sievert</td>
</tr>
<tr>
<td>Chest CT scan</td>
<td>5 milli-Sieverts</td>
</tr>
<tr>
<td>Cross-country airplane flight</td>
<td>0.5 milli-Sieverts</td>
</tr>
<tr>
<td>Threshold for radiation sickness</td>
<td>1,000 milli-Sieverts (1 Sv)</td>
</tr>
<tr>
<td>Threshold for an increase in cancer risk</td>
<td>100 milli-Sieverts</td>
</tr>
</tbody>
</table>

The Events at Fukushima Highlight the Need for Effective Communication in Disasters

The Japanese nuclear crisis will continue to evolve and hopefully the release of radioactive material from the power plant will soon subside. However, officials will be dealing with the long-term consequences of this crisis for years. A greater nuclear/radiation literacy among the public, press, and officials will be needed to understand these consequences. The events at Fukushima illustrate the need for effective communication of complex scientific and medical matters to reduce confusion and fear regarding unquantified risks—a facet of most public health emergencies. Other resources, accessible to the lay public, include the websites of the World Nuclear Association and the Health Physics Society, listed below.
References


