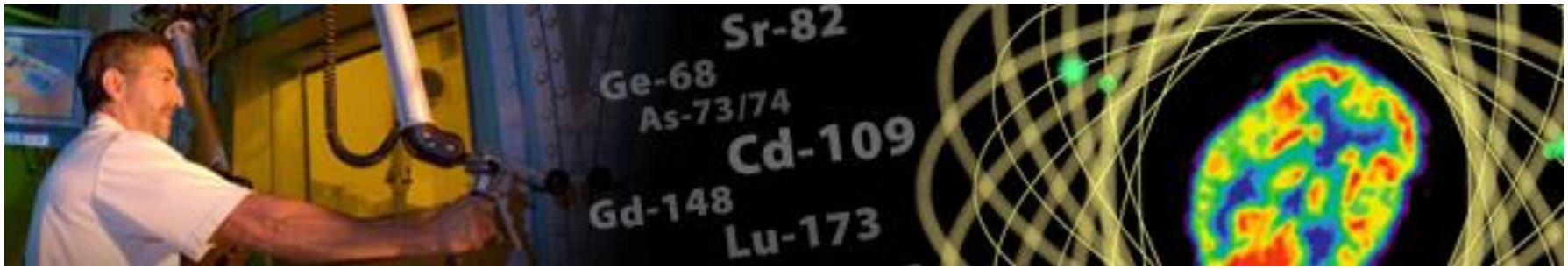
U.S. DEPARTMENT OF ENERGY | Office of Science

Isotope Program
U.S. Department of Energy

DOE Isotope Program
R&D and Production of Isotopes for Space Applications



2021 Nuclear and Emerging Technologies for Space Conference
April 29, 2021

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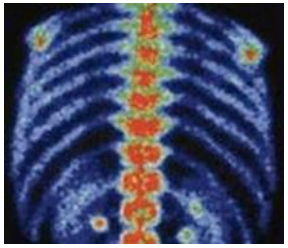
Program Manager, Isotope Reactor Facilities
Office of Isotope R&D and Production (SC-24.3)
Office of Science, U.S. Department of Energy

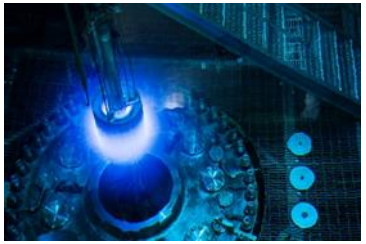
Role of the DOE IP

- Isotopes enable a broad suite of applications: medicine, research, environmental, national security, agriculture, clean energy, quantum information, defense, space applications, nuclear batteries

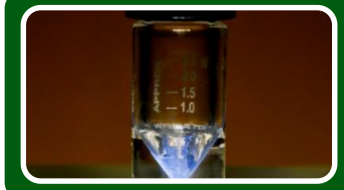
- Substantial national and international research, medicine, industry, and national security relies upon the use of isotopes and is strongly dependent on the Department's products and services

- DOE Isotope Program (DOE IP) is the sole authority in DOE to produce isotopes for sale and distribution (exceptions: Mo-99 (NNSA), Pu-238 (NE), and special nuclear material for weapons (NNSA))




DOE IP Mission



Produce and/or distribute radioactive and stable isotopes that are in short supply; including by-products, surplus materials and related isotope services

Maintain the infrastructure required to produce and supply priority isotope products and related services

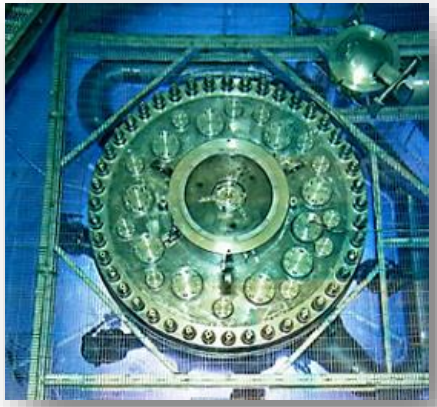
Conduct R&D on new and improved isotope production and processing techniques which can make available priority isotopes for research and applications. Develop workforce.

Ensure robust domestic supply chains. Reduce U.S. dependency on foreign supply to ensure National Preparedness.

Mitigation of U.S. Dependence on Foreign Sources

Sr-90 for cancer therapy, radioisotope power demonstrations

- Processed at PNNL (more later)



Cf-252 for well logging, industrial applications

- **Maintaining supply of 97% of the domestic market**
- Working with industrial consortium
- Long term contract in place; provision for research quantities

Am-241 for oil-gas exploration, other uses

- Re-established production capability in U.S.
- Extraction from plutonium waste stream at LANL

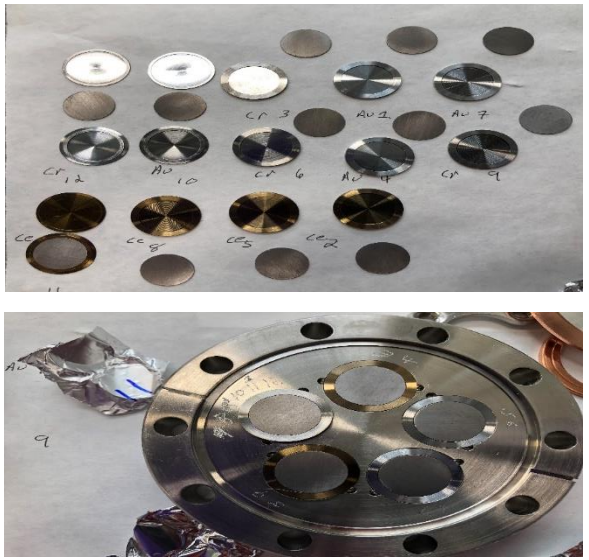
Have mitigated dependence of 18/21 isotopes of which we are dependent upon Russia and other countries

Isotope Production R&D

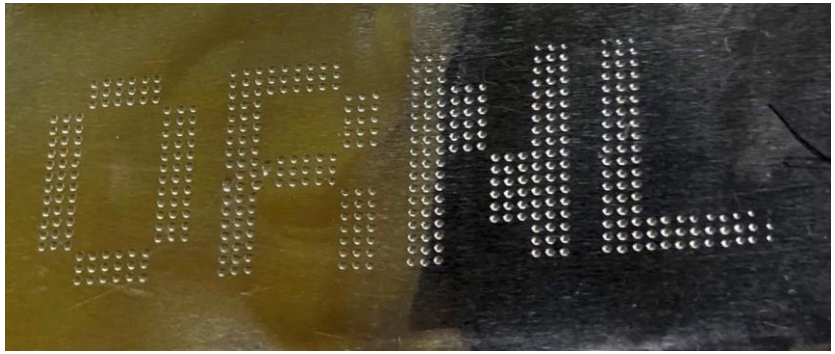
Transmutation and nuclear data (neutrons, charged particles, high energy gamma photons)

- Targetry (thermal hydraulics, materials, particle transport modeling)
- Processes for recovery and purification of radioisotopes; remote handling/automation
- Mass-separation for enriched stable isotopes and HSA radioactive isotopes

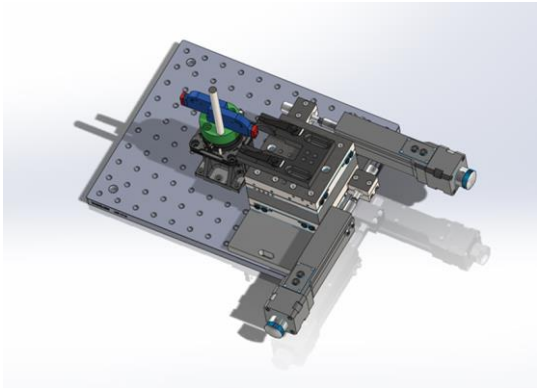
- ➢ Advanced manufacturing techniques
- ➢ Transformative approaches to targetry to facilitate research and commercial isotope production
- ➢ Application of robotics, AI/ML for machine operations



Preparation of parts for initial thermal bonding studies to inform next-gen LANL target design (top) all parts with various coatings (bottom) materials packaged for shipment for thermal pressing



Inkjet printing of Targets: Successful Printing of Bitmap Patterns: 50 nL drops of water on aluminum



Custom Designed and Fabricated Biofluidix Printer

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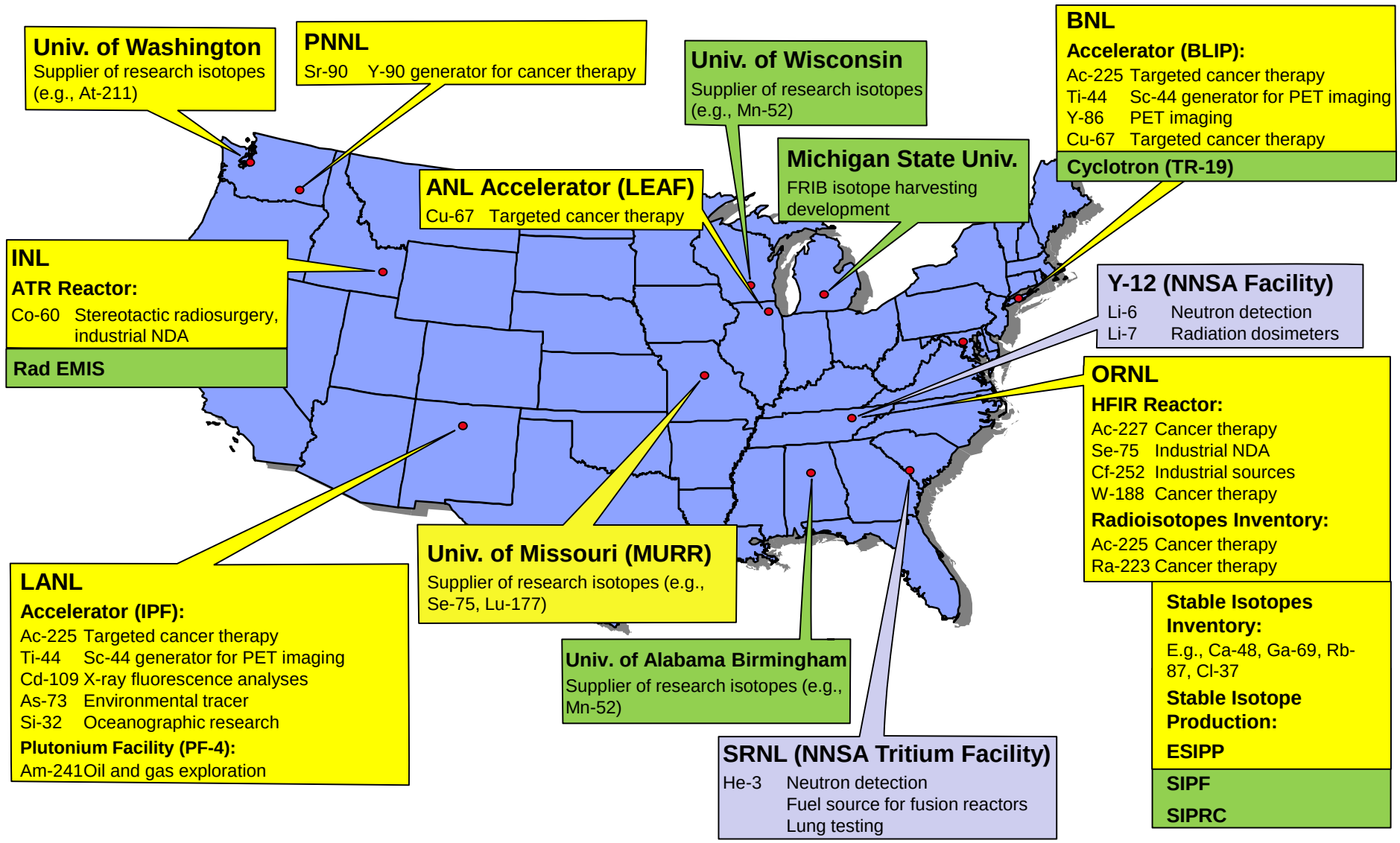
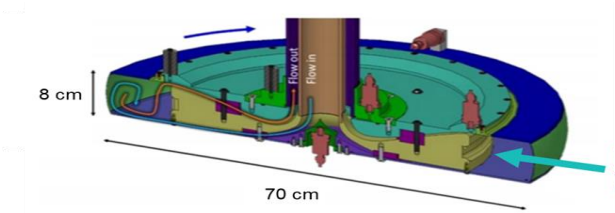
DOE Isotope Program Production Sites

Isotope Program
U.S. Department of Energy

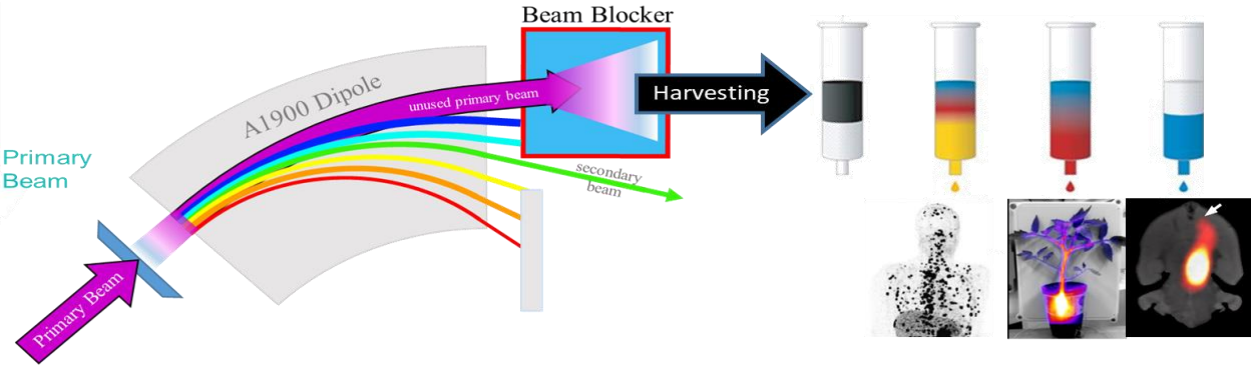


FRIB Isotope Harvesting Facility

- New research project to enable harvesting of radioisotopes from the Facility for Rare Isotope Beams at Michigan State University (~2024)



FRIB Beam dump: dissipates the FRIB beam energy and in the process radioisotopes are created in the cooling water.



Conceptual view of new hot cells for purifying and harvesting the radioisotopes from the FRIB beam dump system.

The Facility for Rare Isotope Beams (FRIB) will uniquely afford access to eighty percent of all isotopes predicted to possibly exist in nature, including over 1,000 never produced on Earth, answering long-standing "grand challenge" questions such as the astrophysical sites and isotopic paths to heavy element production in the cosmos of significant interest to NASA research

DOE Isotope Program Support for Space Applications – Examples

- **Current examples that support space applications**
  - DOE IP plays a lead role in the IAG He-3 Working Group; **He-3** used for cryogenics to support space science
  - DOE IP is a member of the IAG led by the Interior/Bureau of Land Management (BLM) for monitoring **He-4** supply chains for rocket fuel use
    - DOE IP collects He-4 usage from all federal agencies on alternate years and provides it to BLM
  - Re-establishment of **Am-241** production in the U.S. (2018)
  - Re-establishment of **Sr-90** processing in the U.S. (2019)
  - DOE IP has completed production R&D and entered the market in 2021 for **Pm-147**: beta-voltaic nuclear batteries
  - **Tm-170** production R&D for a radioisotope power source
  - Provision of stables isotopes for space-qualified atomic clock research
  - Provision of **Rb-87** stable isotope for navigation satellite systems
  - Provision of **Al-26** for astrophysics research
  - Production of **Pu-238** and RTGs through the combined efforts of the Oak Ridge, Los Alamos, and Idaho National Laboratories (Office of Nuclear Energy)

Helium is used to make rocket fuel

Sr-90 capsules at PNNL

*MARS Rover **Curiosity** with Pu-238 RTG*

Radioisotopes of Current Interest for Radioisotope Power Sources

Radioisotope	Half-Life (y)	Comment
^{170}Tm	0.35	Production R&D ongoing
^{210}Po	0.38	Commercially available
^{147}Pm	2.6	DOE IP entered market in FY21 for Pm-147 (fission product)
^{60}Co	5.3	DOE IP entered market in FY20 for HSA Co-60
^{3}H	12.3	Commercially available
^{90}Sr	28.8	DOE IP has kCi available
^{238}Pu	87.7	NE; DOE IP has small quantities for research
^{63}Ni	101.2	DOE IP produces hundreds of Ci per year at high specific activity (>13 Ci/g)
^{241}Am	432.6	DOE IP entered market in FY18
^{14}C	5730	Production R&D ongoing

Americium-241 Recovery

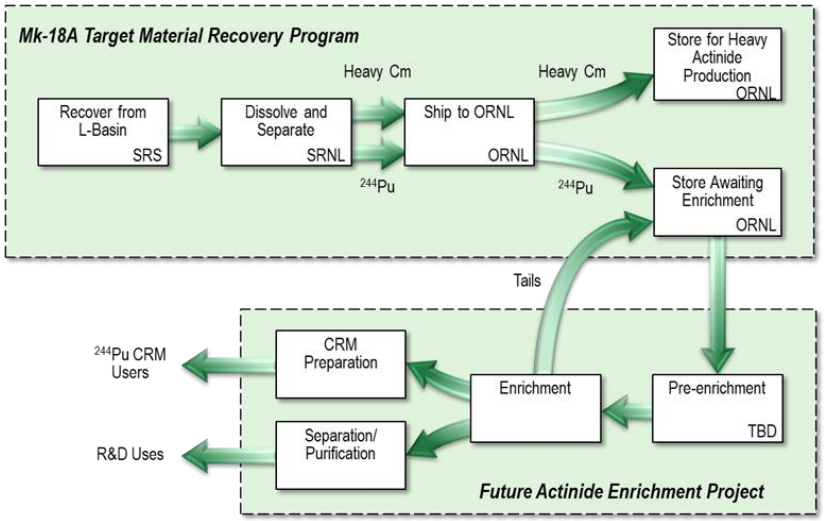
- **Applications: fundamental research, radioisotope power sources, commercial**
- **Cooperative effort with NNSA to provide an efficient and reliable source of Am-241 oxide for research, industry and space applications**
- **DOE re-established Am-241 production in 2018 through recovery of Am-241 from plutonium-239 residues in waste streams**
- **FY21 aqueous purification process optimization to enhance throughput and improve efficiency with stable specification product**
  - Ion exchange, precipitation, and extraction chromatography
  - Extraction chromatography provides specification product but with extended process times

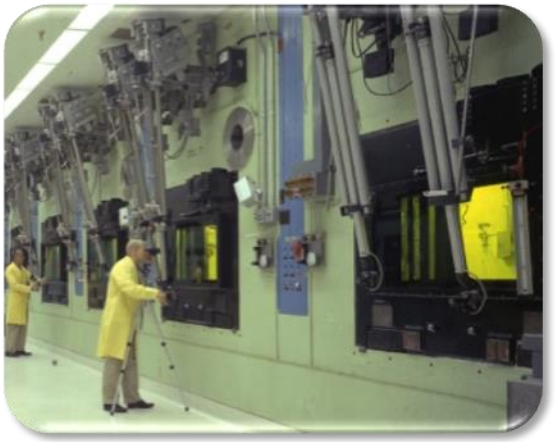
Packaging of Americium-241 in LANL glovebox

Am-241 glovebox

Mark-18A Am/Cm/Ln Recovery

- **86 targets were irradiated in K-Reactor at SRS**
  - Irradiated at a high neutron flux (6×10^{15} n/cm^2-s)
- **21 targets were previously processed at ORNL in 1972-73 to recover Cf-252, heavy curium, and Pu-244**
- **65 targets remain in SRS L Basin**
  - Contain 80% of the global supply of invaluable Pu-244 and heavy curium
- **3QFY23 – first Mk-18A target planned to be processed at SRNL**
  - Am/Cm/Ln oxide - shipments to ORNL every other month the next ten years
- **ORNL will receive, store, and process the Mk-18A Am/Cm/Ln oxide material for DOE IP**

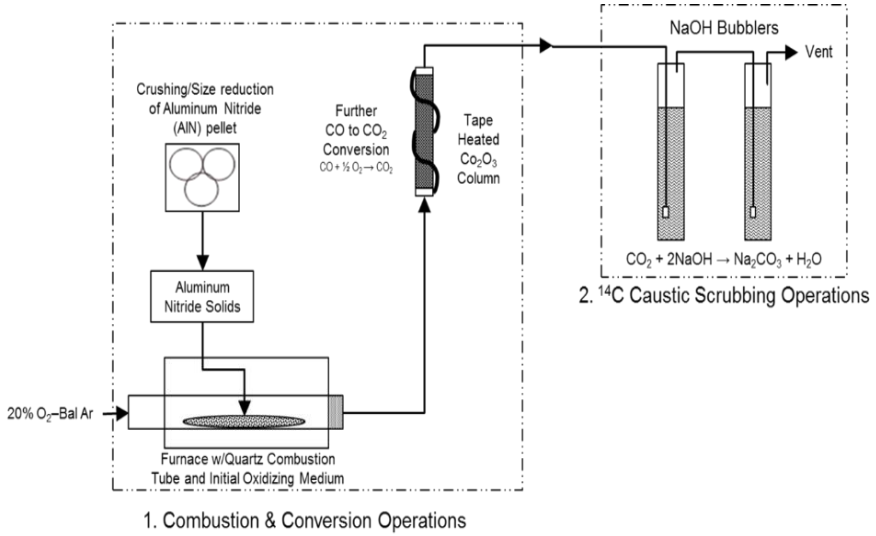




7920 Hot Cell Bank

Carbon-14

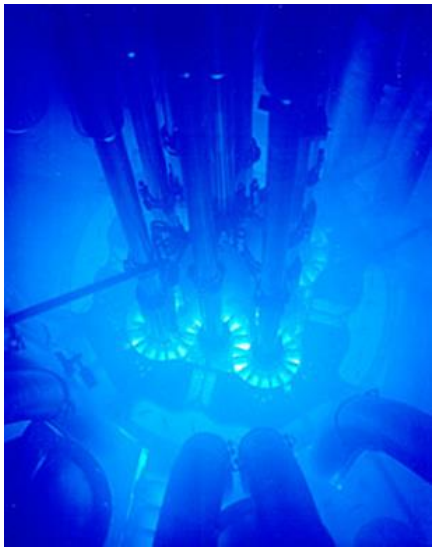
- Useful for medical/age dating applications but recent research on diamond beta-voltaic nuclear batteries
- Russia is the sole C-14 supplier
- DOE IP is working on production process development at ORNL for availability in ~3 years
- ORNL has completed small scale experimental evaluation on two aluminum nitride (AlN) pellets
- FY21-FY22 - irradiation of AlN target for research quantities and setup of dry processing infrastructure
- AlN production targets would be used for larger quantities in a few years



1. Combustion & Conversion Operations

2. ^{14}C Caustic Scrubbing Operations

Cobalt-60



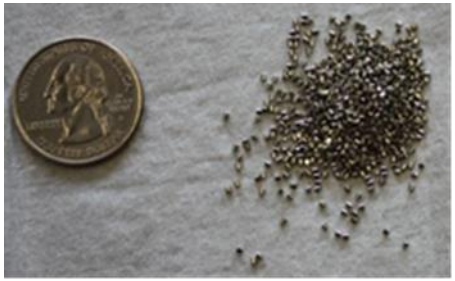
ATR Core Irradiation

Loading Co-60 into the BRR Cask

- **Co-60 is critical for source applications for cancer radiotherapy, cancer radiosurgery (Gamma Knife®), and industrial gamma radiography.**
- **The U.S. has been dependent upon foreign suppliers for high specific activity (HSA) Co-60 (Russia and Canada).**
- **INL shipped the first HSA Co-60 in 6 years to a commercial vendor in March 2020, using a new BRR Type B Cask, re-establishing the U.S. as a domestic supplier of Co-60.**
- **DOE produces kCi quantities of high specific activity Co-60 (>225 Ci/g)**

ATR Canal Operations

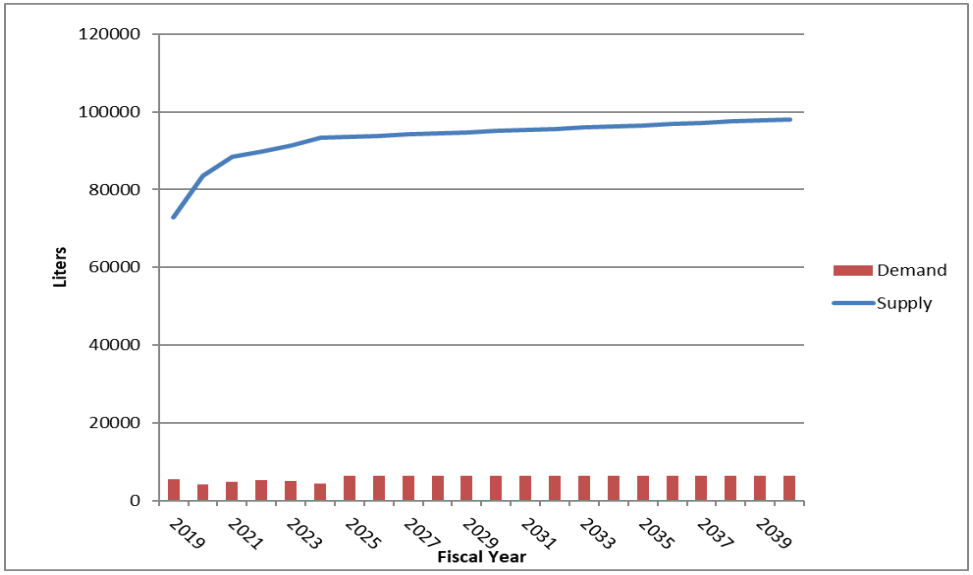
Co-60 loaded in BRR Cask for Shipment to a commercial vendor; first use of the BRR Cask



HSA Co-60 Pellets

Helium-3

- DOE Isotope Program plays a lead role in the Interagency He-3 Working Group- reports to White House National Security Staff. 14 Federal agencies.
- Mitigation and prioritization efforts on behalf of IAG have successfully addressed He-3 shortage.
- The current supply is anticipated to meet Federal agency needs.
- At Savannah River Site, DOE IP is working on:
  - He-3 extraction from NNSA tritium and other sources
  - Independent He-3 purification
  - Developing new sources of He-3
- Seeing increase in He-3 for cryogenics for QIS



Promethium-147

- Application: radioisotope power sources, pacemakers, material thickness gauge, guided missiles, radios, solar cells
- Reactor production of Pm-147 (2.6 y)
  - $^{237}Np(n,fission)^{147}Pm$
    - Now available (tens of Ci; up to several hundreds Ci in future)
  - $^{146}Nd(n,\gamma)^{147}Nd(\beta)^{147}Pm$
    - Production in development (high yield; Ci to kCi production)
- Previously only available as fission product from fuel reprocessing in Russia – no longer available
- DOE entered market in FY21 for fission product in Pu-238 waste stream (co-produced with several other isotopes of interest including Ru-106, Eu-155, I-129)
- DOE production (both routes) yields a purer product then Russia
  - Less Pm-146 and Pm-148m which have high energy gamma emissions
  - Shorter irradiations (1 or 2 HFIR cycles) than reactor fuel and Nd-147 “delay” reduce production of Pm-146 and Pm-148m
- Pm-147 (fission product) processed for each Pu-238 campaign

Promethium-147 purification process

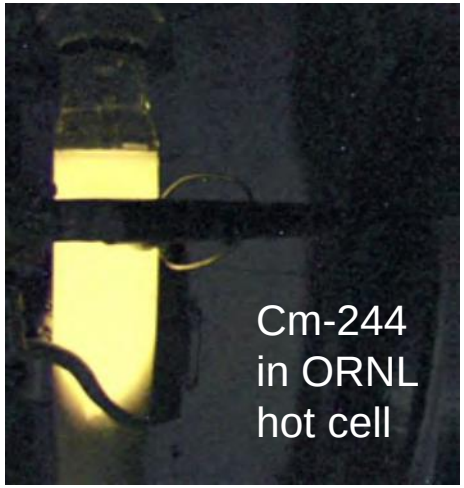
Strontium-90

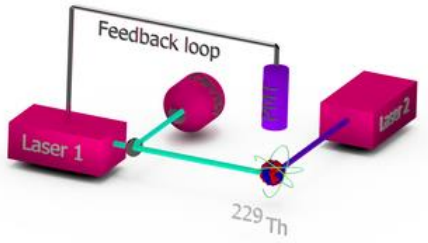
- *Application: radioisotope power sources, medical*
- Sr-90 power sources for terrestrial and space (moderately long-lived radioisotope power sources), reduce foreign dependence
- Recovery of legacy Sr-90 (29 y)
  - Material generated decades ago from Hanford tank wastes from plutonium production
  - Re-established Sr-90 processing in 2019
  - kCi quantities placed in inventory at PNNL
  - >30 years old (specific activity ~ 25 Ci/g)

Hot cell work on Sr-90 conversion and purification

DOE Isotope Program Support for Space Applications - Opportunities

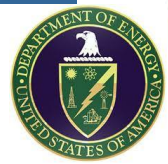
- **Opportunities**
  - Next generation RTG
  - Next generation beta-voltaic nuclear batteries
  - Additional isotopes for astrophysics research (e.g. **Ho-163**)
  - Potential use for **Cm-244** as an X-Ray and alpha particle calibration and test source for X-Ray Fluorescence and Particle Induced X-Ray Emission (PIXE) measurements
    - For example, lunar petrology using an Alpha Particle X-Ray Spectroscopy (APXS).
    - Cm-244 has been used on AXPS devices for Mars rovers.
  - Other isotopes needed for next generation atomic/nuclear clocks (e.g. **Th-229**)
  - Other isotopes needed for research/space applications
    - DOE IP has unique facilities and access to legacy inventories





Strong communication with and impact on stakeholders

- White House Working Groups
- Inter-agency Working Groups
- Community Users Working Group
- Professional Society Meetings and Councils
- Commercial stakeholder meetings twice a year
- Annual Industrial Survey
- Bi-ennial Federal Workshops and Survey
- Sponsorship of workshops, symposium at conferences

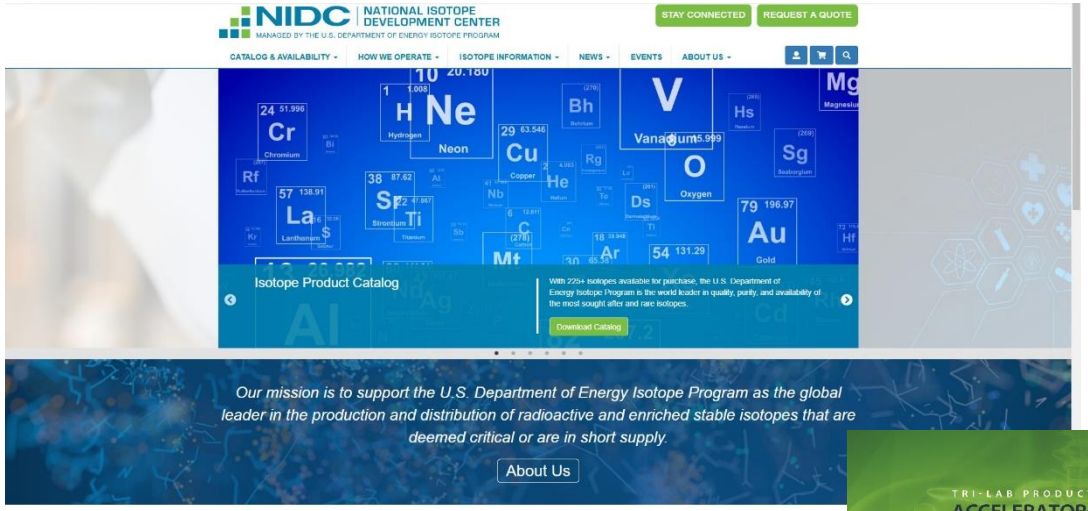


National Isotope Development Center

- The Department of Energy NIDC, located at ORNL, coordinates the distribution of all DOE isotope products and services available from DOE facilities

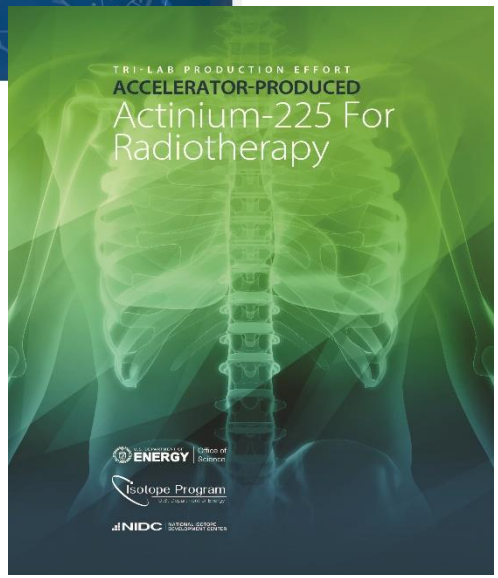
- All contractual discussions with customers

- Responsibilities in transportation, Q&A, public relations (website, newsletter, booth), cross-cutting technical topics, marketing strategy and assessments.



NIDC website homepage

- www.isotopes.gov



NIDC brochure

Summary

Substantial national and international research/applications relies upon the use of isotopes and is strongly dependent on the DOE IP's products and services

DOE IP has the sole authority in DOE to produce isotopes for sale and distribution
Exceptions are Mo-99, Pu-238, and SNM for weapons

World leaders in developing novel isotope production approaches and bringing rare and critical isotopes to the global community

The DOE IP utilizes particle accelerators, nuclear reactors, enrichment technologies, and radiochemical processing capabilities throughout the DOE national laboratory complex and at universities to most cost effectively meet the requirements of the nation in isotope demand

DOE IP supports space applications through providing isotopes in inventory, developing production of isotopes of interest for the space community, and pursuing beneficial R&D to meet future requirements (next generation power sources, research isotopes, next generation atomic/nuclear clocks, etc.)

Isotopes of interest should be brought to the attention of the DOE IP and NIDC