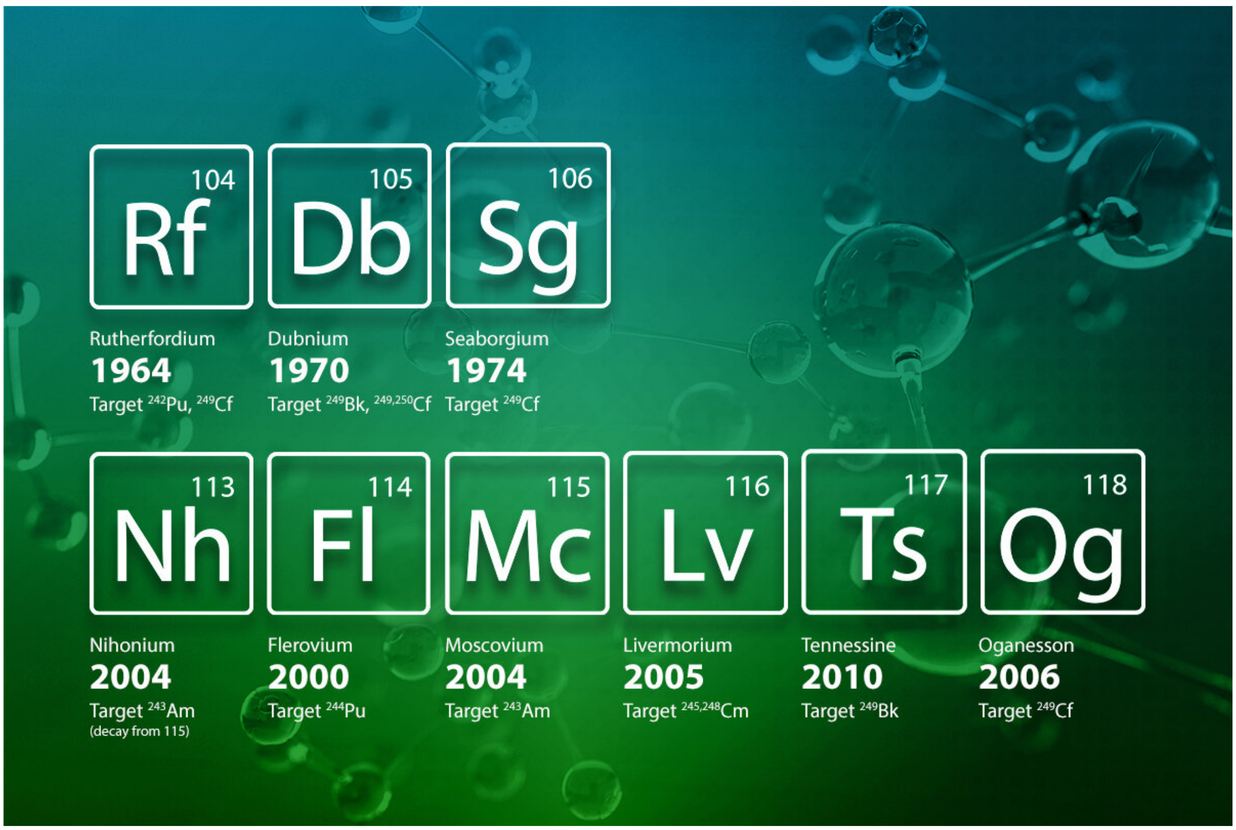
# Superheavy science: Lab's actinide abilities enable the discovery of new elements

December 8 2021




Nine superheavy elements have been discovered with help from target materials produced at ORNL. Some scientists believe that the periodic table might extend as high as an element with the atomic number 153. Credit: Jaimee Janiga / ORNL, U.S. Dept. of Energy

It's elemental—scientists agree that the periodic table is incomplete.

And when it comes to unveiling parts of the periodic table yet undiscovered, the Department of Energy's Oak Ridge National Laboratory is doing some heavy lifting.

A combination of unique facilities, people with specific skills and expertise, and a storied history has the lab leading the effort for superheavy element discovery.

But why do we care about expanding the periodic table?

## Understanding atoms

Why scientists want to discover new elements is easier to explain than how they do it.

Hint: It's all about the atoms.

"When scientists worldwide are exploring the periodic table, it's really the exploration of nuclear physics: What makes up an atom?" said nuclear engineer Susan Hogle, group leader for the Target Design, Analysis, and Qualification Group in ORNL's Radioisotope Science and Technology Division. "We can predict the chemical behavior of most elements on the periodic table, but there are certain regions of the table where you can't predict the behavior."

From the discovery of new elements, scientists learn more about existing elements—specifically, are they in the right places on the periodic table? Elements are placed on the table according to their atomic numbers—the number of protons in the nucleus of an atom. That number determines the chemical properties of an element, scientists theorize. The current periodic table postulates that elements that share chemical properties are grouped together; therefore, you could determine the properties of an element by where it falls among the table's "periods."

"Once we go beyond currently discovered portions of the periodic table, we're not sure what the chemical behavior of those elements are going to be," Hogle said. "If we can find that out, it will help lead us to the understanding of why those elements behave in a certain way. What does that tell us about the basic properties of atoms?"

The discovery of new, heavier elements could change not only the look of the table, but—someday—the way elements are arranged on it.

"Right now, the table looks nice and pretty and complete," said nuclear engineer Julie Ezold, who heads ORNL's Radioisotope Production and Operations Section. "But the next piece is when we start to be able to do the chemistry and really understand if everything is where it's supposed to be from a chemistry point of view. Is the chemistry of superheavy elements really the same as the chemistry in those columns? Learning the answers to that, to me, would be fascinating."

Ezold was one member of the ORNL team that helped discover element 117—named tennessine for the roles of ORNL, the University of Tennessee and Vanderbilt University—in 2010. The most recently discovered element, it's now the second heaviest on the periodic table, behind oganesson, discovered in 2002 and named for Russian nuclear physicist Yuri Oganessian, who led the discovery of element 118 and others.

Both elements could fall in the "island of stability," a theorized portion of the periodic table that could explain why some superheavy elements are more stable, when the other known elements beyond element 83, bismuth, decrease in stability. Discovery of new elements could confirm the island of stability exists.

On the periodic table, these superheavy elements, also called transactinides, immediately follow the actinides—the 15 metallic chemical elements from 89 to 103, which are radioactive and release energy when they decay.

The actinides were grouped and named by nuclear physicist Glenn Seaborg, who believed the periodic table might go as high as an element with the atomic number 153. Uranium and thorium, the first actinides discovered and the most abundant on earth, found initial use in nuclear weapons and nuclear reactors. Today, they and other actinides—which also include actinium, plutonium and neptunium—play diverse roles in energy, medicine, national security, space exploration and research.

For some actinides, ORNL is the only place in the world where they're made.

## Only at ORNL

ORNL's actinide production makes the lab essential in the hunt for superheavies. Right now, ORNL and other U.S. institutions are engaged in joint experimental programs to find elements 119 and 120, collaborating with Riken, Japan's largest comprehensive research institution, and the international Joint Institute for Nuclear Research in Dubna, Russia. The DOE Isotope Program funds ORNL's production of these actinides and has contributed them to the international superheavy element community to enable the science.

"We are only one of two places in the world that can make the actinide target materials that are necessary to do the superheavy element discovery," Ezold said. "In order for these discoveries to happen, it takes international collaborations. One organization, one country, cannot do these alone at this time."

Once, scientists looked for new elements in nature. These days, new elements are created in laboratories by putting a heavier element onto a target and then using a beam accelerator to fire projectiles of a lighter element at it, at a rate of a trillion or more per second. Add together the number of protons between the two elements, and the total could be the number of a new element. It might appear for only fractions of a second, but scientists can observe what it decays into and work backward to verify its existence.

But getting the elements needed to create new elements is no easy feat. They're rare, expensive and highly radioactive, with short half-lives. The process of creating them takes months of irradiation, decay, separation from byproducts and purification, all done by an experienced team in unique facilities built specifically for the processing of highly radioactive materials. All that effort yields minuscule amounts—but enough to put on a target to go under a beam.

"With the Radiochemical Engineering Development Center, we have the facilities for physically handling these materials, which give off a lot of radiation," Hogle said. "We've been working really closely with the nuclear physics community for decades now. ORNL supplied the materials for every superheavy element discovery since 2000: Elements 114 through 118."

Isotopes of newly discovered elements have such a short half-life—sometimes existing only for fractions of a second—that they don't yet have any practical uses, Hogle said.

"But in terms of what they could teach us about nuclear physics, there are untold benefits there," she said. "It really is a vast unknown."

Their short half-lives don't mean they'll never be useful. Take americium, for example. When it was discovered in 1944, the short half-life seemed to preclude any utility. It took decades to harness it for one of its best-known uses: the most common type of household smoke detector.

"Actinides are like no other element in the periodic table," said chemist Sam Schrell, who specializes in actinide research and development in ORNL's Radioscience and Technology Division. "Their chemistry is rich but unpredictable, which makes them intriguing to study. Discovering how useful some of these elements can be, whether it's for medical applications or national security, is exciting."

## Focused on the future

Some research taking place at ORNL involves creating targets that are better able to withstand being bombarded with the periodic table's heavier elements with higher atomic numbers, such as titanium, vanadium and chromium. The heavier the beam, the harder it is on the targets, and the lower the probability the two elements will fuse to create a new element.

Another focus of the lab is finding ways to create larger quantities of in-demand isotopes—for example, californium-252, which is used to start up nuclear reactors.

"Cf-252 is a great neutron source because of its short half-life, but there's just not a lot of it," said ORNL radiochemist Shelley VanCleve. "Fortunately, less Cf-252 material is necessary to make the same source compared to other radioactive elements. Cf-252 gives off a lot of neutron decay, and the neutron is more difficult to shield compared to an alpha particle. We have the capabilities at REDC—hot cells and smaller caves—that we can work with larger quantities of it."

VanCleve's work played a role in processing legacy Cf-252 sources in which most of the Cf-252 had decayed to curium-248. Her team separated the long-lived californium from curium daughter ingrowth for target fabrication. Those long-lived californium targets are used for superheavy element research.

"The material produced here is very pure," VanCleve said. "It goes through so many different separations. Customers really appreciate the quality of material that we give to them."

VanCleve was involved in the final purification of the berkelium used to discover tennessine.

"It's very exciting, but it's humbling when you think about all the different people who have to be involved," she said. "I played a very small part. The material is first separated in the hot cells, then it goes up to the alpha labs. I did the final cleanup of the material before it was shipped off site."

Isotope production happens with researchers, hot cell technicians, analytical chemists, operators of ORNL's High Flux Isotope Reactor (a Department of Energy Office of Science user facility), and staffers who keep the reactor and research facilities up and running—along with the customers who need the isotopes for their world-changing research.

"Anything is possible; what's important is the curiosity of it," VanCleve said. "That's the great thing about the customers we work with: Their curiosity, their desire to continue their research and continue moving forward. They're very passionate people, and they're fun to work with. I know that every customer needs our best quality in order to get their research done—and that's what we're trying to provide."

Hogle's group is working on new designs and novel ways to produce isotopes in HFIR, hoping to increase the availability of these short-lived isotopes for the DOE Isotope Program, which manages isotope production efforts makes the isotopes are available for research and industry through the National Isotope Development Center.

"Our program was developed in the 1960s-1970s, producing californium, and we've always kind of done things the same way," she said. "It's an amazing story, how we took the byproducts of a weapons campaign, and we turned them into radioisotopes that are being used all over the world for industrial and research purposes. In a 50-year of tradition of excellence, we've learned a lot. It excites me that after doing something a certain way for 50 years, we could suddenly revolutionize the way we're doing this production activity."

Hogle finds it rewarding to see how isotopes are used once they leave ORNL.

"Sometimes when you're a researcher, you do a lot of theoretical work—you do a calculation, and that's where it stops," Hogle said. "It's really exciting to see the work you do actually makes something physical that you can see. We occasionally get letters from people overseas and elsewhere thanking us for supplying these materials to them. It makes you happy to be able to enable other people's work."

With every improvement in the production of actinides, scientists learn more about their properties.

"Continuing to understand the fundamental science of the actinides will provide insight to their medical applications, how they behave in the environment, and how we can harness their unique properties for new applications that we have yet to discover," Schrell said. "Actinide science at ORNL has a long, rich history that we hope to continue to build upon. At ORNL, we are well-positioned to have a multidisciplinary actinide science effort that reaches across directorates to advance actinide science and train the next generation of scientists and engineers."

Provided by Oak Ridge National Laboratory