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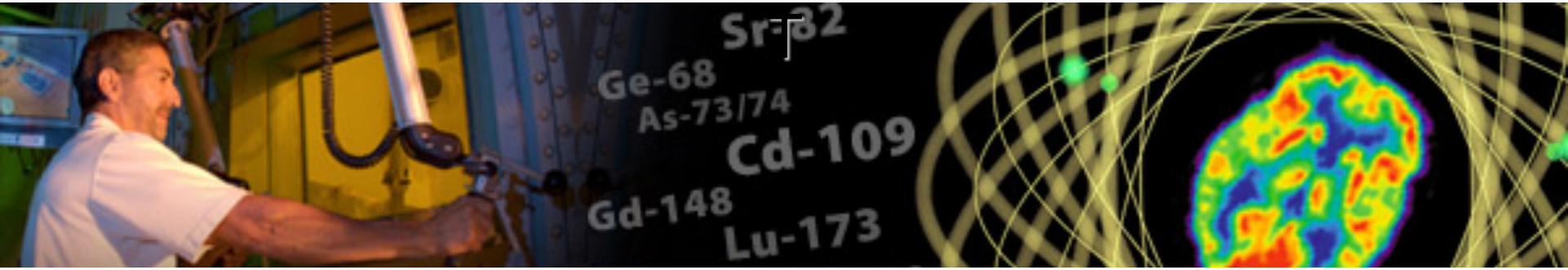
DOE Isotope Program Needs



Workshop on Applied Nuclear Data Activities (WANDA)
January 22, 2019

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Office of Nuclear Physics, Office of Science, U.S. Department of Energy

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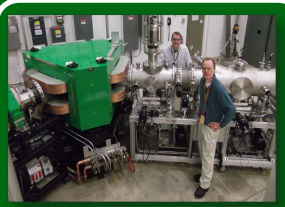
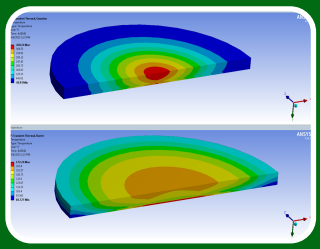
DOE Isotope Program Mission

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.

Reduce U.S. dependency on foreign supply

National Isotope Development Center

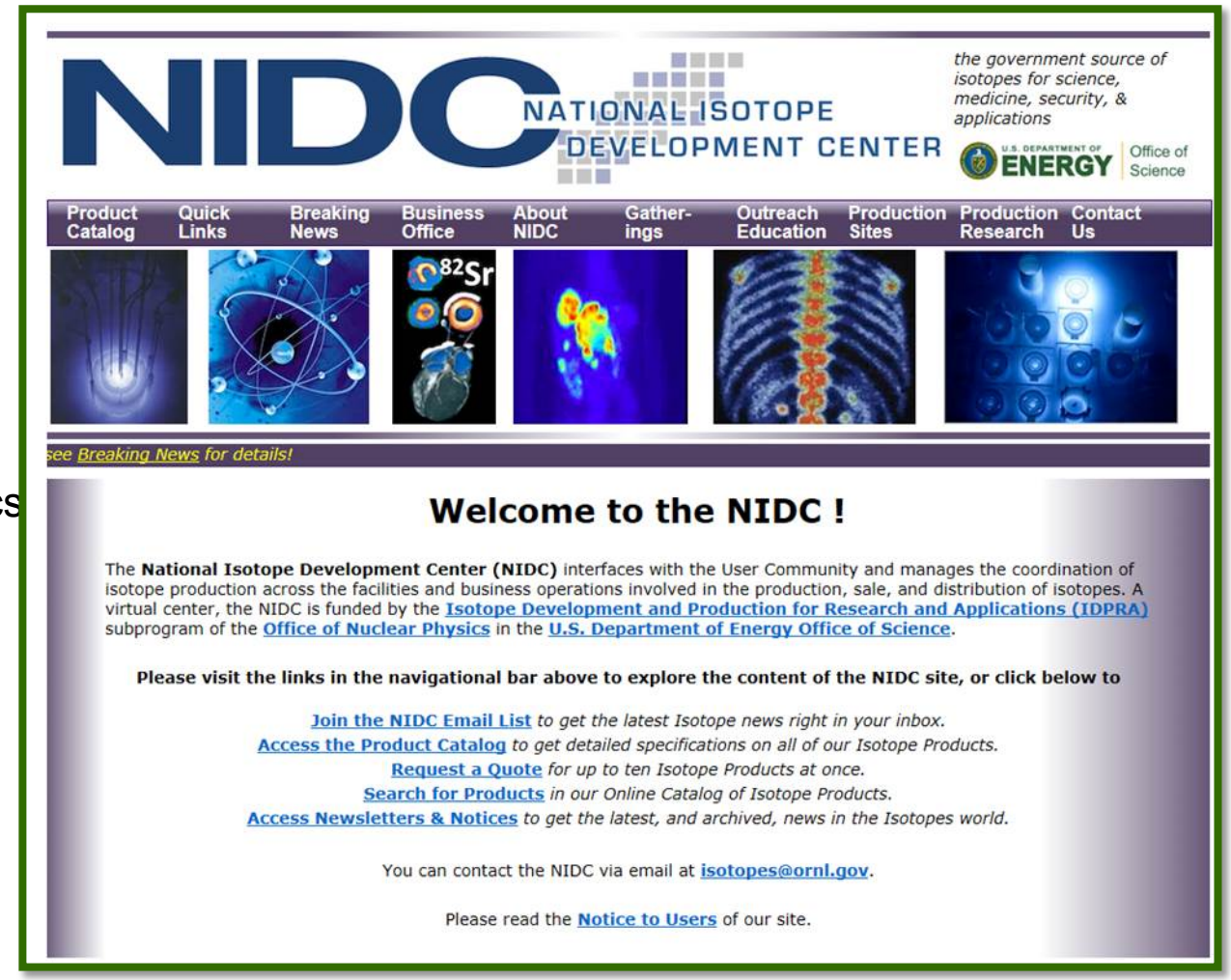
- The Department of Energy NIDC (includes the Isotope Business Office located at Oak Ridge National Laboratory) coordinates the distribution of all DOE isotope products and services available from DOE facilities.

- 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.

- http://www.isotopes.gov



Strong Communication with Stakeholders

- OSTP High Activity Sources Subcommittee (GARS)
- OSTP Subcommittee on Critical Materials
- Interagency He-3 Working Group – White House National Security Staff
- 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**
- **Nuclear Data Interagency 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)
- DOE Iran Working Group
- 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

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

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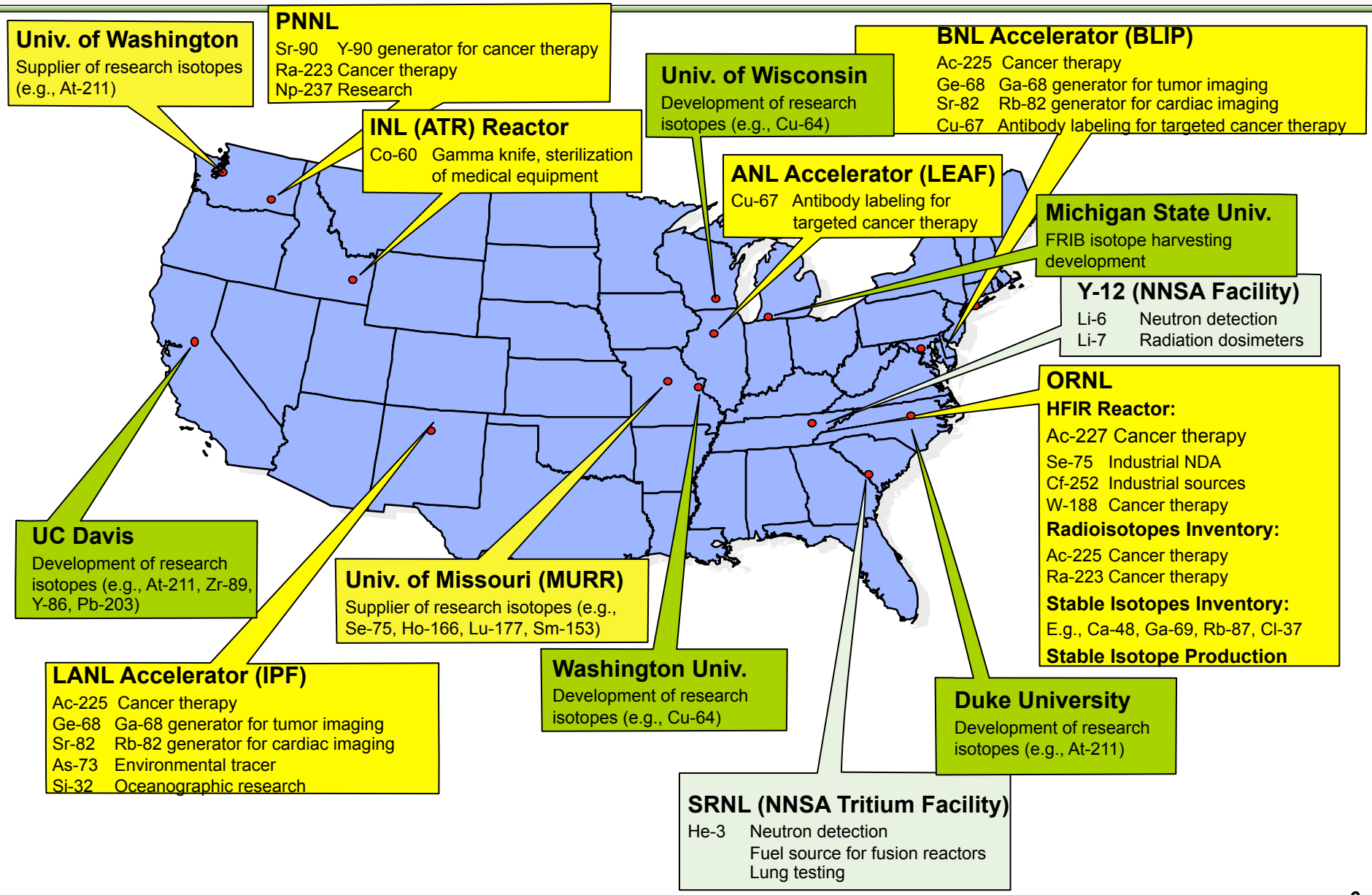
DOE Isotope Program Production and/or Development Sites - 2018

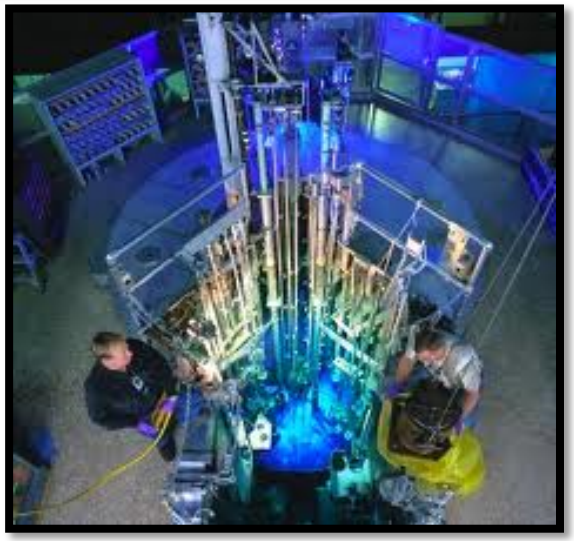


University Facilities

- 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 University

UW Cyclotron

- 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

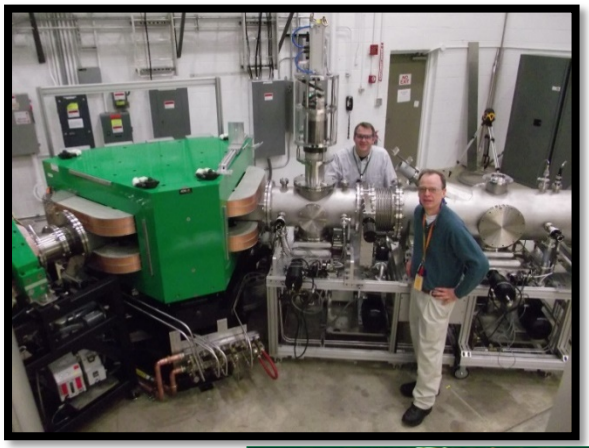
Stable Isotope Enrichment and Distribution

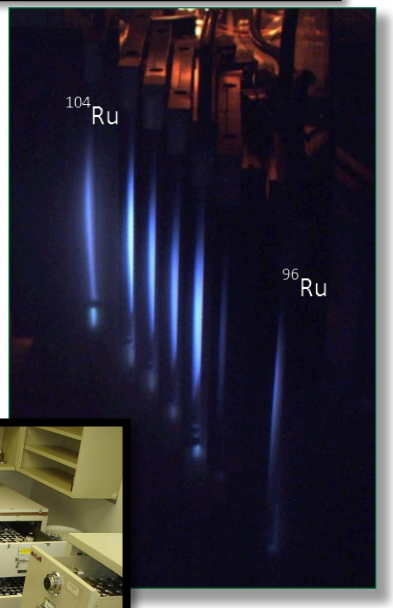
- Isotope Program manages the Nation's inventory of stable isotopes

- Have re-established enriched stable isotope production in the United States – ESIPP - 2017
  - Electromagnetic separation and gas centrifuge
  - Production started 2017 – 500 g of Ru-96 for RHIC
  - Xe-129, Mo-98, Mo-100, Yb-76

- Stable Isotope Production Facility MIE - ongoing
  - Leveraged by NNSA
  - Kg through put capability
  - Basic research, applications, industry
  - Quantum Information Science

- National Stable Isotope Facility
  - CD-0 Approved January 4, 2019
  - $150 – 200M TPC
  - Additional EMIS and gas centrifuge capability





Actinium-225 Tri-Laboratory Effort

High-Level Statistics:

- To date production yield ~1800 mCi of Ac-225
- Routinely achieve production yields of >120 mCi (decay corrected to EOB)
- Single experiment yield record by the team is approximately 200mCi at EOB so far…
- Demonstrated the capability to isolate ~50mCi from processing of single batch

Thorium Target Material and De-bulking Strategy:

- Target is 11g or 20g of Th-232 depending on where activation occurs
  - BNL = 11g targets
  - LANL = 20g targets
- Current de-bulking and processing strategy uses ion-exchange resins
- Preliminary data using alternative solvent systems is promising

Stage two deliverables are on track and logistics are being worked out:

- Currently approved to use a Special Form Capsule for shipments of irradiated targets
- Working with a vendor on a Type B cask

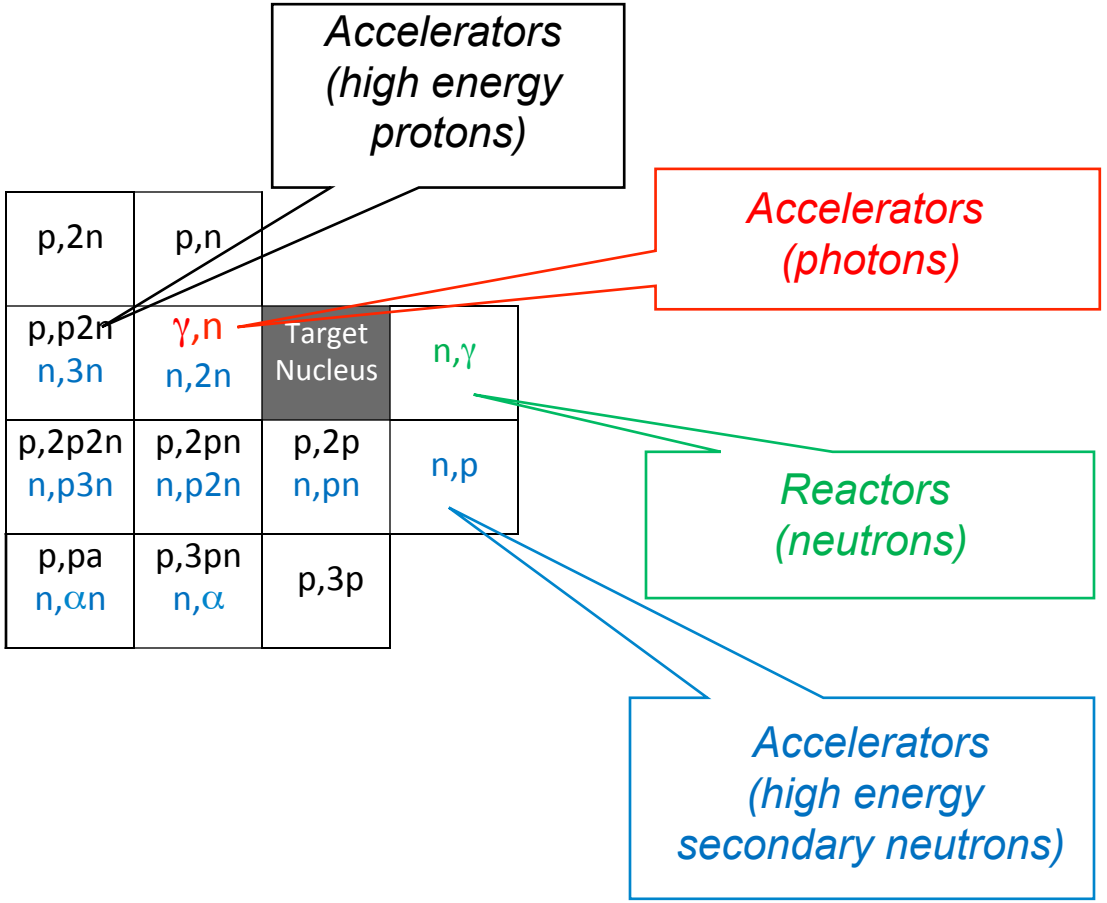
Support of Nuclear Data Applications

- Np-236 is a highly desirable isotope within the National Technical Nuclear Forensics Center.
- An R&D investment by the DOE Isotope Program in FY14 allowed collaborative research specifically aimed at developing production technologies using proton bombardment of uranium targets at the Los Alamos Isotope Production Facility (IPF) and deuteron bombardment at the University of Washington cyclotron facility.
- Initial methods chosen were ineffective as cross sectional information and optimal target material were not available.
- In FY18 the DOE Isotope Program initiated support for a 36 month collaborative nuclear data effort between LANL and LBNL to improve the cross sectional information on uranium to enable experiments to produce Np-236.

- There is a lack of nuclear data related to phototransmutation reactions.
- An R&D investment by the DOE Isotope Program in FY17 allowed collaborative research between Argonne National Lab and researchers at TUNEL's HIGS facility specifically aimed at the development of a library of phototransmutation based nuclear data

Cross Section Needs Are Extensive

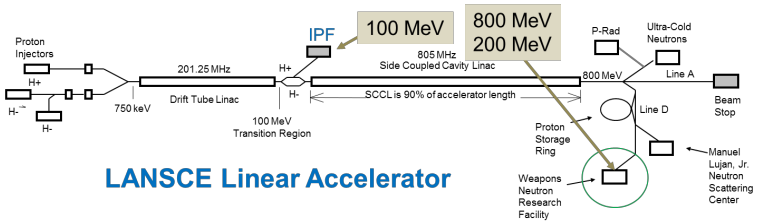
- **Cross sections for reactor production**
  - **Effective cross sections**
  - **Excitation functions**
- **Energy resolved cross sections for accelerator production with**
  - **High energy protons**
  - **High energy neutrons**
  - **Photons**



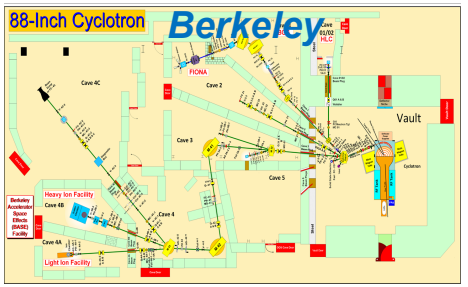
Nuclear Data Initiative

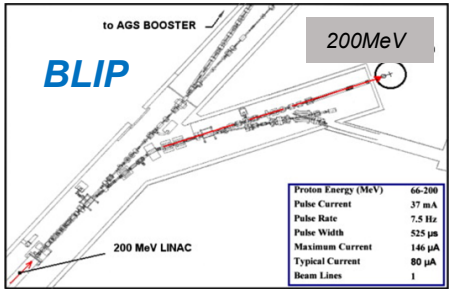
Expanding measurement capability to multiple facilities to better cover proton energy ranges up to 200 MeV

- **Berkeley (<60 MeV) - includes Faraday cup style chamber for monitor reaction measurements**
- **LANL – IPF (40-100 MeV) – includes new low beam current measurement capability for monitor reaction measurements (100 nA with 1% accuracy)**
- **BNL – BLIP (100-200 MeV)**



LANSCE Linear Accelerator





Recent and Ongoing Measurements

High Energy Protons

- Th+p for production of therapy isotopes ^{225}Ac, ^{227}Th and ^{223}Ra
- ^{nat}Sb,^{121}Sb+p for production of ^{119}Te/^{119}Sb, a promising Auger e-emitter for therapy
- La+p for production of ^{134}Ce/^{134}La (PET analogues for ^{225}Ac and ^{227}Th)
- Fe+p, Cu+p for production ^{52g}Mn, ^{54}Mn, ^{48}Cr, ^{55}Co, ^{58m}Co, ^{57}Ni
- Nb+p for ^{93}Nb(p,4n)^{90}Mo as monitor reaction
- As+p for production of ^{72}Se – generator for ^{72}As (PET imaging isotope of the ^{72}As/ ^{77}As theranostic pair)

High Energy Neutrons

- Production of ^{193m}Pt, ^{64}Cu/^{67}Cu, ^{47}Sc, ^{77}As via (n,p)

Photonuclear

- ^{48}Ti(γ,p)^{47}Sc, ^{196}Pt(γ,n)^{195m}Pt

Low energies

- ^{232}Th(p,x)^{229}Th for production of ^{229}Th/ ^{225}Ac
- ^{238}U(p,xn) and ^{235}U(d,xn)$^{235\text{-}237}$Np for Production of ^{236g}Np

Vision for a Nuclear Data Effort Within the DOE Isotope Program

- DOE Isotope Program is unique in its relationship with nuclear data.
- Charged particle induced nuclear data is often in discrepant, missing, or just plain old.
- Everyone benefits when data sets are improved.
- Creation of an ENDEF like library for charged particle induced reactions.
  - Ideally stemming from an evaluation effort for reactions in similar mass regions.
  - Would allow for more effective predictive modeling for optimized targetry.

Summary

- DOE IP has and will continue to have significant nuclear data needs requiring investment from it's R&D portfolio.
- Our investments will have a direct impact on the products and services that we are able to provide.
- If you have target material needs (i.e. stable or radioisotopes) please contact either your federal program manager, the NIDC for a quote, or me for further discussion.
- Come to the Isotope Production breakout session tomorrow for more information.


Thank You!

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
- At-211: Funding production development at multiple sites 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, radioanalysis
- 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; 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 and heavy element chemistry research
- He-3: MRI imaging of lung function for pediatric apps; strict government controls mitigated shortage
- Heavy water: PET imaging instrumentation; 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; therapeutic apps
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-228:	Recovered from Ac-227 production to supply Ra-224 for Pb-212/Bi-212 generators
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

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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
- Co-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: PET diagnostic applications
- Nb-90: PET diagnostic applications
- Np-236/Pu-236: Ongoing R&D for accelerator-based production for 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; theranostic medical applications
- Se-72: Accelerator production for Se-72/As-72 generator
- Sc-47: Exploring accelerator production; theranostic medical applications
- Si-28: Considering EMIS and centrifuge production 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
- Yb-176: Stable production capability for production of Lu-177 (HSA)
- Zn-62/Cu-62: Funding production development for generators for medical diagnostic imaging applications