Why ORNL isotope production is so important to the U.S.

(As published in The Oak Ridger's Historically Speaking column the week of June 15, 2026)

Carolyn Krause and I recently heard a fascinating talk on important radioisotopes and stable isotopes produced at Oak Ridge National Laboratory. Jeremy T. Busby, associate laboratory director for the Isotope Science and Enrichment Directorate (ISED) at ORNL, spoke to Friends of ORNL on "Isotopes: Vital to U.S. Success." His talk mentioned some history of the lab's isotope production and research, as well as current achievements.

At my request Carolyn conducted some additional research by delving into websites to learn more about the fascinating history and significance of certain ORNL-produced isotopes. ISED has fact-checked her series of three articles for this column to ensure its accuracy and clarity. ORNL has also provided photos of the work being done in the Radiochemical Engineering Development Center at ORNL.

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Alvin Weinberg, the director of Oak Ridge National Laboratory from 1955 to 1973, famously wrote in an ORNL publication almost 50 years ago: "If at some time a heavenly angel should ask what the Laboratory in the hills of East Tennessee did to enlarge man's life and make it better, I daresay the production of radioisotopes for scientific research and medical treatment will surely rate as a candidate for first place."

One interpretation of the quote is that Weinberg was highlighting ORNL's transition from harnessing nuclear energy for use in helping make wartime weaponry to helping achieve peacetime benefits for society. Examples are building reactors to produce electricity and producing isotopes that can extend the lives of cancer patients.

What became ORNL started in 1943 with the world's first continuously operating reactor, later called the Graphite Reactor. Talented staff used it to demonstrate that gram quantities of plutonium-239 (an atomic bomb fuel) could be chemically separated from a nuclear reactor's irradiated uranium. The information was vital to the development of the plutonium-fueled atomic bomb that helped end World War II, the most devastating war in human history.

In his recent talk to Friends of ORNL titled "Isotopes: Vital to U.S. Success," Jeremy T. Busby, associate laboratory director for ORNL's Isotope Science and Enrichment Directorate (ISED), agreed with much of Weinberg's assessment.

Record isotope production. However, in his talk he stated that ORNL is producing stable isotopes as well as radioisotopes, and that the practical uses of some of these isotopes include not only "medical treatment" and research but also space exploration, production of energy and national defense. These applications will be described in the next two articles.

Isotopes are variations of an element in the periodic table in that, while they both have the same number of protons in their atomic nuclei, isotopes have different numbers of neutrons, giving each isotope a different atomic mass number and properties which may be different from those of the element."

"ORNL has been a world leader in isotope enrichment, generation and separation technologies and processes since World War II," Busby said. "Today, ORNL experts continue in this mission using the lab's unique infrastructure, such as a research reactor and hot cells, and modern tools."

He noted that ORNL's production of a large variety of isotopes is especially important today because of the national need to reduce U.S. reliance on potentially unreliable foreign sources. He added that ORNL can produce up to 300 isotopes but not all at the same time.

"We have the Amazon warehouse of all stable isotopes in a small room filled with file cabinets containing foils, powders and wires of different purities and different assays," Busby noted. Some can be used as targets for exposure to neutrons in the lab's research reactor to make radioisotopes. To learn about what's available in this repository ORNL maintains for the nation, visit DOE's isotopes.gov website."

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ORNL pioneered the production of radioisotopes especially after World War II using its Graphite Reactor (1943-1963). Since 1965 radioisotopes have been produced at ORNL in the High Flux Isotope Reactor (HFIR).

The lab also made stable isotopes last century between 1946 and 1998 using some of the Y-12 electromagnetic isotope separators that had produced enriched uranium for the first atomic bomb used in war. ORNL remained the world's primary source of isotopes for nuclear medicine and research but as demand grew, industrial firms began producing and selling isotopes from the 1950s through the 1970s.

As Western isotope facilities aged and closed in the 1990s and 2000s, Russia became the world's dominant producer of isotopes, filling a critical gap in the global supply chain. Between 1989 and 2018, Russia was the chief supplier of the vital isotope molybdenum-99. It's the parent isotope of technetium-99m, the most widely used radioisotope in medical diagnostic imaging. In the last seven years, thanks to assistance from an ORNL manager and others, an American company has been producing technetium-99m.

"Since 2022, Russia's isotope market has been closed off to the western world," Busby said. "The Western world found itself without many needed isotopes. In the past four years, the U.S. Department of Energy has been working hard to re-establish a secure supply chain for isotopes to avoid shortages. And ORNL, which is at the very center of this effort, is delivering record isotope production."

Advancing enrichment technologies. In addition to "meeting critical national needs by producing and distributing both stable isotopes and radioisotopes," Busby said that ORNL staff have also advanced two technologies for enriching materials in certain isotopes. The technologies ORNL has made more efficient and capable of improving product quality and quantity are electromagnetic isotope separators and gas centrifuges, both of which were first used to enrich uranium. Gas centrifuges are widely used today internationally to produce enriched uranium for use in nuclear power plants. (See sidebar on how these technologies work.)

New isotope production facilities. To help our nation achieve isotope independence, Busby said, DOE's Isotope R&D and Production Office has already committed $1 million to funding ORNL's construction and operation of the U.S. Stable Isotope Production and Research Center. It is estimated to start production of stable isotopes on the lab campus around 2027-2030.

"This 64,000 square-foot facility now under construction will house 24 electromagnetic separation units and two gas centrifuge cascades," he added.

"We will take possession of the building in about 15 months and start filling it with equipment, some of which will arrive soon. The modern magnets for the next generation of electromagnetic isotope separators are already on the boat from New Zealand."

Busby said that the next generation of electromagnetic isotope separators (EMIS) that ORNL has developed is based on the wartime calutron concept at the Y-12 Plant. However, the EMIS units are smaller and use modern magnets and modern alignment systems, making the separators more efficient.

ORNL can now get far more purity and throughput with each pass through a magnetic field of a gaseous ion beam containing two isotopes to be separated, he added. These modern EMIS systems are used to produce small amounts of specialized isotopes for medical treatments an scientific research.

ORNL has also developed a hybrid enrichment strategy that uses gas centrifuge isotope separation to pre-enrich a material and then passes it to EMIS to make the material 99% pure. The combined method for the first time also enables kilogram-scale production of stable isotopes.

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Another planned facility to be located near HFIR and to begin operation around 2032 is the Radioisotope Processing Facility (RPF). Looking ahead at the planned expansion of isotope production capabilities, Busby said, "I've got 600 staff, and I need 800 workers. In the last five years, we've hired 300 staff. I need 200 more in the next three years. Because of all the nuclear companies who are in business in the Oak Ridge area, the job market is thin and competitive."

Nuclear workforce issues. Busby acknowledged that the nuclear workforce is aging nationwide and that the many nuclear companies in East Tennessee will be competing for workers trained to handle materials and equipment associated with operating nuclear reactors and producing nuclear fuel and isotopes. It has been stated that for every nuclear engineer, 10 technicians are needed by nuclear firms.

"A lot of the nuclear knowledge base we have will retire in the next decade," Busby said.
"ORNL's isotope directorate needs about 120 new operators, technicians, mechanics and electricians to keep all of our equipment operational. We must train a new workforce.

"ISED needs a lot of technical workers who don't have to be Ph.Ds. What we need most are radiochemical operators who have associate degrees and bachelor's degrees and are skilled in separating isotopes in hot cells."

A hot cell is a heavily shielded, enclosed laboratory space designed to ensure safe handling of highly radioactive materials. "Hot" refers to highly radioactive materials inside the cell that could injure or kill the operator outside without the cell's protective technologies. They include heavy shielding, lead-glass viewing windows and availability of remote manipulators to handle radioisotopes inside the hot cell from the outside.

Busby said that three years ago ORNL started a partnership with Pellissippi State Community College that led to the establishment of a program for training future radiochemical technicians in two years for local jobs and awarding them an associate's degree.

"Since 2023 the Pellissippi radiochemical technician program has enrolled 14 students, and ORNL has already hired four of the first six graduates," Busby said. "We are encouraging Roane State Community College to set up a similar program for educating interested students to become radiochemical operators."

Hot cell issues. Busby said that ISED manages six different hot cells in ORNL's Radiochemical Engineering Development Center next to HFIR, each of which is 65 to 70 years old and "is operated roughly 70% of the time, which is by far a record." To recover valuable space in the hot cells, he added, in the past five years, "we have been working with UCOR (United Cleanup Oak Ridge) to increase the available space for us to work in by getting rid of waste. Our ability to do more real-world chemistry will increase by freeing up some space.

"Last year, we removed roughly 8,000 cubic feet of transuranic waste that had accumulated in the hot cells. It has been packaged and will eventually be shipped to the Waste Isolation Pilot Plant, or WIPP, in New Mexico."

To improve safety and efficiency for the extremely hazardous hot-cell projects to separate plutonium-238 from neptunium targets irradiated in HFIR, Busby said he has a team "working on using machine vision, machine learning and artificial intelligence to automate that process in a hot cell facility." One reason: some workers doing neptunium processing have received among the highest radiation doses allowed at the lab.
Busby said one of his goals is to "hand off some of the routine work his staff is doing to another national lab or industry partner, because we have talented researchers who want to spend more of their time solving the hard problems, including making scientific discoveries and technical breakthroughs."

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Need for redundancy. As DOE continues to build the national isotope production and distribution capability, Busby wants to see “more redundancy in the network.”

For example, ORNL is the only U.S. source of certain fast-decaying radioisotopes that can treat cancer patients effectively with their radiation if the tumor-targeting medicines incorporating decaying isotopes arrive at the hospital in time. “We’re only one bad ice storm away in East Tennessee from having to stop cancer shipments for a week or two,” Busby said. “We’ve had that happen!”

Here is some background on separating isotopes by electromagnetic fields and gas centrifuges:

Small electromagnetic isotope separation (EMIS) systems are used today to produce extremely pure samples of various elements and their isotopes. They can separate the isotopes of almost any element in the periodic table for use in scientific research and medical treatment.

The first electromagnetic separators were known as “calutrons,” which stands for **CAL**ifornia **U**niversity Cyclo**TRON**s. They were used at the Oak Ridge Y-12 Plant to separate uranium isotopes for producing highly enriched weapons-grade uranium during the last two years of World War II. They operated on the same principle as the more modern and more efficient EMIS systems at ORNL.

At the Oak Ridge plant, uranium tetrachloride was placed in a container at the base of each calutron and heated until it became a vapor. The vapor was bombarded with a high-energy electron beam that knocked off electrons from the uranium-238 and fissile uranium-235 atoms, making positively charged ions. The uranium ions were attracted electrically into a vacuum chamber with magnets on either side. Because of centrifugal force, the lighter uranium-235 ions were bent in a smaller arc than the heavier uranium-238 ions in the magnetic field.

Imagine that you are holding two rubber bands in your hand with a golf ball attached to one and a ping-pong ball to the other. As you swing the balls overhead in an arc toward a wall, the golf ball will pull the rubber band more, making a larger arc than the lighter ping-pong ball. The golf ball will strike the wall at a slightly higher spot, and the ping-pong ball will strike the wall at a slightly lower spot.

At the top of the arc in a Y-12 calutron, receiving units for collecting the separated ions were placed in the ions’ path. The space between the units corresponds to the difference in the ions’ paths based on the difference in the ions’ weights (atomic masses) and the resulting centrifugal force, altering the trajectories of the uranium-235 and uranium-238 ions.

Instead of relying on a calutron’s arc, the gas centrifuge uses a circular motion to separate uranium isotopes for uranium enrichment.

Small state-of-the-art gas centrifuges being developed at ORNL work on the principle of the AC100 gas centrifuge machines several stories high that are used today to provide enriched uranium for nuclear power plants. To greatly increase the concentration of uranium-235 in the uranium gas to make a reactor fuel, a series of thousands of hollow tubes receiving the gas and spinning at extremely high-speed fling the heavier uranium-238 molecules in the gas toward the outer wall. There, the gas slightly depleted in uranium-235 exits the spinning cylinder and moves to the lower-stage machines.

The lighter uranium-235 molecules tend to stay in the center as the gas centrifuge rotates. The uranium hexafluoride slightly enriched in uranium-235 flows upward and out to the hundreds of higher-stage centrifuges. They carry out all the separation steps required to attain the desired enrichment.

Next: ORNL has produced many radioisotopes that have extended the lives of cancer patients.

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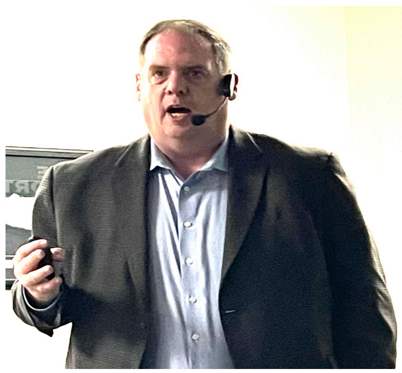
Thanks, Carolyn. The isotopes being provided by ORNL contribute much to our world. It is good to look in such details as you are providing to help the general public better understand.



Jeremy Busby, ORNL associate laboratory director for the Isotope Science and Enrichment Directorate (Courtesy of Carolyn Krause)

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ORNL's Radioisotope Engineering Development Center. REDC provides world-class capabilities in isotope production, research and development, source fabrication, and the distribution of various unique isotopes. (Courtesy of Carlos Jones, ORNL/U.S. Dept. of Energy)