NIDC Newsletter
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NIDC | NATIONAL ISOTOPE DEVELOPMENT CENTER
Managed by the US Department of Energy's Office of Nuclear Physics

Inside This Issue

DOE Produces First Newly Enriched Stable Isotope in Nearly Two Decades

On January 30, the U.S. Department of Energy Isotope Program (DOE IP) provided more than 500 mg of highly enriched ruthenium-96 (Ru-96), most of which was newly produced at Oak Ridge National Laboratory's (ORNL) Enriched Stable Isotope Pilot Plant (ESIPP). This marks the first production and shipment of a newly enriched stable isotope by the DOE IP in nearly 20 years. In addition, this milestone addresses a recommendation by the Isotope Subcommittee of the Nuclear Science Advisory Committee for the DOE IP to re-establish a domestic stable isotope enrichment capability.

In 2009, the Isotope Program began investing in the development of modernized stable isotope enrichment technology to replace Manhattan Project-era calutrons used for stable isotope production until 1998. The electromagnetic isotope separator (EMIS) developed as part of this effort was first commissioned in 2012, and an upgrade for even higher throughput was completed in 2016. The EMIS technology was transitioned to production operations in 2017, and the first priority isotope for production was Ru-96.

The Ru-96 was needed for experiments at Brookhaven National Laboratory's (BNL) Relativistic Heavy Ion Collider (RHIC). Due to insufficient quantities of this rare isotope in DOE's inventory and availability from other sources worldwide, a new production campaign at ESIPP was initiated. The RHIC experiment required enrichment exceeding 92 atom % with high chemical purity (>98%). Ruthenium-96 in naturally occurring Ru metal is 5.5 atom %.

With the Ru-96, the RHIC nuclear physics experiment will study the dynamics of the quark gluon plasma created in ion collisions in response to resultant electromagnetic fields;

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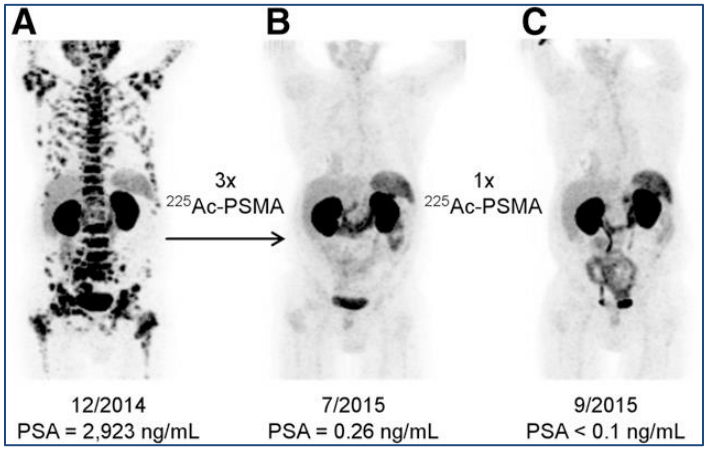
The production and shipment of highly enriched Ru-96 comprised years of preparation from a technically diverse team at ORNL (From left: David Dean, Jay Pruitt, Bobby Whitus, Kevin Hart, Adam Stevenson, Joe Tracy, Derek Byrd, Brian Egle, Gerald Mills, Brian Ticknor, Alan Tatum, Cole Hexel, Clint Ausmus, Jack McCollister, Mike Zach, and Claude Sampson; not pictured: Richard Wunderlich) (Image courtesy of ORNL)

Tri-Lab Effort Ramps Up Actinium-225 Production to Support Clinical Trials

A robust and reliable supply of actinium-225 (Ac-225) moves closer to fruition with accelerator-based material now regularly produced at Brookhaven and Los Alamos national laboratories (BNL and LANL) and routinely available through the DOE Isotope Program. Actinium-225 is a radioisotope whose high-energy, short-range alpha particles are well suited for destroying targeted cancer cells while leaving healthy tissue largely unscathed. It can be applied directly in targeted radiotherapy or used to manufacture generators for bismuth-213, another powerful alpha emitter in clinical trials for cancer therapy.

The demand for Ac-225 continues to grow at a rapid pace due to its great promise in the field of radiotherapy, but current worldwide supply (less than 2 Ci/yr) limits treatment to only a few hundred patients annually. For this reason, the DOE IP began evaluating options to boost production within its national laboratory network and support critical research and applications.

The large majority of Ac-225 available through DOE is collected from gradually decaying thorium-229 (Th-229) housed at ORNL. While this Ac-225 exhibits exceptional quality, supply is inadequate to support the completion of clinical trials for therapeutic applications. High-energy proton accelerators at BNL and LANL could produce the much larger volumes of Ac-225 in a shorter timeframe. The quantities would be sufficient for both trial completion and therapeutic applications. Realizing the potential to significantly expand domestic supply, DOE IP chose to leverage capabilities across the three national labs, and in 2015 the "Tri-Lab" research effort was formed.



Patient PET/CT scans show pretherapeutic tumor spread (A), 2 months after third cycle of Ac-225 drug (B), and 2 months after one additional therapy (C). (J Nucl Med December 1, 2016 vol. 57 no. 12 1941-1944; image courtesy of the Journal of Nuclear Medicine)

Tri-Lab is divided into three stages designed to navigate preliminary (5-50 mCi), intermediate (50-100 mCi), and final (100-1,000 mCi) preparation for routine production.

Stage 1: Technical Feasibility and Optimization

The primary objective of Stage 1 was to demonstrate that the accelerator-based products were "acceptable" and "equivalent" compared to the conventionally produced products. In other words, accelerator-produced Ac-225 must exhibit acceptable chemical and radiopurities relative to Ac-225 derived from Th-229, and accelerator-produced Ac-225/Bi-213 generators must perform in the same manner as Ac-225/Bi-213 generators derived from Th-229.

continued on page 3: "Tri-Lab"

Isotope Availability Alert

Newly Available

- *Actinium-225 (accelerator-produced)*
- *Aluminum-26*
- *Americium-241*
- *Astatine-211*
- *Barium-133*
- *Copper-67*
- *Lutetium-177*
- *Ruthenium-96*
- *Selenium-75*
- *Silicon-32*
- *Strontium-89*
- *Thorium-232*
- *Titanium-44*
- *Uranium-234*
- *Yttrium-86*

Coming Soon

- *Cadmium-109*
- *Carbon-14*
- *Cerium-139*
- *Iridium-192*
- *Iron-55*
- *Iron-59*
- *Holmium-163*
- *Promethium-147*

Under Investigation

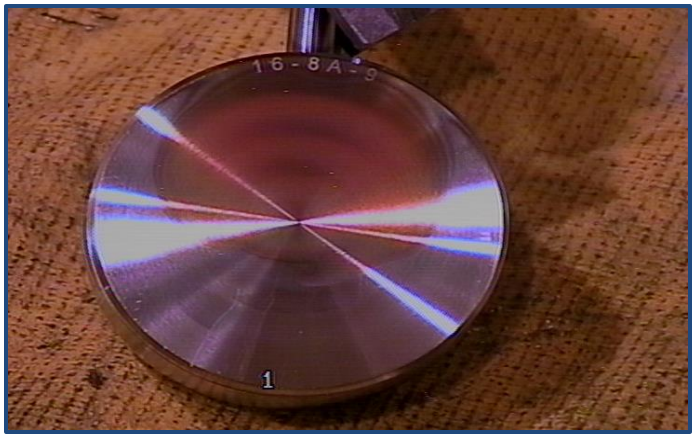
- *Gadolinium-153*
- *Lithium-7*
- *Molybdenum-98*
- *Molybdenum-100*
- *Scandium-47*
- *Silver-111*
- *Tellurium-119*
- *Uranium-230*
- *Xenon-129*

Los Alamos Upgrades to Metal Targets for Enhanced Production

To efficiently produce strontium-82 (used in Sr-82/Rb-82 generators for cardiac imaging) and other isotopes simultaneously, LANL now routinely uses rubidium metal targets for irradiation at the Isotope Production Facility (IPF), transitioning away from rubidium chloride (RbCl) salt targets. While RbCl targets have excellent historical reliability and the purification chemistry is well established, the relatively poor thermal performance of RbCl targets presently limits beam current to 230 μA, which falls below the maximum available current at IPF. Rubidium metal is anticipated to have significantly better thermal performance, removing this limitation. The change from salt to metal also eliminates co-production of undesired contaminants and increases overall yield.

Before this material could be routinely utilized at IPF, a number of unique logistical and safety challenges had to be addressed. A new shipping container appropriate for transporting the pyrophoric and highly reactive Rb metal was required to move the irradiated targets on the public road between IPF and the processing facility. A modified target design was tested to minimize risk of target failure and validate the purification.

Four sets of Rb metal targets were safely irradiated at IPF this run cycle at currents up to 250 μA, resulting in roughly 60% more Sr-82 than similar irradiations of RbCl targets.



A Rb metal target irradiated at IPF at 250 μA (Image courtesy of LANL)

The current will continue to be raised in the coming run cycle, further enhancing production. A key benefit of the higher production is the increased flexibility for irradiations. Historically, two RbCl targets have been irradiated, encompassing the high and medium energy positions at IPF. With a higher yield Rb metal target in the medium energy slot, production levels can be maintained, opening up the high energy position for production of other important isotopes, such as thorium targets for direct production of Ac-225. ◇

"Tri-Lab" *(Continued from page 2)*

Key steps to achieving these objectives and, consequently, successfully advancing to Stage 2, included:

- Fabrication of thorium targets capable of withstanding the proton beams at IPF and the Brookhaven Linac Isotope Producer;
- Independent evaluations of the accelerator-produced products by multiple institutions confirming comparable labeling efficiency, radiopurity, specific activity; and
- Completion of dosimetry/toxicity studies to ensure a minimal and, therefore, acceptable impact of Ac-227, an impurity present in accelerator-produced Ac-225.

Stage 2: Support for Initial Clinical Trials

In Stage 2, the team is focused on building production momentum to continue supporting clinical trials. One major component of this transition will be to develop a strategy for streamlining the entire process through co-location of the production sites and processing facilities. By doing so, the radioisotope's lifespan could be maximized, providing the customer with more flexibility.

Major anticipated milestones for this stage include:

- Continued improvements to the design and preparation of thorium targets by LANL and BNL;
- Radiochemical processing of newly irradiated thorium targets at ORNL;
- Further investigation into thorium debulking methods at BNL and ORNL to improve Ac-225 yield and radiopurity;
- Focus on improvements to the general logistics of shipping raw materials and final products;
- Submittal of a Drug Master File on the accelerator-produced Ac-225 to inform the FDA of the chemistry, manufacturing, and controls; and
- Continued stakeholder and customer interactions.

Stage 3: Routine Production for Therapeutic Applications

Assuming the Tri-Lab team receives a green light to proceed to Stage 3, they will build upon Stage 2 achievements to make final operational adjustments and facility enhancements to reach full-scale production capability for therapeutic applications, routinely producing between 100 and 1,000 mCi of Ac-225. ◇

Stable Isotope Proves Valuable in Study of Fusion Reactor Wall Erosion

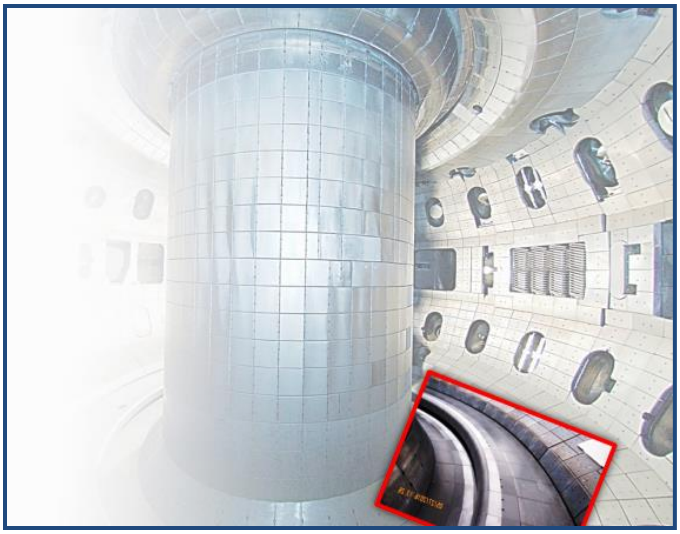
CONTRIBUTIONS BY MIKE ZACH AND ZEKE UNTERBERG, ORNL

With cutting edge research, comes ever changing experimental needs. Perhaps a new isotopic target is required to carry out a novel reaction, or maybe a modified physical form is needed to operate under certain conditions. Oftentimes, no clear path forward exists since these researchers are entering uncharted territory.

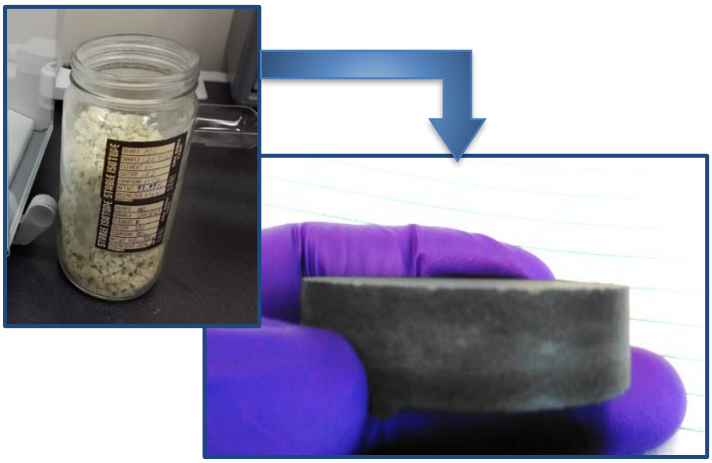
Researchers in ORNL's Stable Isotope Group are accustomed to helping researchers identify solutions that optimize the design of the experiment and enable the novel use of isotopes. This group has amassed the experience, knowledge, equipment, and skills needed to maximize research outcomes while minimizing cost and loss of isotopes.

A 2015 special request from ORNL's Fusion and Material for Nuclear Systems Division was no different. This division works closely with California-based General Atomics on a national fusion energy tokamak device called DIII-D, located in San Diego, and was collaborating with them on improving methods for tracing the erosion, transport, and re-deposition of tungsten (W) at the plasma material interface in the fusion reactor. Tungsten is used in many fusion reactors along with graphite and other refractory metals. Because it boasts the highest melting point and lowest vapor pressure of all known metals, it is a leading candidate for coating fusion reactor first walls, which are subjected to some of the harshest conditions known to man—e.g., heat fluxes more extreme than space shuttles experience when re-entering earth's atmosphere.

Despite these benefits, a better understanding of how W erodes from various surfaces of the tokamak was needed before it would be accepted for use as a fusion reactor first wall. One approach for tracing the erosion would be to introduce two variations of the element (i.e., both natural and isotope-enriched W) into the tokamak. Enriched W is identical in all chemical properties as natural W, but the different isotopic ratio allowed for the distinction of different wall locations within the reactor—in some ways analogous to trace nuclear forensics.



DIII-D tokamak, operated by General Atomics, with natural and W-182 coated molybdenum tiles highlighted in red box (Image courtesy of General Atomics)



ORNL's Engineering Services team transformed stock WO_3 into metal "puck" evaporation source in preparation for e-beam deposition (Image courtesy of ORNL)

The ORNL Stable Isotope Group researchers helped the team identify the experiment requirements, determined the resources needed, and planned a series of trial experiments. The particular batch of enriched W (W-182) was chosen based on the level of enrichment and to balance cost with selecting effective analytical methods for determining the W wall erosion properties. An experiment of this sort had never been tried in a fusion device.

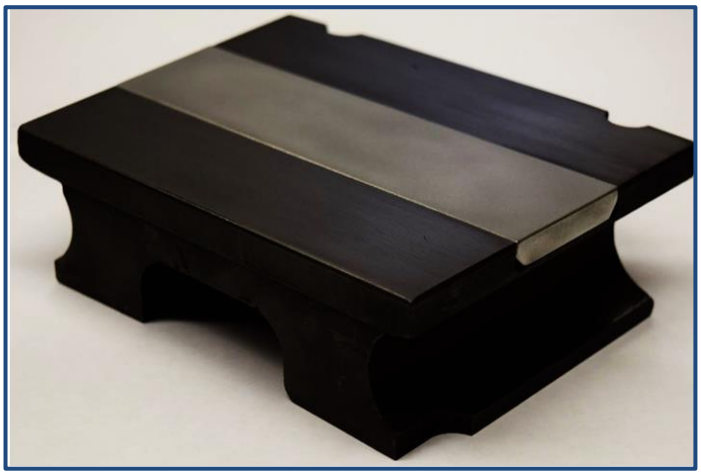
Given the project timeframe, budget, and technical considerations, a new method had to be developed for introducing the W-182. An array of molybdenum alloy (TZM) inserts was designed to efficiently hold the coating of W-182 in the right location yet be compatible with the existing graphite fusion reactor wall design. Of the viable coating choices, e-beam deposition was ultimately selected since equipment with a large chamber was readily available, the hot atomic vapor enabled good adhesion to TZM, and the hemi-spherical evaporation plume provided good coverage. However, this approach had never been attempted at ORNL.

continued on page 5: "Stable"

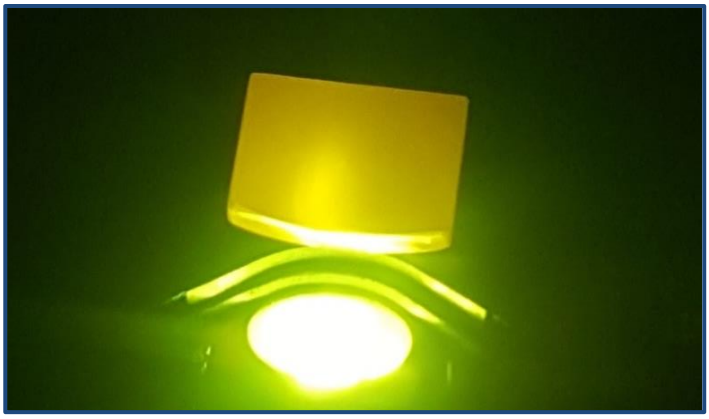
"Stable" *(Continued from page 4)*

Before e-beam deposition could take place, the stable WO_3 in the DOE IP's inventory was first converted from a powder to a metal form by multiple rounds of hydrogen reduction. The resulting W metal powder was formed into a solid e-beam target "puck" by vacuum hot pressing. The tile inserts were bolted onto a rotating stage held directly over the W-182 "puck" within a vacuum chamber. This source was heated by an electron beam to the point of vaporizing W (>4000°C) where the plume of vaporized W could coat the tiles.

The lower efficiency and losses typical with most e-beam techniques were minimized through design of tiles that fit the tokamak reactor and could efficiently pack within the e-beam evaporator to capture most of the plume. Any material not captured on the tiles was collected on the aluminum foil lining in the chamber for reclamation and reprocessing back to an inventory form. These techniques were developed through many studies performed with natural W coating.



Final resulting W-182 coated molybdenum alloy tile inserted in the DIII-D reactor graphite floor tile before plasma exposure (Image courtesy of ORNL)



W-182 being heated (round) within the e-beam chamber and specially designed Mo heat shield (rectangle) glowing from secondary electrons (Image courtesy of ORNL)

Before and upon arrival at General Atomics, the coatings were subjected to many additional tests to demonstrate good quality before being placed into the DIII-D first wall. The experiments with full fusion-reactor-relevant plasma conditions were run in June of 2016. Initial data using the W isotopes has shown that the degree of wall erosion changes depending on the level of plasma transients that occur. These plasma transients (called edge-localized modes) occur as the tokamak reaches more reactor-like conditions and are a very big concern for the ITER device—the world's first prototype fusion reactor being built in Cadarache, France.

While results continue to pour in from these experiments, these initial first-of-a-kind experiments have stimulated greater interest from the world's fusion community. In fact, the same technique will be used on the WEST tokamak at ITER. This is the first chapter in an emerging path to better first wall technology for fusion reactors.

This initiative was a collaborative effort between ORNL, General Atomics, University of Tennessee-Knoxville, University of California-San Diego, Lawrence Livermore National Laboratory, and Sandia National Laboratory. ◇

"Ru-96" *(Continued from page 1)*

the quark gluon plasma is a new form of matter discovered at RHIC and has not existed since the infant universe. The availability of the Ru-96 makes this research viable.

Production of Ru-96 will continue at ESIPP through 2018, then will be followed with production of other stable isotopes approaching critical supply levels, to grow the robust supply needed for future research, development, and applications. Parties interested in procuring Ru-96 or other stable isotopes can request a quote through the NIDC's product catalog. For additional inquiries on Ru-96 availability, please contact the Isotope Business Office. ◇

ISOtopics

VISITS

Paul Dabbar, DOE Under Secretary for Science (then nominee), toured BLIP during a recent visit to BNL to learn about its technical capabilities and the research staff's recent accomplishments. As the science and technology advisor to Energy Secretary Rick Perry, Dabbar's portfolio includes the Office of Science and its 10 national laboratories.

UPCOMING EVENTS

13th International Symposium on the Synthesis and Applications of Isotopes and Isotopically Labelled Compounds, June 3-7, 2018, Prague, Czech Republic

2018 American Nuclear Society Annual Meeting, June 17-21, 2018, Philadelphia, PA, USA

Society of Nuclear Medicine and Molecular Imaging 2018 Annual Meeting, June 23-26, 2018, Philadelphia, PA, USA, including the following DOE IP-hosted user meetings:

- At-211 User Group Meeting (4:00 - 5:00 PM, June 24, 2018)
- Pb-212 User Group Meeting (5:00 - 6:00 PM, June 24, 2018)
- DOE IP Meeting (7:00 - 8:00 AM, June 25, 2018)

FEATURED PUBLICATION

An automated column-based purification process of zirconium-89 (Zr-89) from a yttrium target developed by researchers at the **Pacific Northwest National Laboratory** (in collaboration the University of Washington Department of Radiology) is detailed in the February 2018 issue of *Applied Radiation and Isotopes*.

The new process presents a simple, automated fluidic system prototype that requires a lower concentration of Zr-89 eluent, resulting in less metal contaminates that compete for labeling sites. In addition, demonstrated purity levels are on par with conventional approaches.

This research was supported by the DOE Isotope Program.

EMPLOYEE EXCELLENCE

Dr. Stephen G. Johnson, who leads the Isotope Production Group at the Idaho National Laboratory (INL), received the Director's Award for Lifetime Achievement in Science and Technology. This award recognizes his sustained outstanding scientific research and technical achievements supporting INL's mission.

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