ABCs of Radioactivity

A Long and Winding Road to Achieve Stability

To the average layperson, "radioactivity" is a harsh and scary word. But the fact is that radioisotopes, both natural and artificial, are all around us. And for marine scientists in particular, they are important tools. Oceanographer Claudia Benitez-Nelson reviewed some of the fundamentals at the start of the Fukushima and the Ocean conference in Tokyo in November 2012.

To begin at the beginning, radioactivity is a spontaneous emission of radiation resulting from changes in the nucleus of a chemical element, said Benitez-Nelson, who earned her Ph.D. from the MIT/WHOI Joint Program in 1999 and now directs the marine science program at the University of South Carolina. "We radiochemists have a whole suite of elements that we consider radioactive. They're simply unstable. In the process of getting rid of that instability, they release energy to the surrounding environment in the form of radiation."

That radiation comes in two broad types. The non-ionizing type, which includes visible light and microwaves, lacks enough oomph to create charged ions, and thereby to alter the structure of an atom. It poses little threat to our health. Ionizing radiation, however, can actually change the atomic structure of living tissue—killing cells or making them cancerous. That's why we try to avoid direct exposure to medical X-rays and the sun's ultraviolet rays.

All radioisotopes—also called radionuclides—lose excess energy by emitting ionizing particles such as neutrons, protons, electrons, or photons. In the process, these so-called parent radioisotopes transform, or decay, into daughter isotopes containing different numbers of protons and neutrons. Daughters with the same number of protons are isotopes of the parent element; daughters with a different number of protons are actually different elements, with different chemical properties.

Each change along the way, Benitez-Nelson noted, follows a unique timetable, or half-life. The half-life of an isotope is the time it takes for one-half of the atoms in a given sample to decay. This daughter isotope can decay into another radioisotope, or the daughter isotope, that will continue the radioactive decay chain or decay into a stable element that ends the chain.

> **"We live in a sea of radioactivity. The danger is in the dose."**
>
> *—Ken Buesseler*

For example, one of the most common naturally occurring radioisotopes, uranium-238, has 92 protons and 146 neutrons. It decays into thorium-234 (90 protons, 144 neutrons), which decays into protactinium-234 (91 protons, 143 neutrons), and so on. The half-lives for each of these radioisotopes, respectively, are 4.468 billion years, 24 days, and 1.2 minutes—and each of these elements chemically reacts in a different manner (see next page).

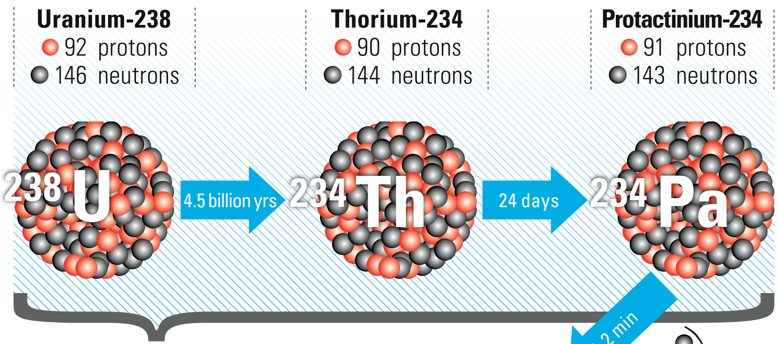
"Because that half-life differs from one radioisotope to the next, we can use it as a simple clock to study a host of ocean processes that take place across different timescales, from days to years to millennia," Benitez-Nelson said. So-called radioactive "tracers" are present in the ocean for eons—some formed by the interaction of incoming cosmic rays from space with atmospheric gases, and still others introduced by human activities. These tracers help scientists unravel how fast ocean waters mix, how quickly groundwater from land enters the ocean, and how rapidly carbon and other elements are cycled through air, sea, seafloor, and continents.

Several common naturally occurring radioisotopes—uranium, thorium, and potassium—are always present in seawater. In fact, noted Benitez-Nelson, the amounts of these isotopes present in the ocean are thousands of times higher than those of even the largest human sources of radioactivity.

Ken Buesseler, a marine chemist at Woods Hole Oceanographic Institution, put it this way: "We live in a sea of radioactivity, but this does not present a problem to us or to sea life because the radioactive elements found in our oceans are at such minute concentrations." As Buesseler added, "The danger is in the dose." (See Page 20.)

—*David Pacchioli*

Radioactive Decay Chains



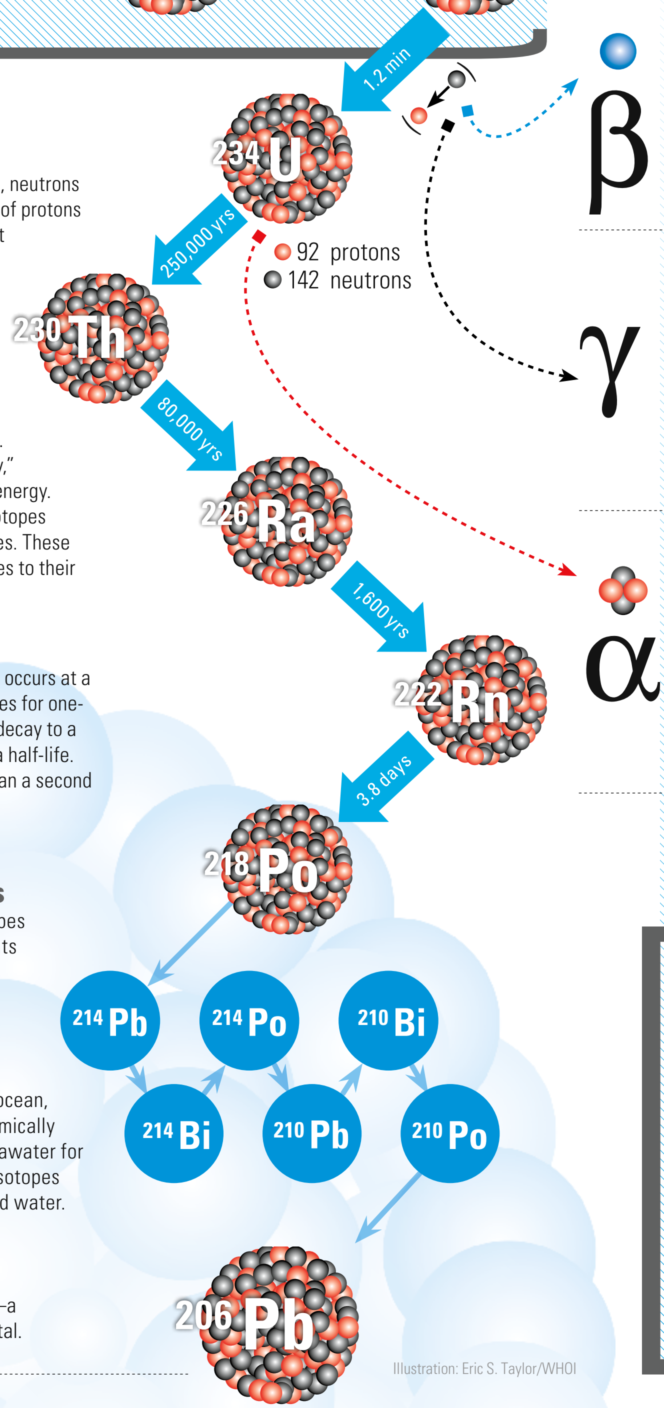


Illustration: Eric S. Taylor/WHOI

Atoms

Atoms are made of protons, neutrons and electrons. The number of protons determines what element it is. Atoms have the same number of protons. Atoms with different numbers of neutrons are called isotopes.

Radioactive elements, called radioisotopes or radionuclides, are unstable. They spontaneously "decay," releasing particles and/or energy. In the process, "parent" isotopes become "daughter" isotopes. These may become parent isotopes to their own daughter isotopes.

Half-lives

Each decay along the chain occurs at a unique rate. The time it takes for one-half of a parent isotope to decay to a daughter isotope is called a half-life. Half-lives vary from less than a second to billions of years.

Elemental and chemical changes

Parent and daughter isotopes are often different elements with different physical and chemical properties. Thorium-230 is a metal, but radon-226 is a gas, for example. Th-234 adheres readily to particles in the ocean, while Pa-234 is not as chemically "sticky" and remains in seawater for centuries. All these radioisotopes occur naturally in rocks and water.

End of the chain

occurs when polonium-210 decays into lead (Pb-206)—a stable, non-radioactive metal.

Different types of radioactive decay

Radioisotopes can emit three kinds of ionizing radiation from their nuclei:

Beta particles are released when a neutron in nuclei turns into a proton, or vice versa. They are charged electrons or positrons that have high speed and energy and can travel far into the body.

Gamma rays are emitted during beta decay. They are pure energy on the electromagnetic spectrum that includes light and X-rays. They have no mass or charge but have high energy and can travel much farther than α or β particles.

Alpha particles have two protons and two neutrons and a +2 charge. They are 2,000 times larger than β particles and travel relatively slowly and lose energy fast in air. They can't penetrate clothing, skin, or even paper, but they can be ingested or inhaled.

Radiation and health

When ionizing radiation strikes tissue, cells, and DNA, it can break chemical bonds and otherwise damage cellular machinery. Depending on a variety of factors, health impacts can occur immediately, such as burns, or over longer terms, such as cancer. All three types of radiation can cause damage, but the larger particles, if inhaled or ingested, can cause the most damage to living tissue. (See Page 20.)