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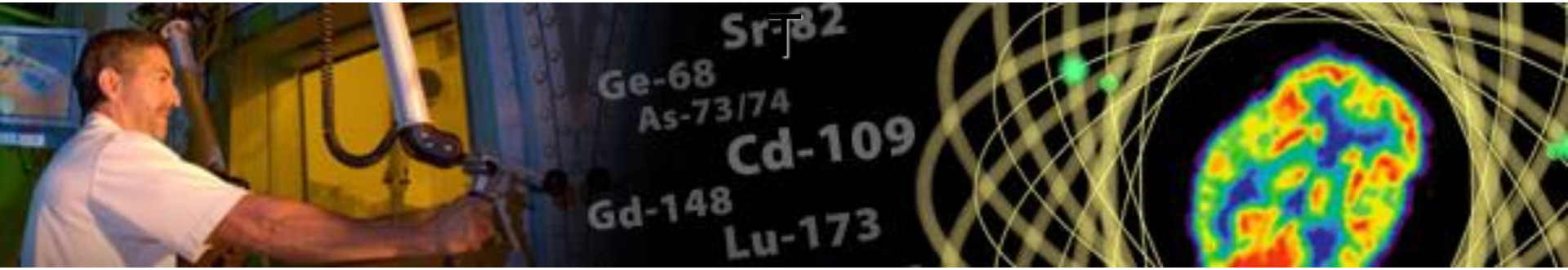

DOE Isotope Program Overview
July 13, 2018

Dr. Jehanne Gillo
Director, Facilities and Project Management Division
Director, DOE Isotope Program
Office of Nuclear Physics, Office of Science, U.S. Department of Energy

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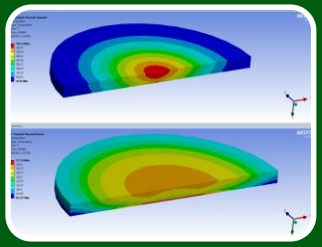
DOE Isotope Program Mission

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

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



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

Managed by the Office of Science Office of Nuclear Physics since FY 2009

Isotope Program Authority

- Isotope Program in DOE has sole authority to produce isotopes for sale and distribution – **Other DOE Offices and labs may not embark on isotope production and sales on their own.**

- Isotope Program operates under a **revolving fund** and is audited annually.
- Program costs are financed by two resources: **appropriation and revenue**.
- Commercial isotopes at full-cost recovery or market price; research isotopes at reduced prices.

- **Monitor and anticipate isotope demand for federal missions, research and U.S. industry**
  - **Increase availability of isotopes in short supply**
  - **Mitigate potential shortages**
  - **Develop new production and processing techniques of isotopes currently unavailable**
  - **Reduce U.S. dependencies on foreign supply**

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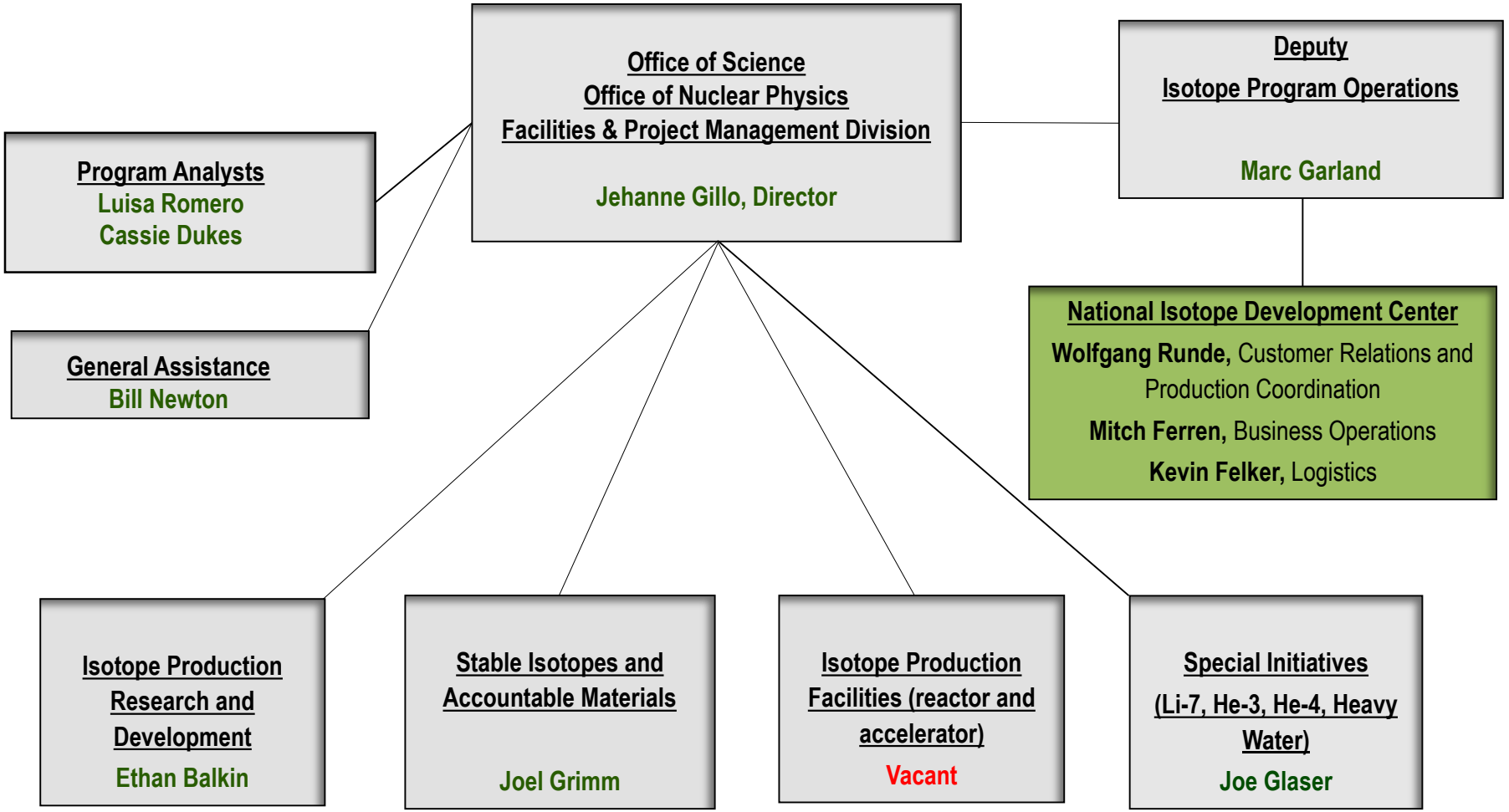
DOE Isotope Program Organization



National Isotope Development Center

- The Department of Energy NIDC (includes the Isotope Business Office located at Oak Ridge National Laboratory) 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.
- Customers maintain technical discussions with sites.
- www.isotopes.gov

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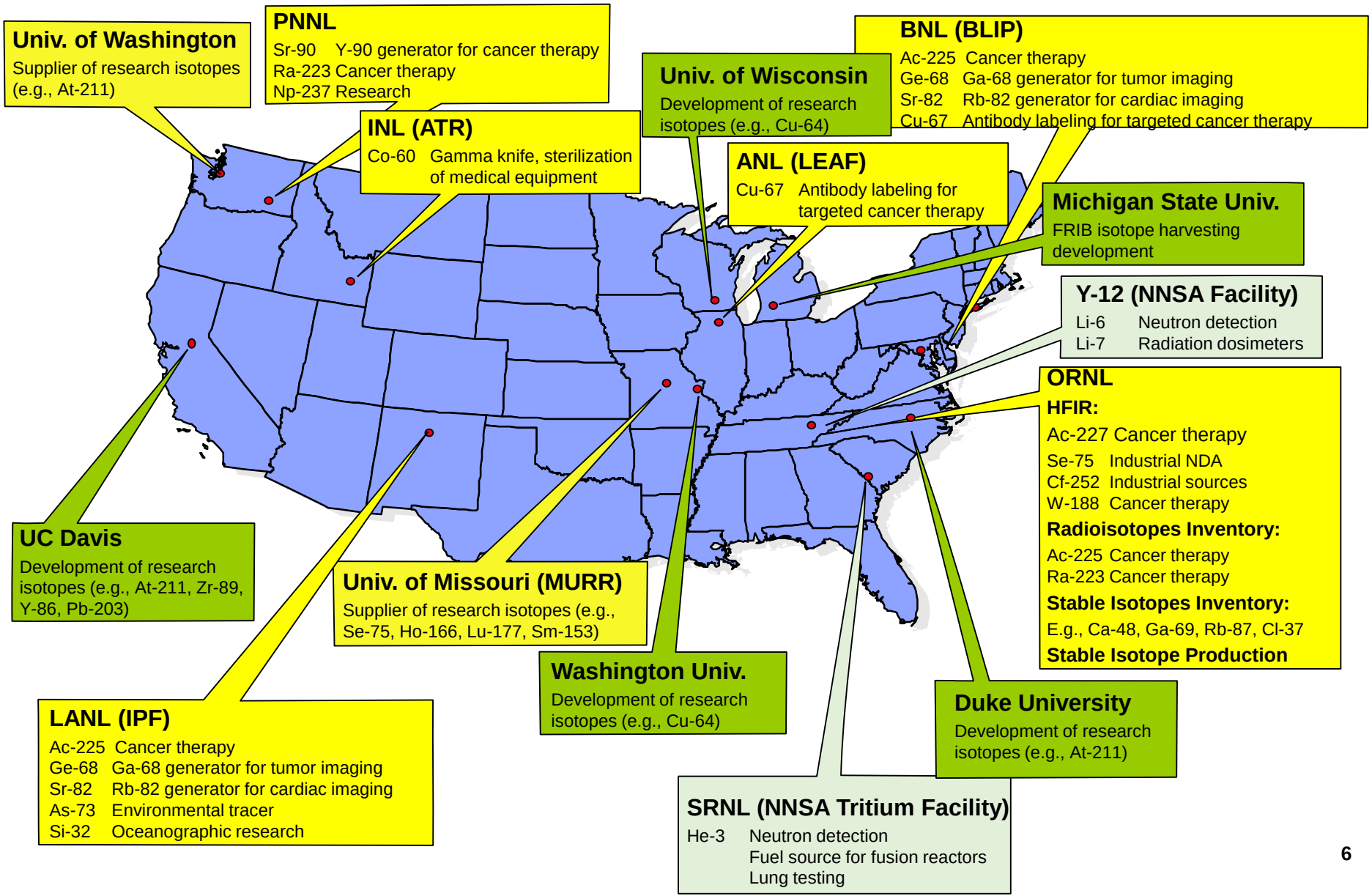
DOE Isotope Program Production and/or Development Sites -2018



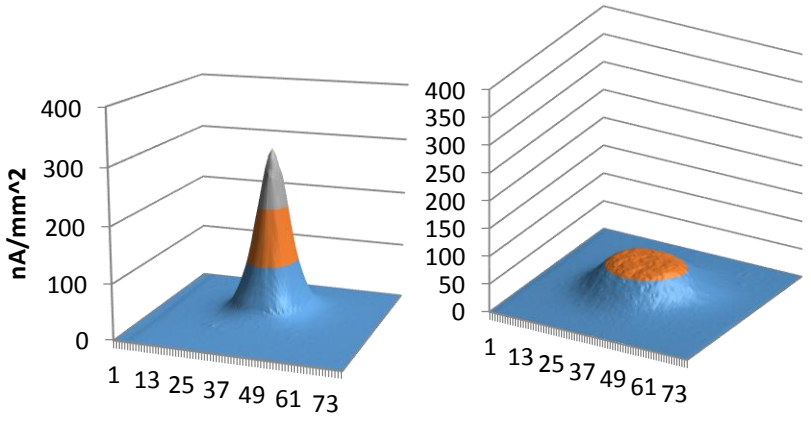
Strong communication with stakeholders

- OSTP High Activity Sources Subcommittee (GARS)
- OSTP Subcommittee on Critical Materials
- Interagency He-3 Working Group – White House National Security Staf
- Iran Joint Comprehensive Plan of Action
- DOE/NIH Working Group
- Mo-99 Stakeholders Working Group
- NRC Sealed Sources Working Group
- BLM He-4 Interagency Working Group
- Certified Reference Materials Working Group
- CRM Np-236 Sub working group
- New Brunswick Lab Interagency Working Group
- DOE Nuclear Materials Advisory Board
- Mark 18 Interagency Working Group
- IN Nuclear Materials Information Program
- Li-7 Intra-agency Working Group
- U-233 Intra-agency Working Group
- Pb-212 Users Working Group (medical)
- At-211 Users working Group (medical)
- Council on Radionuclides and Radiopharmaceuticals
- Society of New Medicine and Molecular Imaging
- Commercial stakeholder meetings twice a year
- Annual industrial survey
- Annual Federal Workshops and survey
- Sponsorship of workshops, symposium at conferences

Stewarded Accelerator Facilities

Brookhaven National Laboratory Brookhaven Linac Isotope Producer (BLIP)

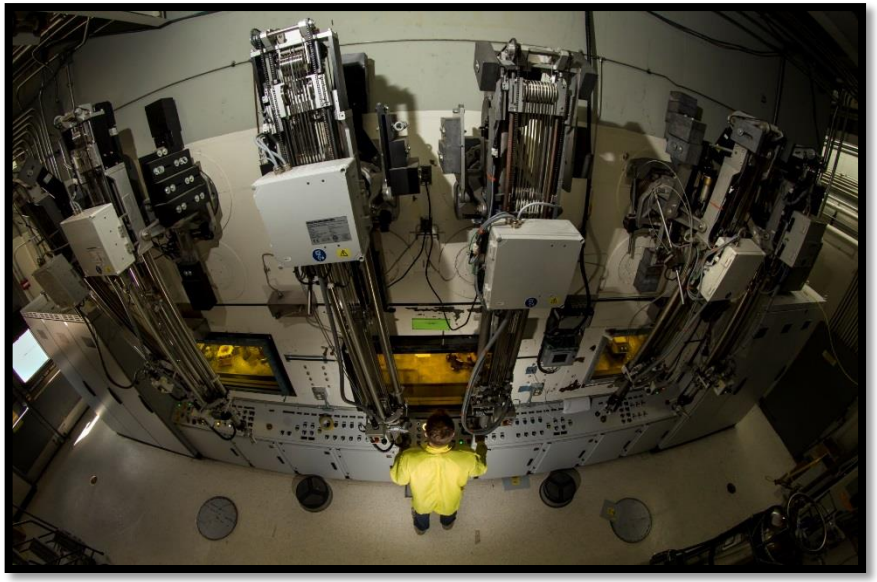
- The BLIP beam line directs protons up to 160 µA intensity to targets; parasitic operation with nuclear physics programs for more cost effective isotope production.
- Ac-225, Sr-82, Ge-68, Be-7, Cu-67, Y-86, Zn-65, Fe-52, Rb-83
- New project completed this year to raster beam to increase isotope yield and decrease target fatigue



No beam raster *With beam raster*

Los Alamos National Laboratory Isotope Production Facility (IPF)

- Diversion of 100 MeV proton beam to target station.
- Irradiates targets while LANSCE operates for NNSA.
- Ac-225, Sr-82, Ge-68, Na-22, As-73, Se-72, Y-88, Si-32, Cd-109
- Upgrade to IPF beam transport system upgrade completed this year to increase isotope yields and enhance R&D capabilities

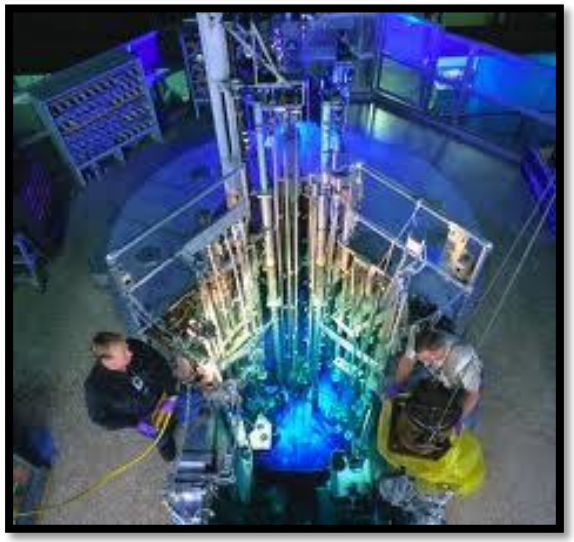


University Facilities

- Unique capabilities and expertise
- Invest R&D and develop capabilities
- Workforce development
- Cost-effective
- Regional networks
- University of Washington; University of Missouri – MURR; University of Wisconsin; Duke University; Washington University; UC Davis; Texas A&M

UW cyclotron: At-211

- **In 2016, University of Washington became part of Isotope Program isotope production network: At-211**
- **In 2018, DOE started stewarding UW Isotope Capabilities**
- **In 2016, agreement finalized with MURR for production of Se-75 for scientific research**
  - Recently updated to include Lu-177 for research



University of Missouri Research Reactor

Other Isotope Program Sites

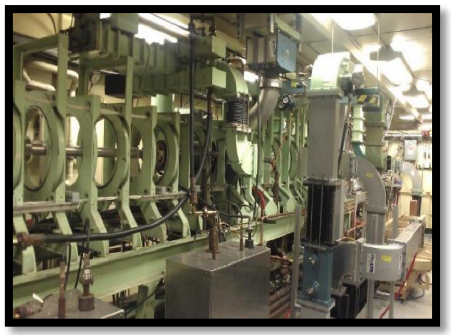
Y-12

- Li-6
- Li-7
- Establishing emergency reserve of Li-7 for nuclear power industry

Preparing for additional cleanup to meet product specifications for future molten salt reactors.

Argonne National Laboratory

- **New for 2016**
- Low Energy Accelerator Facility (LEAF)
- Electron accelerator
- Cu-67 production for cancer therapy



Pacific Northwest National Laboratory

- Radiochemical Processing Laboratory
- Sr-90, Np-237, Pb-212/Bi-212, Th-227, Ra-223

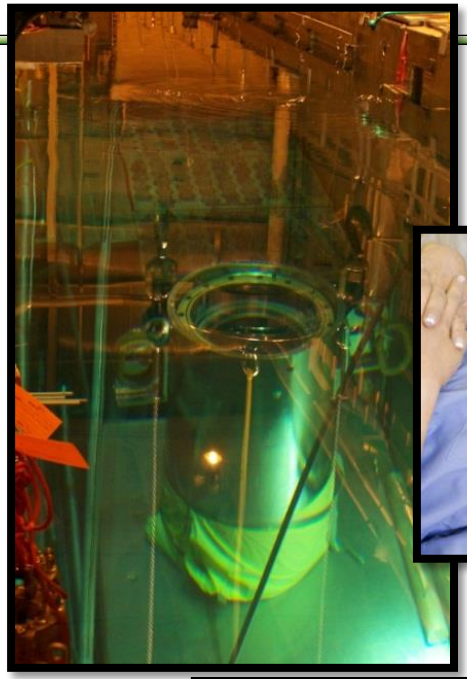
SRS

- He-3 extraction from NNSA tritium
- **Considering new sources He-3**

Reactor Facilities

Idaho National Laboratory Advanced Test Reactor (ATR)

- Office of Nuclear Energy is steward
- Co-60 target design in collaboration with ORNL
- High Specific Activity Co-60 for medical applications
- Developing Ir-192 for industrial radiography



Oak Ridge National Laboratory High Flux Isotope Reactor (HFIR)

- Office of Basic Energy Science is steward
- Radiochemical Engineering Development Center (REDC)
- Ac-227, Cf-252, Se-75, Ni-63, W-188, Lu-177, Th-227, Ra-223, Pb-212/Bi-212, Th-229

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Isotopes at HFIR

Routinely Produced	
^{227}Ac	Generator for ^{223}Ra (Xofigo-Bayer) for treatment prostrate cancer
^{133}Ba	Radioisotope products
^{252}Cf (Bk/Es/Fm)	Oil/gas exploration, nuclear power, construction (physics and chemistry research)
^{63}Ni	Explosives and illicit drug detection for national security
^{75}Se	Radiography, biomedical/medical research
^{89}Sr	Palliation of pain from cancer metastasized to bone
^{228}Th	Generator for ^{212}Pb/^{212}Bi for cancer therapy

Potentially Routine	
^{109}Cd	Analytic apps
^{177}Lu	Cancer therapy
^{188}W	Cancer therapy

Development of Large Scale Production	
^{14}C	Biomedical and medical research
^{192}Ir	Radiography
^{147}Pm	Radioisotope power sources
^{229}Th	Generator for ^{225}Ac for cancer therapy

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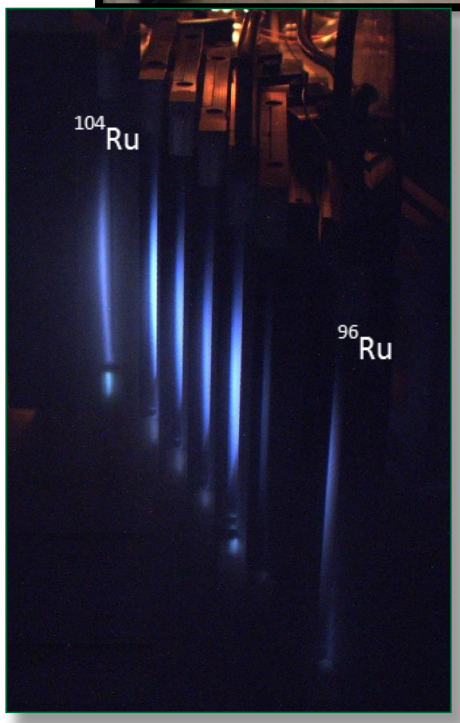
Stable Isotope Enrichment and Distribution

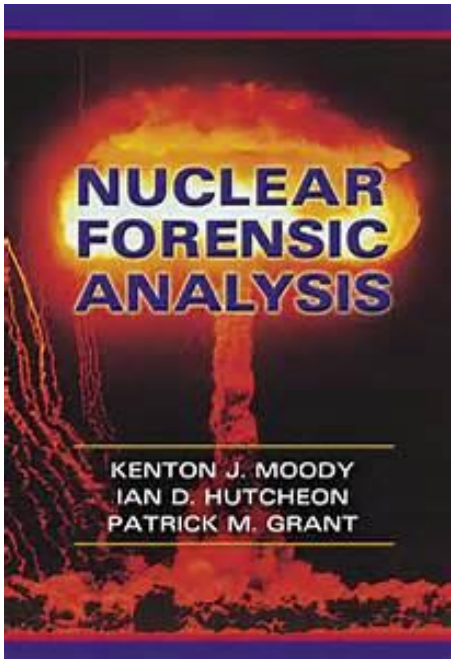
- Isotope Program manages the Nation's inventory of stable isotopes
- Have re-established enriched stable isotope production in the United States - ESIPP
- Electromagnetic separation and gas centrifuge
- Production started 2017 – 500 g of Ru-96 for RHIC
- **Stable Isotope Production Facility MIE - ongoing**
  - Leveraged by NNSA
  - Kg through put capability
  - Basic research, applications, industry
  - Quantum Information Science
- Xe-129, Mo-98, Mo-100, Yb-76



Examples of Support of NNSA

- Neptunium-236 is a highly desirable isotope within the National Technical Nuclear Forensics Center.

- An investment by the DOE Isotope R&D Program is allowing collaborative research specifically aimed at developing production technologies using proton bombardment of uranium targets at the Los Alamos Isotope Production Facility (IPF) and the University of Washington cyclotron facility.



- Mo-99/Tc-99m is the most used diagnostic nuclear medicine isotope generator providing over 50 million diagnostic doses per year
- IP provides technical and policy support
- NSAC assesses NNSA program on an annual basis

- Li-6/Li-7 NNSA/DOE IP Working Group
- DOE IP R&D on Li-7 relevant to NNSA

- DOE IP extracts He-3 from NNSA Tritium reserves
- Working on new initiatives
- Manages federal He-3 reserves

Ensures BES community has the He-3 it needs for research

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Mitigation of U.S. Dependence on Foreign Sources

<u>Rubidium-82 used for PET myocardial perfusion imaging</u>

- France, Russia, South Africa, Canada, U.S.
- Produced at BLIP and LANL
- Major revenue source
- Mitigates Mo-99
- Providing aid to industry to promote commercialization
- **New Domestic Supplier 2017, more expected**

<u>Cf-252 for well logging, industrial applications</u>

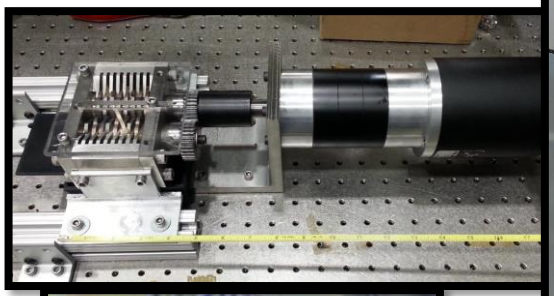
- Russia, U.S.
- **Maintaining supply of 97% of domestic market**
- Working with industrial consortium
- Long term contract in place; provision for research quantities

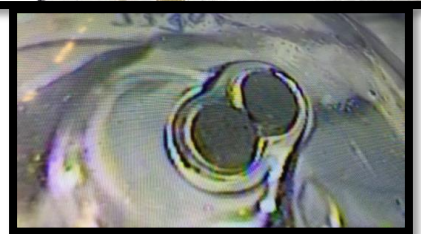
<u>Am-241 for oil-gas exploration</u>

- Re-establishing production capability in U.S.
- Extraction from plutonium waste stream at LANL
- Working with industrial consortium
- **Production started 2018**

Ac-227 Production Development

- Bayer drug Xofigo® treats prostate cancer and severe pain from bone metastases; approved in 48 countries.
- Active ingredient *Ra-223 from limited global supplies of existing Ac-227.*
- Recover Ra-226 from waste medical devices secured by the DOE IP and diverted from a radioactive waste landfill. Ra-226 targets irradiated in HFIR
- Chemically separate and purify the Ac-227 created during irradiation – shipped to Bayer in Norway where they extract Ra-223 which decays into Ac-227and ships it around the world for immediate use as a cancer therapy.
- After 2 years of R&D, scale up to full production in 2017.
- **10-year production contract signed with Bayer end of 2017**





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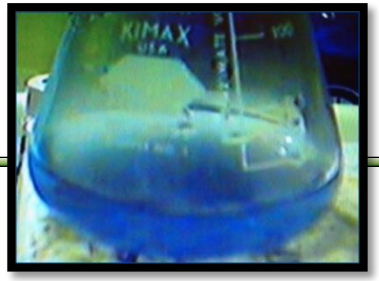
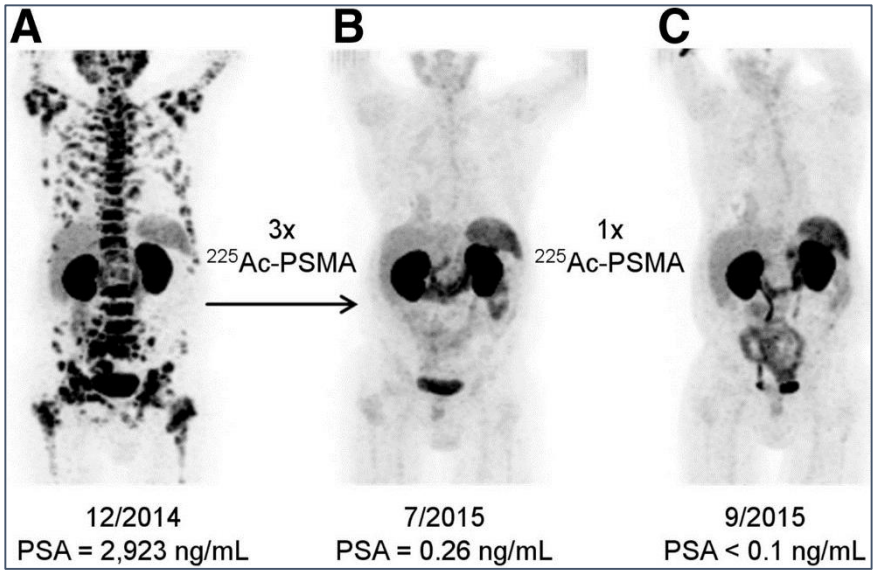
Actinium-225 Production



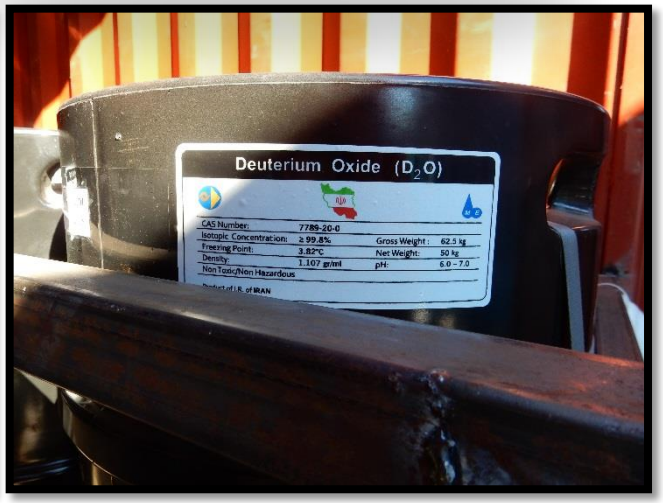
- High priority for NIH for decades
- Since 2009, IP is world leader in R&D
- **ORNL extracts Ac-225 from Th-229 recovered from U-233: 1,200 mCi per year - entire U.S. supply and more than half the worldwide supply.**
- Supply cannot support adequate clinical trials or therapy
- IP has developed accelerator production route- full scale production can meet clinical and therapy demands
- **Accelerator production started 2017**



- **Completed Stage 1: 5-50mCi/B**
- **Stage 2: jan 18: 10-100mCi/B ; already 150mCi**
- **Stage 3: 100-1000mCi/B**
- **IP strategy includes other production routes- reactor production of Th-229, extraction of Th-229 from legacy U-233, low-energy cyclotron production, and electron accelerator production demand.**
- **PRODUCT AVAILABLE NOW**

Iranian Heavy Water

- IP negotiated with Iranian Delegation to purchase 32 Metric Tons as part of JCPOA
- Significant amount went to the SNS
- All HW sold
- Quality pristine
- Conducting R&D on production



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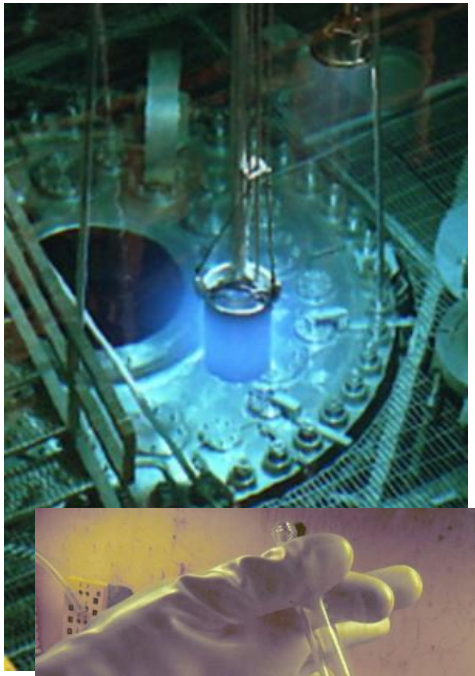
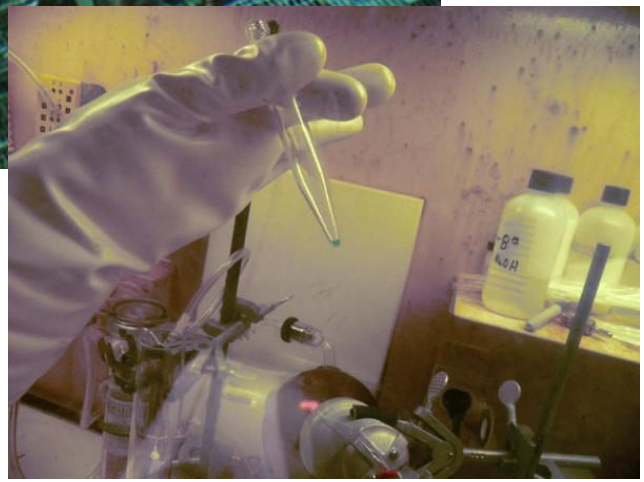
Super Heavy Elements and Heavy Element Chemistry

High Flux Isotope Reactor at ORNL





It took 250 days to make enough Berkelium, shown here, to synthesize element 117

The New York Times

Scientists Discover Heavy New Element
By JAMES GLANZ
Published: April 6, 2010

A team of Russian and American scientists has discovered a new element that has long stood as a missing link among the heaviest bits of atomic matter ever produced. The element, still nameless, appears to point the way toward a brew of still more massive elements with chemical properties no one can predict.

DOE IP requested and received long term plans and needs from the SHE and Heavy Element Chemistry Groups

Working closely with Office of Basic Energy Sciences to provide isotopes for Heavy Element Chemistry: ^{241,243}Am, ^{244,248}Cm, ^{249,251}Cf, ^{249}Bk, ^{237}Np, ^{238,240,242,249}Pu, ^{253,254}Es & ^{256,257}Fm

Isotopes for BES Research

- DOE IP receives input from BES on needed isotopes for BES research.
- BES POC isThiyagarajan (He-3, HEC, BES research)
- He-3 input annually
- Periodic HEC plan; new plan requested
- Biennial request for BES isotope needs
  - Heavy Element Chemistry
  - Neutron scattering
  - Synthesis of new materials
  - NMR
  - Environmental Transport
  - …….
- DOE IP strives to ensure availability of isotopes for BES research

Increased Availability of Isotopes (1)

- Ac-225: Developed large-scale accelerator production capability, therapeutic medical applications research
- Ac-227: Developed reactor-based production, therapeutic medical applications research
- Am-241: Established domestic production capability; product will be available starting 2017
- At-211: Funding production development at four institutions to establish nationwide availability
- Ba-133: Reactor production. Used as gamma radiation reference source. Removed Russian dependency.
- Bk-249: Produced 22 mg target for the discovery of element 117; produced 26 mg for further super-heavy element research
- Cd-109: Developed reactor production routes
- Cf-249: Heavy element chemistry research
- Cm-243: Acquired curium with a high Cm-243 content for research applications
- Cm-248: Developed recovery process for high purity Cm-248 for research applications
- Cf-251: Super-heavy element research
- Cf-252: Re-established production in FY 2009, new 6-year contract through 2018; industrial applications
- Co-60: Re-established domestic production with new target design; cancer therapy (Gamma Knife®), industrial applications
- Cu-64: Medical diagnostic imaging applications
- Cu-67: Cancer therapy research; new electron accelerator production route
- Es-254: provided for SHE nuclear science
- He-3: MRI imaging of lung function for pediatric apps; strict government controls mitigated shortage
- Heavy water: Acquired supply

Increased Availability of Isotopes (2)

- Li-6: Production of metal form for neutron detector isotope sales
- Li-7: Reserve for nuclear power industry to mitigate potential shortage
- Lu-177: Added new production capability at MURR
- Np-237: Inventory for dispensing bulk quantities and capability to fabricate reactor dosimeters
- Pb-212/Bi-212: Therapeutic medical applications research
- Ru-96: Nuclear Physics research
- Se-72/As-72: Developed production capability for Se-72 for As-72 generator; medical diagnostic imaging
- Si-32: Oceanographic and climate modeling research; replenished depleted inventory
- Sr-89 Developed reactor production capability; palliation of bone pain associated with metastases
- Sr-90: Developing reserve to mitigate US dependence on foreign sources
- Th-227/Ra-223: Established Ac-227 cows for the provision of Th-227 and Ra-223, therapeutic medical applications research
- Th-232: New source available for distribution
- Th-238 Recoverd from Ac-227 production Th-228/Ra-224 generator
- Ti-44: Developed accelerator production capability for medical imaging
- U-233: Recovered and purified mass-separated U-233 for research applications
- U-234: Neutron flux monitors
- W-188: Established routine reactor production for therapeutic medical applications
- Y-86: Established production capability for medical diagnostic imaging applications
- Zr-89: Funded development of production at universities; medical diagnostic imaging applications

Isotopes under Development

- As-72/77: Exploring reactor and accelerator production for theranostic medical applications
- C-14: Ramping up to full scale production
- Cm-248: Process Mark 18 targets
- Cu-57: University production development
- Heavy water: Supporting new production techniques
- Ho-163: Demonstrated technical feasibility of production; if interest would need to scale up production
- Ir-192: Multi-lab target design team; mitigate foreign dependence
- Li-7: Developing new production capability: reactor operations, physics research
- Lu-177 HSA Large Scale processing/production capability
- Mo-98/Mo-100: Conducting validation runs
- Mn-52/Nb-90: Medical applications
- Np-236/Pu-236: Ongoing R&D for accelerator-based production for security reference materials
- Pa-231: Purifying 100 mg for applications such as fuel cycle research
- Pm-147 technical feasibility established; ramping up to full scale processing capability
- Pt-191/193m/195m: Exploring accelerator production; theranostic medical applications
- Re-186: Exploring accelerator production
- Se-72: Accelerator production for Se-72/As-72 generator
- Sc-47: Exploring accelerator production; theranostic medical applications
- Si-28: Consider EMIS and centrifuge production of Si-28 for computing and electronic applications
- Sr-89: Investigating economic feasibility of reactor production; palliation of bone pain associated with metastases
- Te-119: Accelerator production for Te-119/Sb-119 generator; technical feasibility established
- Th-229 Developing reactor production route for Ac-225
- U-230/Th-226: Medical applications; technical feasibility established
- Xe-129: Polarized lung imaging – starting validation runs
- Yb-176 Consider production capability
- Zn-62/Cu-62: Funding production development for generators for medical diagnostic imaging applications

Back ups

Guided by NSAC Report released July 20, 2015

Recommendations:

- Significant increase in R&D funding
  - Continue R&D on alpha-emitters (Ac-225, At-211)
  - High specific activity theranostic isotopes
  - Electron accelerators for isotope production
  - Irradiation materials for targets
- Complete stable isotope capability
- Increase in infrastructure investments and operating base
  - Isotope harvesting at FRIB
  - Separator for radioactive isotopes
    -- Several programs looking at actinide EMIS
    - Potential needs for medical and research isotopes
  - BLIP intensity upgrade and second target station
  - IPF intensity, stability and energy upgrades
- Continue integration of university facilities