Health Physics Society
Specialists in Radiation Safety

Fact Sheet
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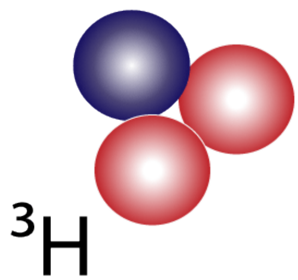
Tritium

General Information

Tritium is the only *radioactive** *isotope* of hydrogen and it is commonly represented by the chemical symbol H-3 or ^3H. While the most common form of the hydrogen atom has a nucleus consisting of a single proton, tritium's nucleus is comprised of three particles: two neutrons and a single proton. This configuration makes tritium's nucleus unstable and tending to undergo a process of radioactive transformation. During this decay process, the tritium atom transforms into a nonradioactive helium atom and, in the process, emits a form of *ionizing radiation* known as a beta particle. The emission of this beta particle during the decay process is what makes tritium a potentially hazardous material.



The *half-life* of tritium is 12.3 years. The beta particle that is emitted by tritium is considered to be very weak, having an average kinetic energy of 6 *keV*. As a result, these particular beta particles can only travel about 6 mm in air before they lose their ability to cause ionizations. In tissue, tritium's beta particle is so weak that it cannot penetrate the typical thickness of the dead layer of skin that exists on the outside of the human body. For this reason, the beta particle emitted by tritium is generally only considered to be hazardous if a significant quantity of tritium is, or has the potential to be, taken into the body.

The chemical behavior of tritium is essentially the same as that of hydrogen. This means that tritium, just like stable hydrogen, can exist in a gaseous state or, more commonly, in the form of water. In fact, tritium atoms have a tendency to replace one of the stable hydrogen atoms in water, H_20, thus becoming a part of the water molecule. The resulting compound is known as tritiated water, with the chemical formula HTO or T_2O. Tritiated water is colorless and odorless, just like regular water, and can exist alongside regular water molecules. Given the chemical properties of tritium and the fact that roughly two-thirds of human body mass is composed of water, it is very common for tritium to exist within the human body.

Sources

Tritium can be produced in several ways and is generated naturally in the atmosphere through interactions between nitrogen in the air and radiations originating from outer space, known as cosmic rays. Tritium is also produced by nuclear reactions that are brought about through man-made processes. These are generally limited to nuclear reactions that occur within a nuclear reactor, during the detonation of a nuclear weapon or, to a much lesser extent, in particle accelerators. All of these processes produce tritium because they create situations where nuclear reactions, such as fission, fusion, and *activation*, can occur.

Nuclear weapons, particularly thermonuclear weapons, have the ability to produce large quantities of tritium. There was a time when the atmospheric testing of nuclear weapons contributed significantly to the amount of tritium present in the environment; however, since the signing of the Partial Test Ban Treaty in 1963, the major nuclear-armed countries have limited their testing activities to underground nuclear detonations. Consequently, the amount of tritium in the environment has been decreasing since 1963. While tritium is still produced during subterranean tests, they are designed to contain the majority of the tritium underground at the test site, preventing releases into the greater environment.

*Words in italics are defined in the Glossary on page 5.

Nuclear reactors produce tritium as a direct product of nuclear fission as well as through activation of other materials that are in close proximity to the fission process. These materials are generally limited to those that are found inside a nuclear reactor core and can include controls rods and cooling water. While most of the tritium that is generated inside a reactor remains there, some of that tritium can be transported, usually via the cooling water, which is continuously circulated through the reactor core during operation. Commercial nuclear power plants produce tritium as a byproduct of generating electricity, while other nuclear reactors, known as production reactors, are specifically designed to produce radioactive isotopes, including tritium. Such reactors are generally limited to government facilities involved in the production and maintenance of nuclear weapons. However, a commercial power reactor was recently authorized to undertake tritium production activities. To a lesser extent, small research and test reactors may also produce low concentrations of tritium.

Tritium can also be released into the environment from facilities that handle the material but do not necessarily produce it. In the United States, these would primarily be Department of Energy (DOE) facilities involved in work related to the nuclear weapons arsenal or limited noncommercial fuel-reprocessing operations.

Tritium in the Environment

Tritium exists throughout the worldwide environment due to both natural and man-made processes. Although tritium is constantly undergoing radioactive decay, which reduces the amount of tritium in the environment, it is also being generated by the processes discussed above. These competing processes of production and decay result in a dynamic worldwide inventory of tritium, which has fluctuated over time and can be correlated with human activities, most notably the atmospheric testing of nuclear weapons.

Tritium is found throughout the global environment: in the atmosphere, ground water, soil, rivers, lakes, streams, and oceans. Over time tritium that is released into the environment becomes distributed by the same processes that transport water, most notably the hydrological cycle, otherwise known as the water cycle. This process tends to dilute tritium releases by spreading them out, largely preventing any concentration in the environment. However, the distribution and dilution of tritium is not instantaneous and, therefore, individuals in close proximity to tritium releases are generally expected to be exposed to a greater extent than others who are farther away. For this reason, regulations have been designed to limit the exposure to members of the public who have potential for exposure. In practice this means that organizations that release tritium, such a nuclear power plants, are required to ensure that their releases will not cause any single individual member of the public to receive an exposure above the prescribed public dose limit.

Applications

In addition to being produced by nuclear detonations, tritium is also a critical component in modern nuclear weapons, and an inventory of tritium is maintained for this purpose. Tritium is also a prospective fuel in the effort to develop commercially viable nuclear fusion reactors. In the life sciences, tritium is often bound to *organic* compounds and used as a radioactive tracer to study the metabolism of that compound in a biological system, such as an organism or cell.

Photo courtesy of [ANS Nuclear Cafe]
Tritium Exit Sign

Tritium is also found in a range of common consumer items because it can be used in combination with phosphors in order to make materials that are self-luminous (glow in the dark), meaning that these items will produce light without any supplemental power supply. These items include gun sights, watch dials, key chains, and tritium exit signs. It has been estimated that there are greater than 2 million self-luminous tritium exit signs in use in the United States. It is important to understand that tritium itself does not produce visible light or glow in the dark and that the tritium in these devices only serves to energize the light-producing phosphors in these items.

While the use of tritium in self-luminous devices is common and not considered to pose any serious threats to safety, health, or security, the devices do have the potential to release tritium to the environment if damaged. If this happens, low levels of tritium exposure to nearby individuals and a potentially expensive cleanup effort can result. This is only known to happen if the tritium-containing device has been physically damaged.

Additionally, devices such as tritium exit signs are prohibited from disposal as regular solid waste. Instead, they should be disposed of in accordance with applicable federal and state regulations, which typically involve the return of the tritium exit signs to the manufacturer, the distributor, or a licensed radioactive waste broker. Failure to dispose of these items properly can result in regulatory penalties from federal and/or state agencies.

Biological and Health Effects

Tritium can potentially be hazardous to human health because it emits ionizing radiation, exposure to which may increase the probability that a person will develop cancer during his or her lifetime. For this reason, it is very important that human exposure to any radioactive material, such as tritium, is minimized within reason. However, it is also important to understand that an individual's cancer risk is affected by many factors, including heredity, lifestyle, and numerous environmental factors, of which radiation exposure is but one of many. It is also important to note that everyone is exposed to radiation every day and, on average, the vast majority of an individual's radiation exposure in the United States results from medical procedures and naturally produced radiation. In fact, humans have always been exposed to radiation and our bodies have mechanisms that can act to repair damage to our cells that is caused by radiation.

As discussed above, tritium is generally only considered to be potentially hazardous when it is inside the body. Tritium can enter the body by inhalation, skin absorption and, mostly commonly, ingestion of tritiated water. For the most part, tritium does not accumulate in any one part of the body, nor does it tend to reside within the body for long periods. Instead, tritium predominantly behaves just like ordinary water in the body, becoming distributed uniformly throughout the body's water and excreted through the same pathways as water, primarily in the form of urine.

A small amount of all tritium that enters the body can become bound to organic compounds. Organically bound tritium atoms do not behave like water, can remain in the body for longer periods, and can accumulate in certain parts of the body; however, the effects of organically bound tritium are generally not significant compared to the predominant form of tritium occurring as water in the body. It also important to note that tritium does not have chemically toxic effects when inside the body and it is hazardous solely due to its radioactivity.

While it has been determined that exposure to high levels of ionizing radiation causes cancer, this effect has not been observed for lower doses on the order of background radiation doses, including with tritium. Although the regulatory process and radiation safety practices operate based on the conservative assumption that all radiation exposure increases cancer risk, credible quantitative risk assessments cannot be made for low background levels of radiation exposure. For this reason, the cancer risk, if there is any, posed to a member of the general public by expected environmental tritium exposure levels cannot be determined reliably. In fact, it has been shown that the health effects, namely cancer induction, resulting from such exposures are too improbable to be observed using current data and analytical methods.

Detection

Ionizing radiation can only be detected using sensitive instruments, but since tritium emits only a very weak beta particle it is very difficult to detect even with normal radiation-detection instrumentation. In fact, the most common portable radiation-detection instruments, such as Geiger counters and ionization chambers, are usually not capable of detecting tritium. The most reliable and widespread method for detecting tritium is known as liquid scintillation counting and involves mixing tritium samples with a phosphor-containing fluid in vials and then placing the vials into a special piece of equipment for analysis. This method can be used to detect the presence of tritium in liquid samples, on surface wipes, or within the human body by collecting and analyzing the urine of a subject. This type of measurement is known as a bioassay.

Regulations

In the United States, the primary federal regulatory agencies that are concerned with tritium are the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC). Additionally, many individual states now assume the regulatory authority of the NRC within their state. The DOE manages the tritium used in nuclear weapons.

The regulations in place are aimed at limiting the amount of radiation dose to any individual member of the public, as well as that which radiation workers can receive in the occupational setting. The protection of the public is achieved via regulations that set upper limits on the amount of tritium that a facility or operation can release through different pathways that could expose members of the public to tritium. These include tritium concentration limits on effluent releases to the environment for both water and air as well as to sewer systems. Additionally, there are regulations that apply during the cleanup of tritium-contaminated sites that limit tritium concentrations in soil and groundwater before a site can be deemed suitable for general "unrestricted use."

Radioactive materials licensees that possess tritium are required to ensure compliance with all relevant regulations. Failure to remain in compliance can result in regulatory and civil penalties, as well as increased regulatory scrutiny. Additionally, information pertaining to regulatory violations is often publicized, which in itself can pose a significant penalizing effect upon those in violation.

NRC regulations can be found in Chapter 10 of the Code of Federal Regulations, Part 20: 10 CFR Part 20.

EPA regulations can be found in Chapter 40 of the Code of Federal Regulations: 40 CFR Part 141.

Protection

Since tritium exists throughout the environment, the protection of the general public with regard to tritium is largely the responsibility of the licensees that produce or possess tritium and the government agencies that regulate them. However, individuals can also help to protect themselves and others from unnecessary tritium exposure by having a general awareness of common consumer products that contain tritium. While such items do not generally pose a hazard under normal use, these objects can release tritium if they are damaged. It is also important for an organization that may possess items such as tritium exit signs to ensure that they are maintained and disposed of properly.

Summary

Tritium is a radioactive form of hydrogen that is produced by both natural and man-made processes. It predominantly exists in the form of water and generally behaves as such in both the environment and the body. For this reason, tritium is widely dispersed in the environment, resulting in worldwide exposure at low background levels. However, due to its biochemical behavior and weak radioactive emissions, tritium is considered to be one of the least harmful radionuclides. Despite this fact, it is important to be aware that tritium is used in some common devices, such as tritium exit signs, which can release tritium if they are improperly disposed of or damaged.

NRC regulations can be found in Chapter 10 of the Code of Federal Regulations, Part 20: 10 CFR Part 20.

EPA regulations can be found in Chapter 40 of the Code of Federal Regulations: 40 CFR Part 141.

Glossary

Activation

The process by which stable atoms are transformed into radioactive atoms due to exposure to special radiological conditions, such as those found within a nuclear reactor core.

Half-Life

The time it takes for one-half of the atoms of a given quantity of a particular radioactive isotope to decay.

Isotope

Atoms of the same element that have nuclei containing the same number of protons but different numbers of neutrons.

Ionizing

Describes radiation that has enough energy to directly ionize or remove an electron from an atom.

keV (kiloelectron volt)

A unit of energy equal to that of an unbound electron accelerated through a potential difference of 1,000 volts.

Organic

Describes a compound containing carbon and generally involved in the chemistry of living organisms.

Radiation

Energetic particles or photons moving through space.

Radioactive

Describes a material that tends to undergo spontaneous nuclear transformations and can result in the emission of ionizing radiation.

Resources for More Information

Health Physics Society. Radiation risk in perspective. Health Physics Society Position Statement. McLean, VA: HPS; 2010. Available at: http://hps.org/documents/risk_ps010-2.pdf. Accessed 24 March 2011.

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The Health Physics Society is a nonprofit scientific professional organization whose mission is excellence in the science and practice of radiation safety. Formed in 1956, the Society has approximately 5,500 scientists, physicians, engineers, lawyers, and other professionals. Activities include encouraging research in radiation science, developing standards, and disseminating radiation safety information. The Society may be contacted at 1313 Dolley Madison Blvd., Suite 402, McLean, VA 22101; phone: 703-790-1745; fax: 703-790-2672; email: HPS@BurkInc.com.