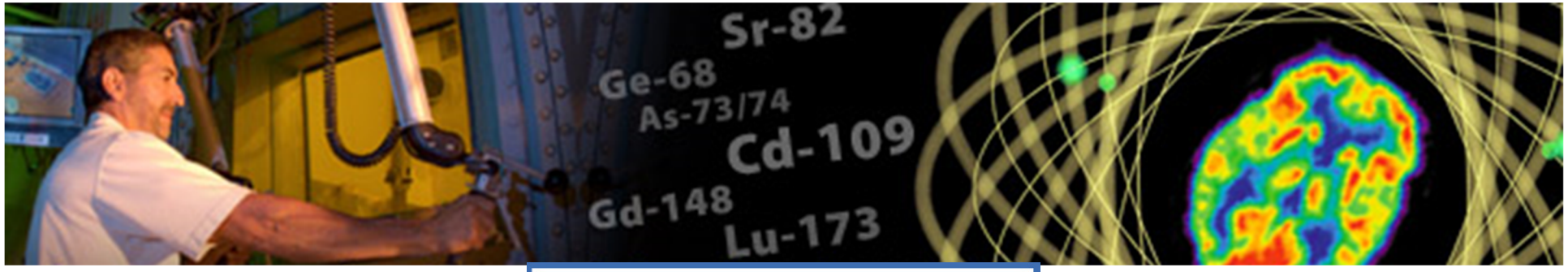
U.S. DEPARTMENT OF ENERGY | Office of Science

# The DOE Isotope Program: Accelerator Production of Isotopes

**Arne Freyberger**
**Program Manager for Accelerator Isotope Facilities**
in lieu of Marc Garland
on behalf of the
DOE Isotope Program
Office of Nuclear Physics, Office of Science
Department of Energy




NAPAC2019

# DOE Office of Science Policy on Diversity and Inclusion

The DOE **Office of Science** (SC) is fully committed to fostering **safe, diverse, equitable, and inclusive work, research, and funding environments that value mutual respect and personal integrity.** Effective stewardship and promotion of diverse and inclusive workplaces that value and celebrate a diversity of people, ideas, cultures, and educational backgrounds is foundational to delivering on the SC mission. The scientific community engaged in SC-sponsored activities is expected to be respectful, ethical, and professional.

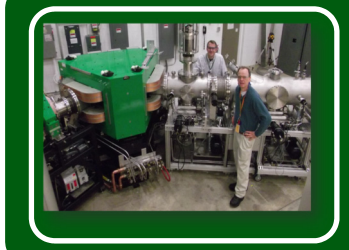
The DOE SC does not tolerate discrimination or harassment of any kind, including sexual or non-sexual harassment, bullying, intimidation, violence, threats of violence, retaliation, or other disruptive behavior in the federal workplace, including DOE field site offices, or at national laboratories, scientific user facilities, academic institutions, other institutions that we fund, or other locations where activities that we support are carried out.

The DOE has long-standing policies and procedures for the prevention of discrimination and harassment. SC has established this site to make those policies and procedures more accessible to the scientific community and the institutions that receive DOE SC funding, as well as to clearly communicate SC's commitment to diversity, equity, and inclusion.

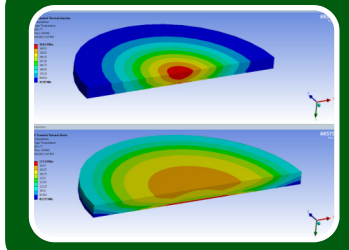
As SC continues to identify opportunities to improve our policies, practices, and communications to advance diversity, equity, and inclusion in furtherance of our core values and mission, updated policies, procedures, and resources will be posted here on an ongoing basis.

# 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

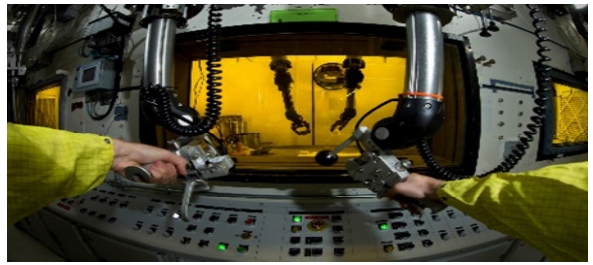


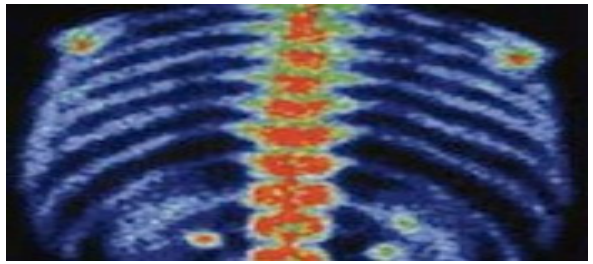
Conduct R&D on new and improved isotope production and processing techniques which can make available priority isotopes for research and application.  Develop workforce.

**Reduce U.S. dependency on foreign supply**

# Isotope Program Authority, Resources, Goals

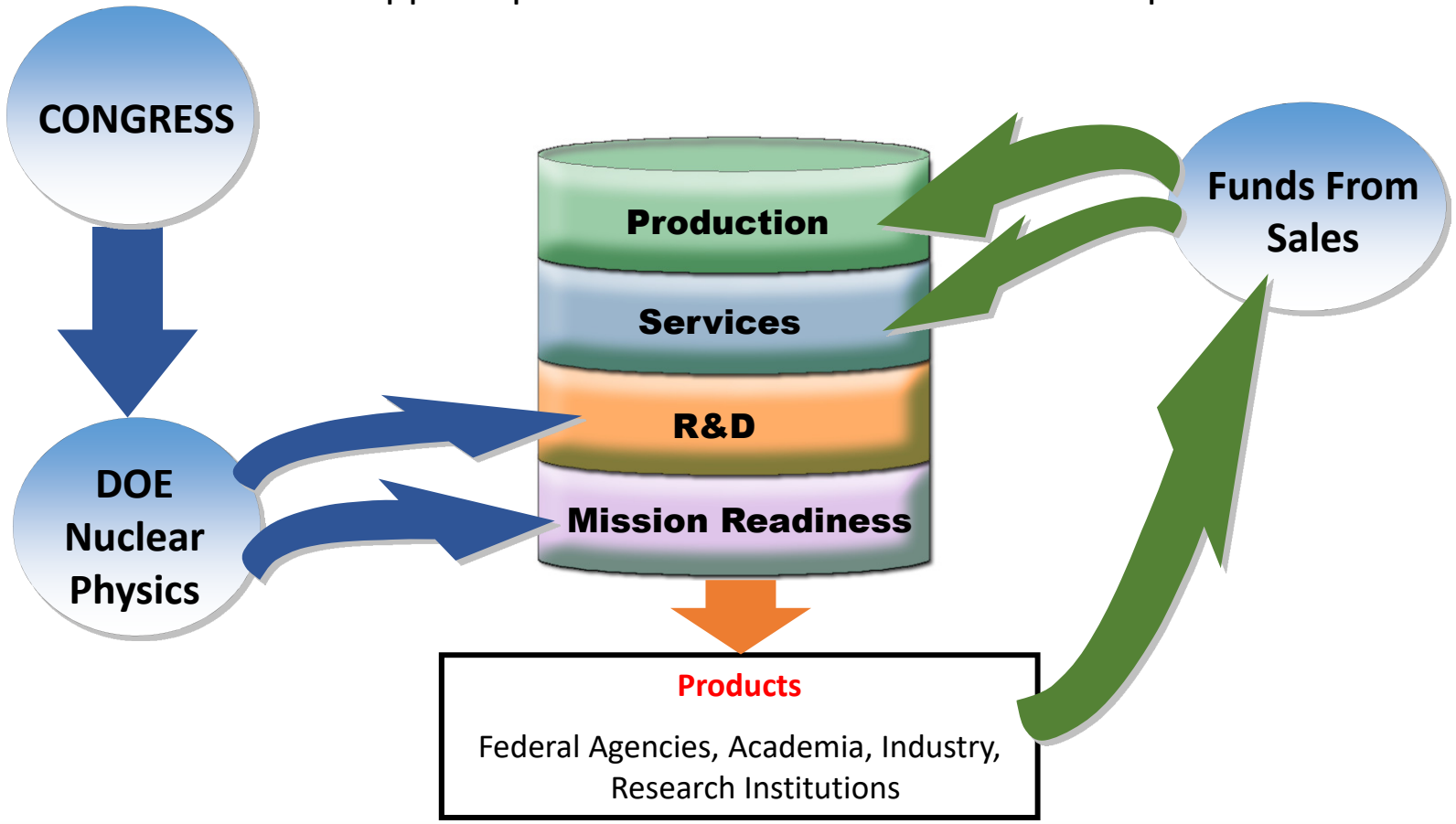
- Isotope Program in DOE has sole authority to produce isotopes for sale and distribution – labs may not embark on isotope production on their own.
- Public Law 101-101 (1990), as modified by Public Law 103-316 (1995) created the Isotope Production and Distribution Program Fund (called a revolving fund) and allows prices charged to be based on costs of production, market value, U.S. research needs and other factors.
  - **Commercial isotopes at full-cost recovery; research isotopes at reduced prices.**
- 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**
- **DOE IP not responsible for Mo-99 (NNSA), Pu-238 (NE) and SNM for weapons (NNSA)**



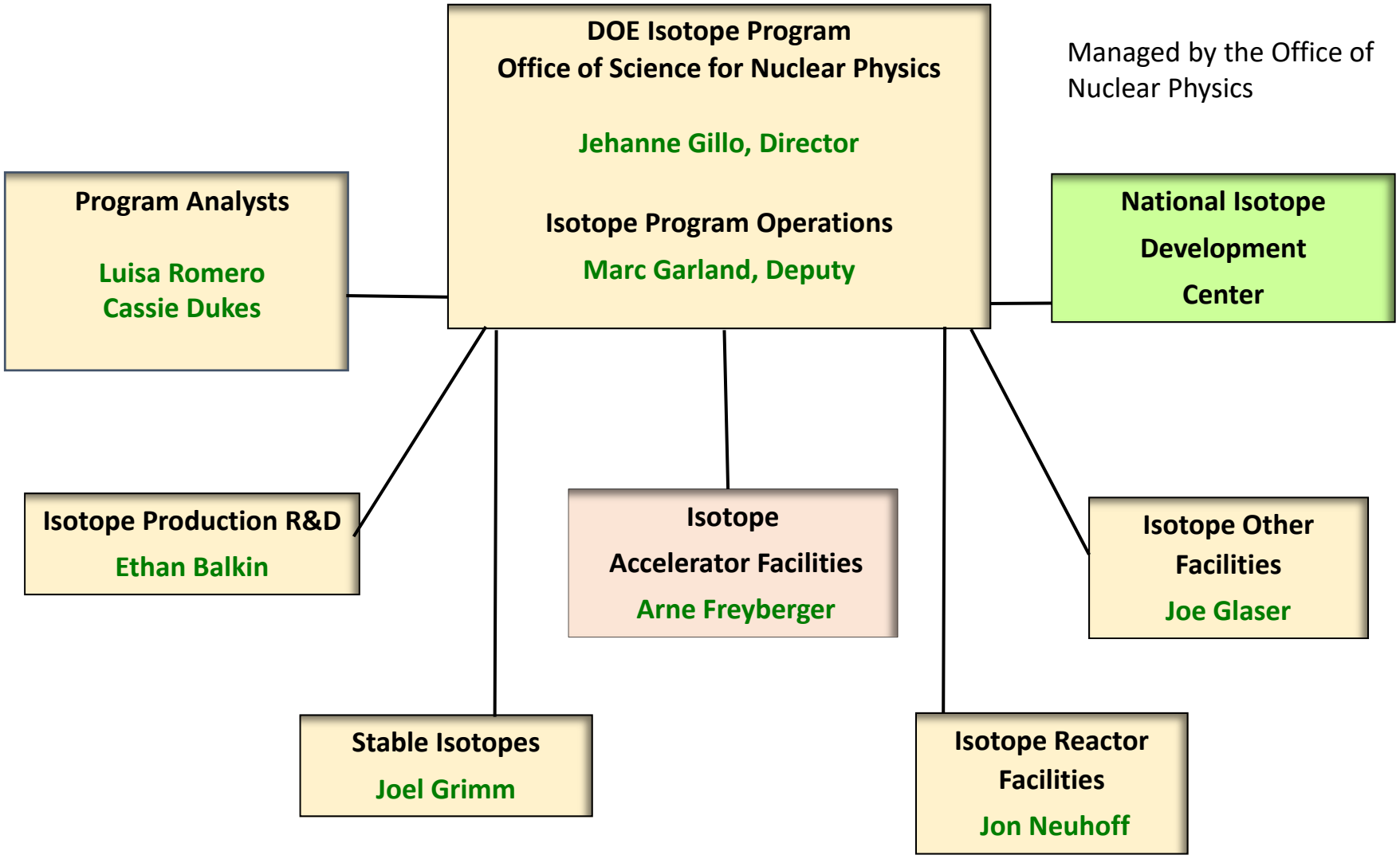


# Isotope Program Resources

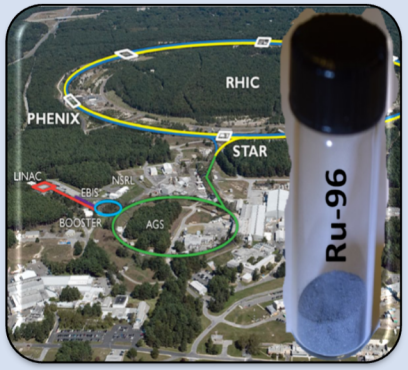
- Isotope Program operates under a **revolving fund** and is audited annually.
- Program costs are financed by two resources: **appropriation and revenue**.
  - Appropriation supports mission readiness and R&D program
  - Revenue supports production and distribution of isotope

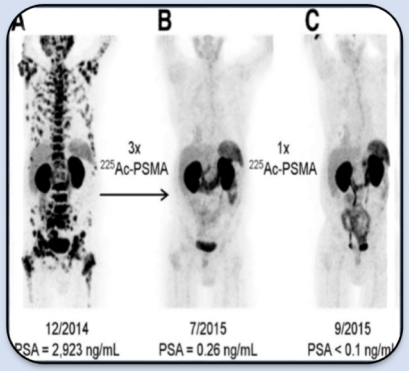


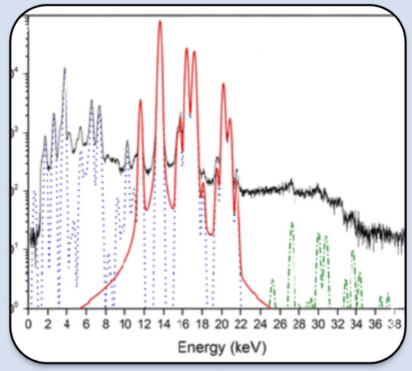
# DOE Isotope Program Organization



# Applications of Isotopes




## Basic Research

- Physics
  - Super Heavy Elements
  - Nuclear Physics
- Environment
- Materials
- Agriculture
- Analytical Chemistry
- Geosciences

## Medicine

- Therapies
- Imaging/Diagnostics
- Research
- Dental

## Industry

- Standards
- Inspections
- Testing
- Sources
- Nuclear Data
- Forensics

## National Security

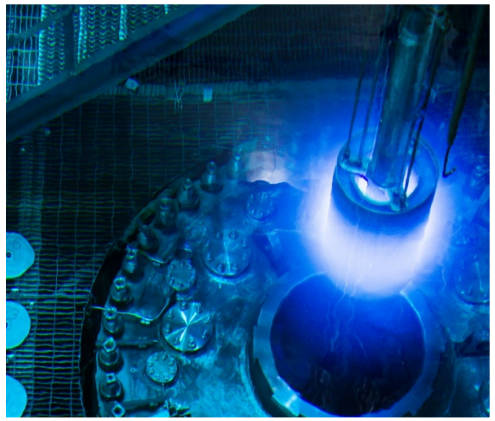
- Communication
- Detection
- Nuclear Data
- Global Positioning
- Sources

# 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](http://www.isotopes.gov)

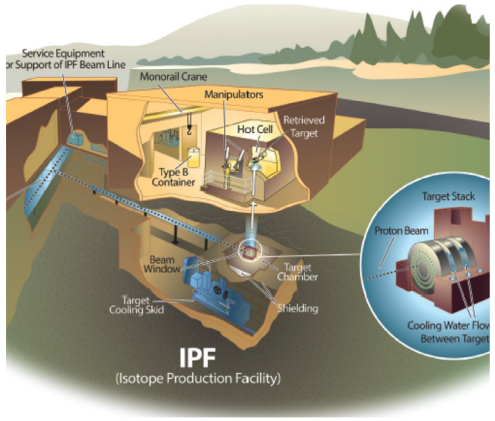
# Isotope Production Triad

## Reactors



- Neutron capture of thermal neutrons
- Isotope production ~ neutron flux: High flux reactor
- $^{226}Ra + 3n => {}^{229}Ra => \beta^- {}^{229}Ac => \beta^- {}^{229}Th$

## Accelerators




MeV'ish proton, deuteron, $\alpha$, electron beams

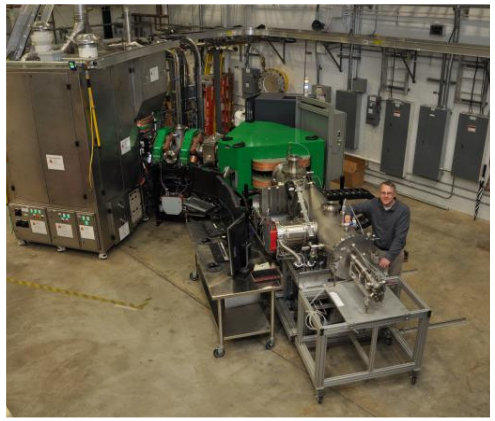
Cyclotrons, linac, …

Up to 100 kW average power

(p,2n), ($\gamma$,p), ($\alpha$,2n)

high energy neutrons

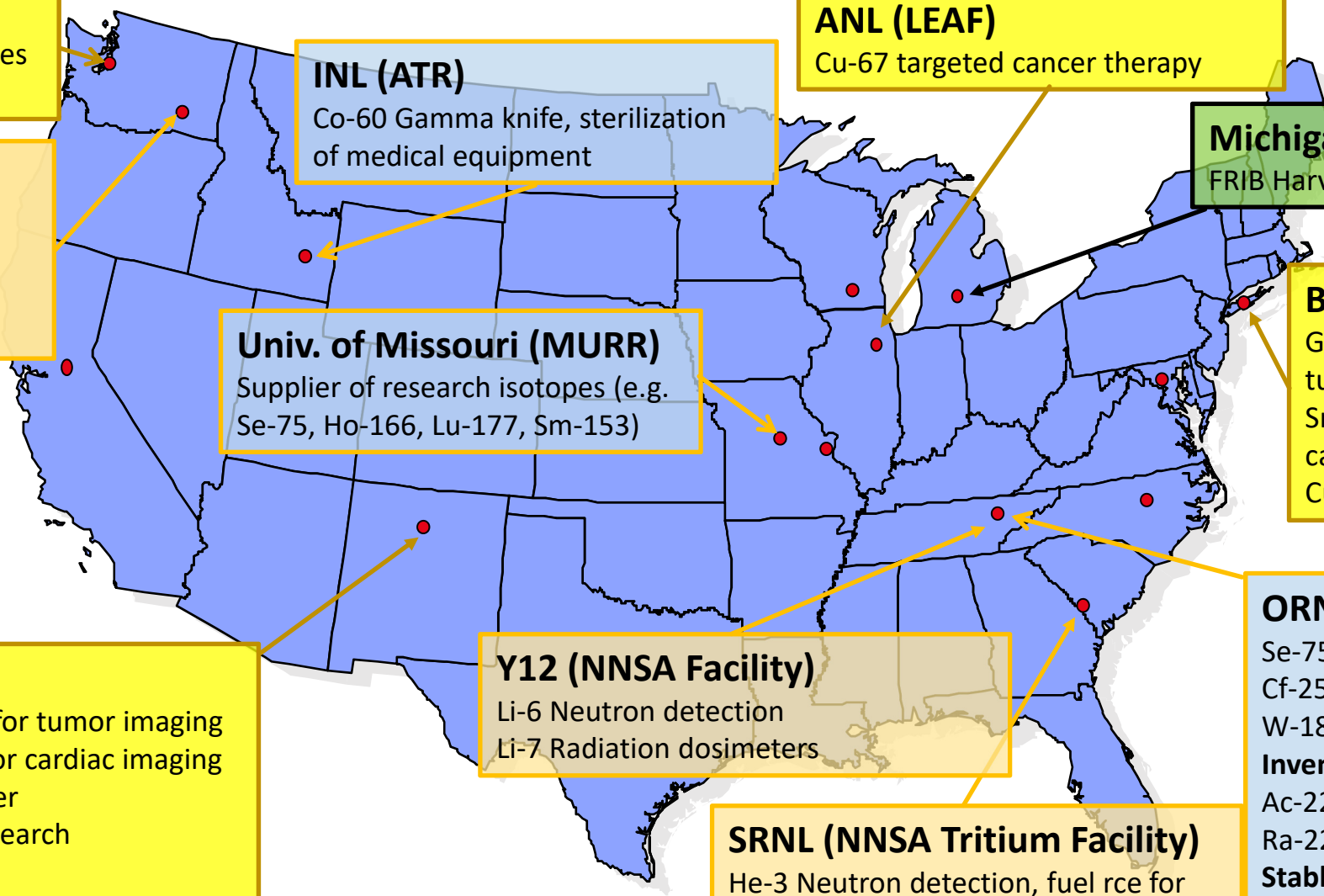
## Separation



Electromagnetic and centrifugal

Rare stable and long-lived isotopes enriched from source material (natural, residual waste)

# DOE-IP Isotope Production Sites



**Univ. of Washington**
Supplier of research isotopes (e.g. At-211)

**PNNL**
Sr-90 Y-90 Generator for cancer therapy
Ra-223 Cancer therapy
Np-237 Research

**INL (ATR)**
Co-60 Gamma knife, sterilization of medical equipment

**ANL (LEAF)**
Cu-67 targeted cancer therapy

**Michigan State U. (FRIB)**
FRIB Harvesting under development

**Univ. of Missouri (MURR)**
Supplier of research isotopes (e.g. Se-75, Ho-166, Lu-177, Sm-153)

**BNL (BLIP/MIRP)**
Ge-68 Ga-68 generator for tumor imaging
Sr-82 Rb-82 generator for cardiac imaging
Cu-67 targeted cancer therapy

**LANL (IPF)**
Ge-68 Ga-68 generator for tumor imaging
Sr-82 Rb-82 generator for cardiac imaging
As-73 Environment tracer
Si-32 Oceanographic research
Ac-225 development

**Y12 (NNSA Facility)**
Li-6 Neutron detection
Li-7 Radiation dosimeters

**SRNL (NNSA Tritium Facility)**
He-3 Neutron detection, fuel rce for fusion reactors, Lung testing.

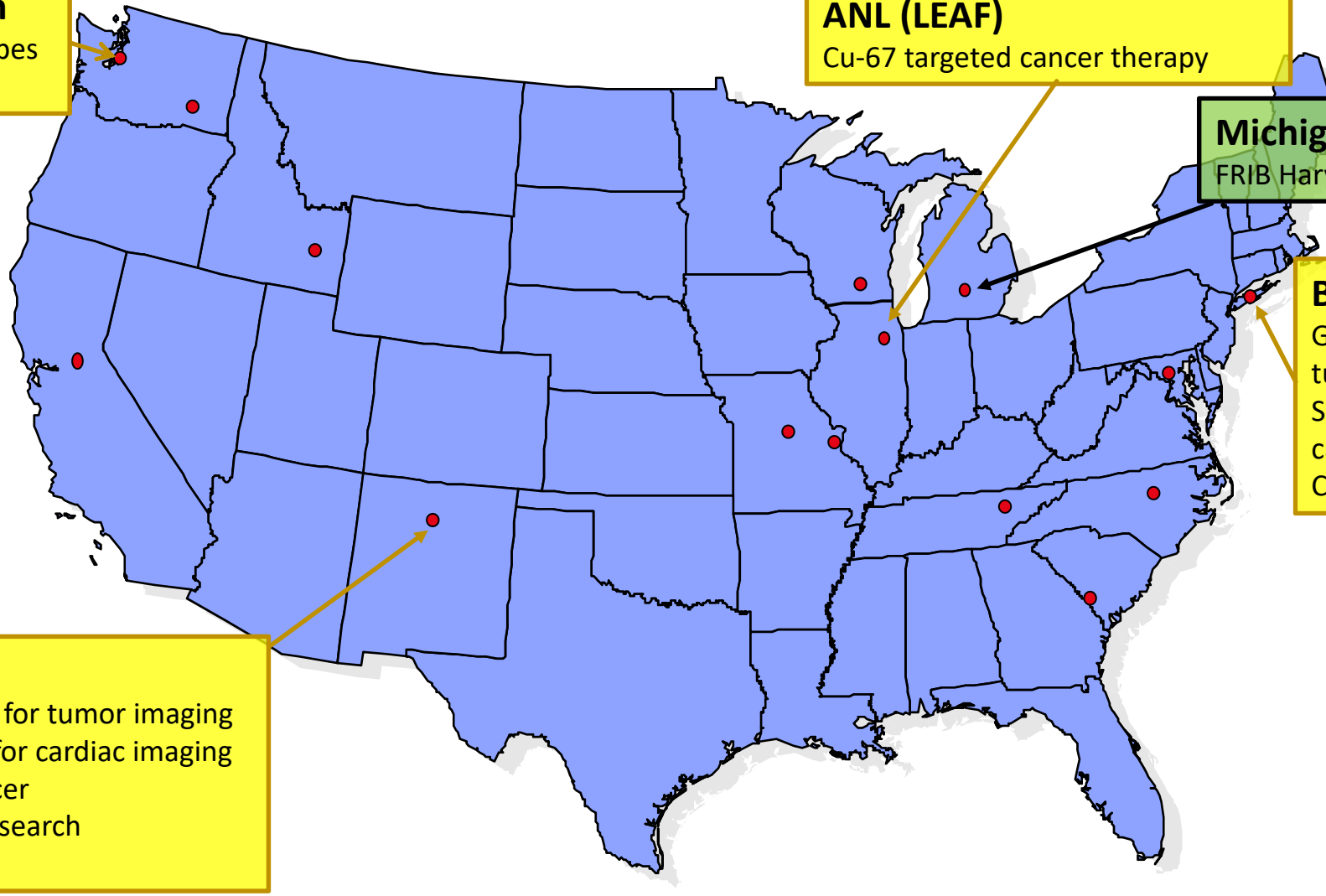
**ORNL (HFIR)**
Se-75 Industrial NDA
Cf-252 Industrial Sources
W-188 Cancer therapy
**Inventory:**
Ac-225 Cancer therapy
Ra-223 Cancer therapy
**Stable Isotope Inventory**:
Ca-40, Ga-69, Rb-87, Cl-37…

# DOE-IP Isotope Production Sites (Accelerators)

**Univ. of Washington**
Supplier of research isotopes
(e.g. At-211)

**ANL (LEAF)**
Cu-67 targeted cancer therapy

**Michigan State U. (FRIB)**
FRIB Harvesting under development



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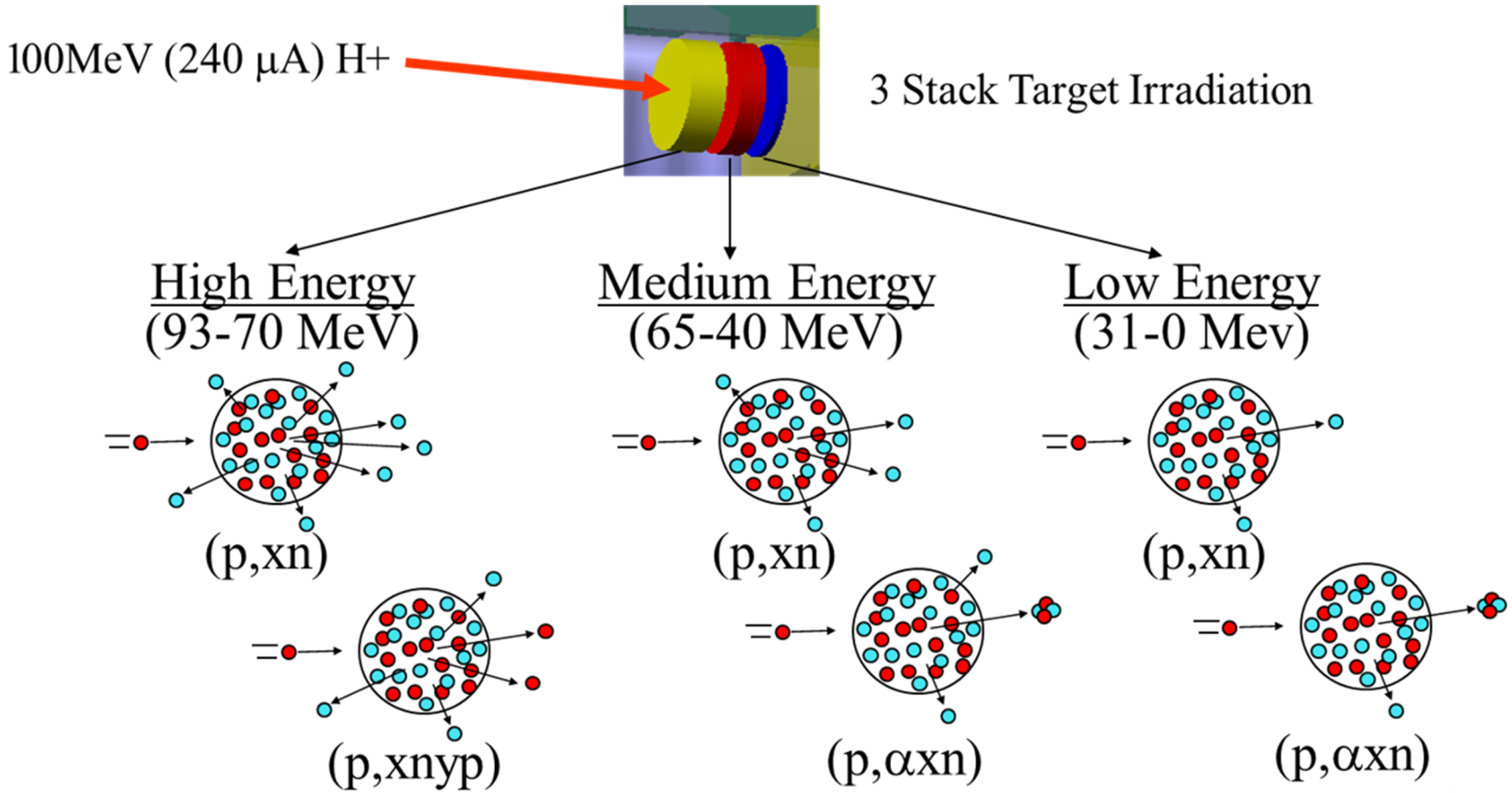
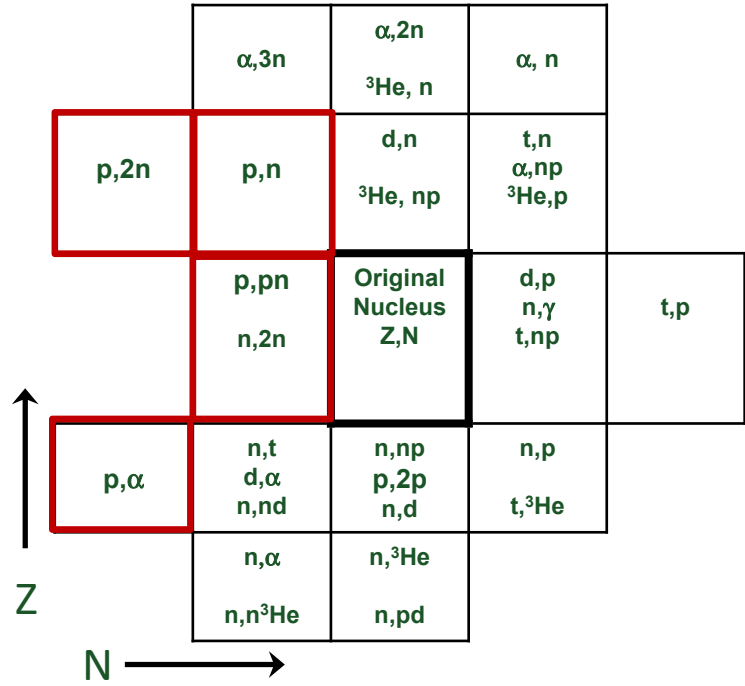
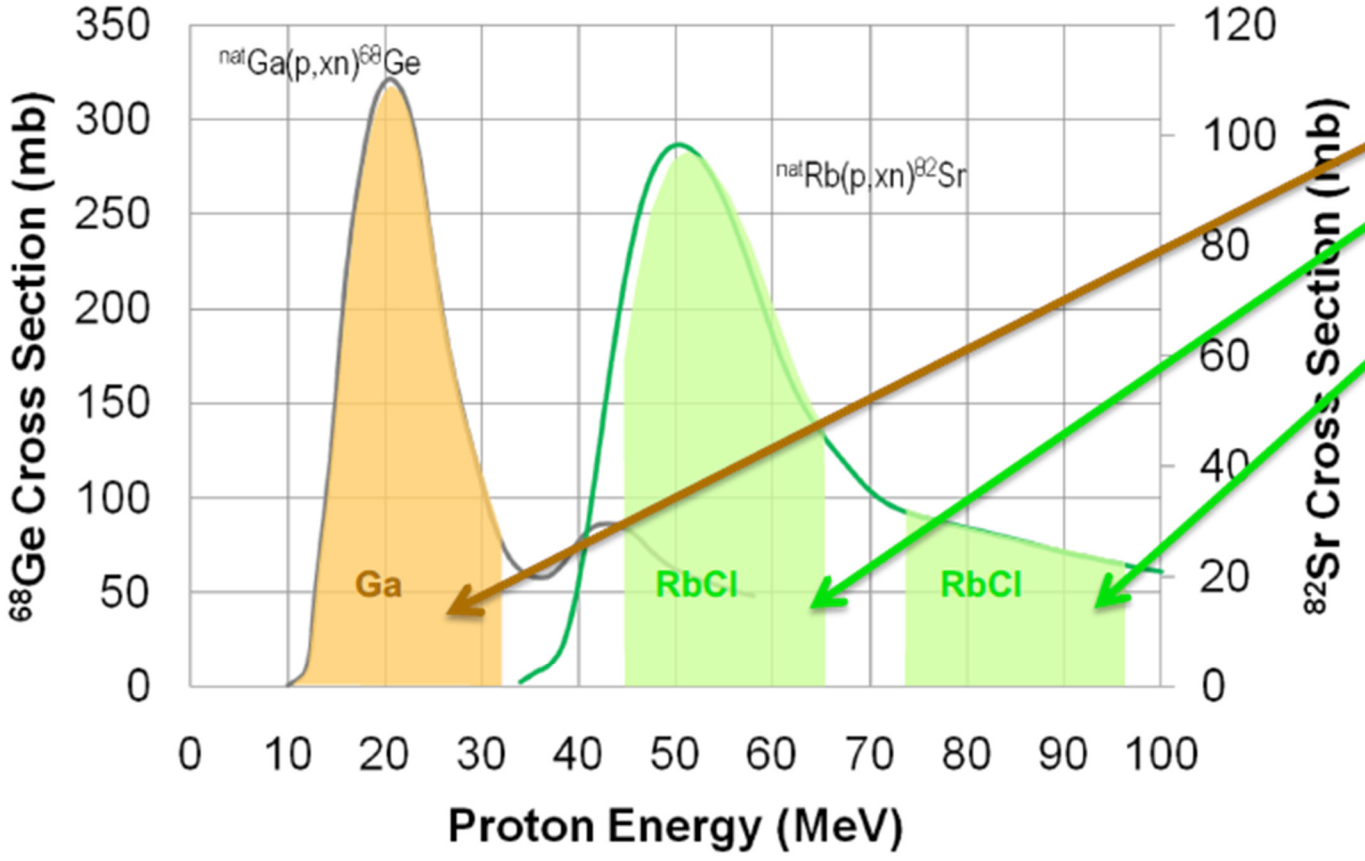
# Accelerator Production of Isotopes

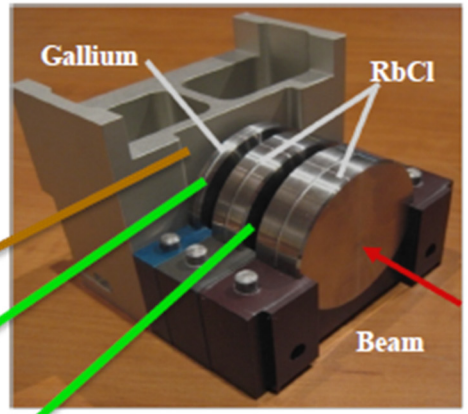



n = neutron
p = proton (H)
d = deuteron ($^2$H; [pn])
t = triton ($^3$H); [p2n]
$^3$He = [2pn]
α= alpha particle ($^4$He); [2p2n]

# Accelerator Production of Isotopes




Three different target *slots*:

- A-slot high energy
- B-slot medium energy
- C-slot low energy

Additional configurations have a “n-slot” after the C-slot for high energy neutron interactions

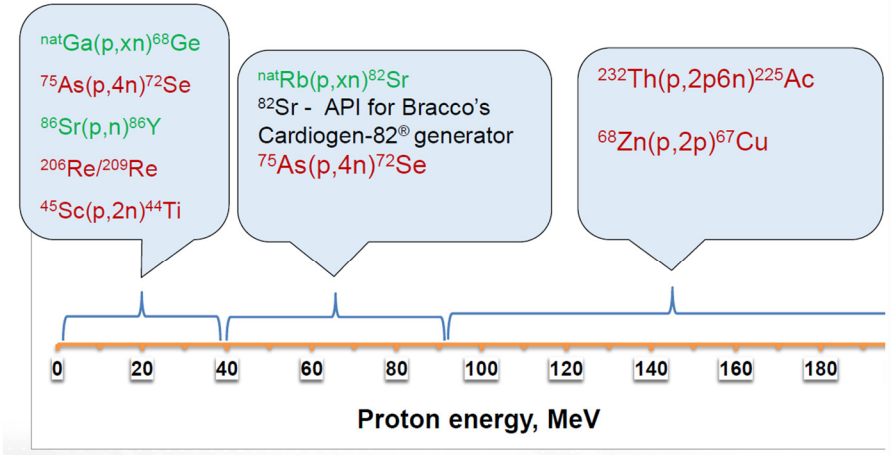
# Isotope Program Accelerator Facilities

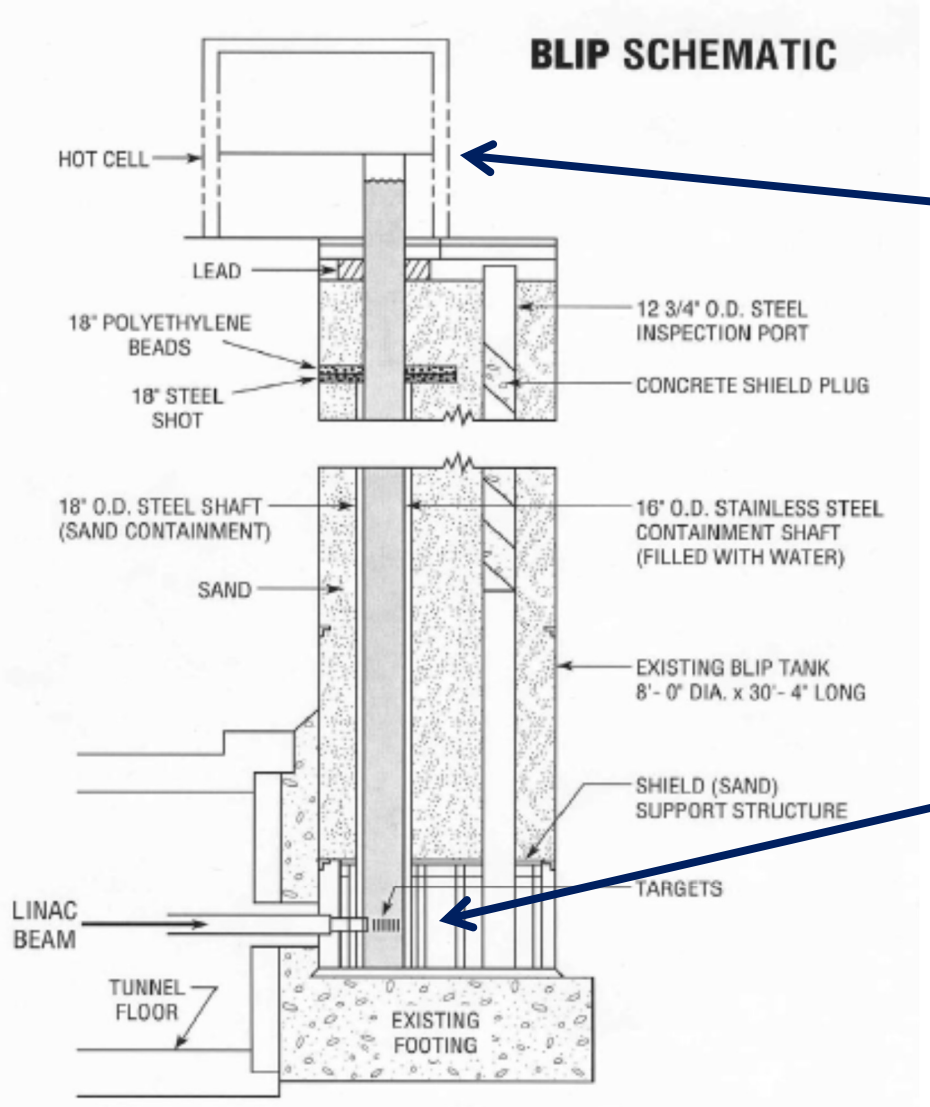
Update with new numbers.
Add LEAF? UW?

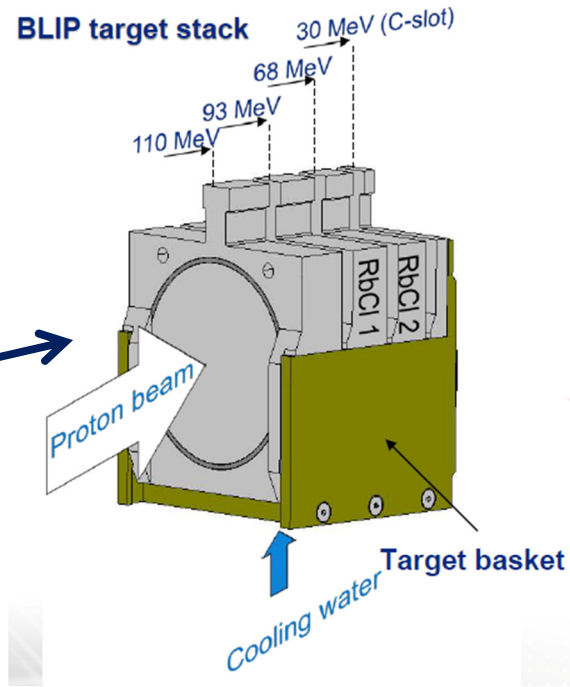
| | BLIP | IPF | LEAF | U. Of Washington |
|---|---|---|---|---|
| Species | Proton | Proton | Electron | Proton, deuteron, a |
| Energy (MeV) | 66, 117,160,180,200 | 100 | 20-50 | 6-12, 28-50.5 p+ 27-47.3 a |
| Pulse Rate (Hz) | 6.67 | 30 | 1-240 | 60 |
| Pulse Peak Current (mA) | 55,000 | 13,300 | 10,000 (@ 50 MeV) | |
| Average Current (mA) | 170 | 250 | 13 (@ 50 MeV) | Up to 75 |
| Average Beam Power (kW) Limit | 34 (at 201 MeV) | 25 | 0.6 (@ 50 MeV) | Up to 4 |
| Transverse size on target | 12.5 mm diameter, raster | Adjustable collimator/raster | | mm |

# BLIP/MIRP and BNL

- 1972 first use of a high energy proton accelerator to produce isotopes
- Runs in parallel with RHIC operations
- 62-200 MeV $p^+$ diverted from the RHIC Booster, into the BLIP transport line
- Cost effective synergistic operation of BLIP & RHIC
- Operate out-of-phase with IPF@LANL for full 12 month coverage



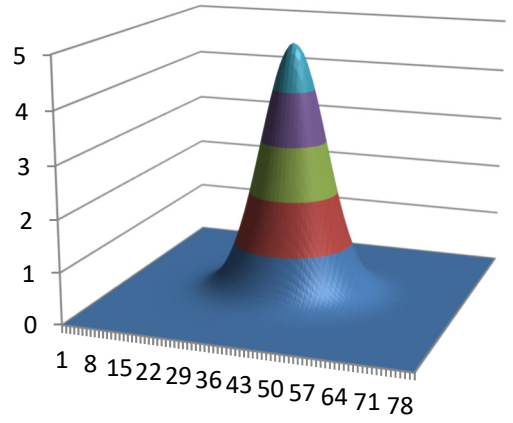



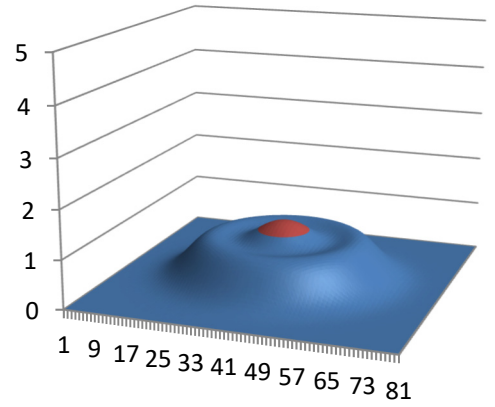
# BLIP/MIRP upgrades

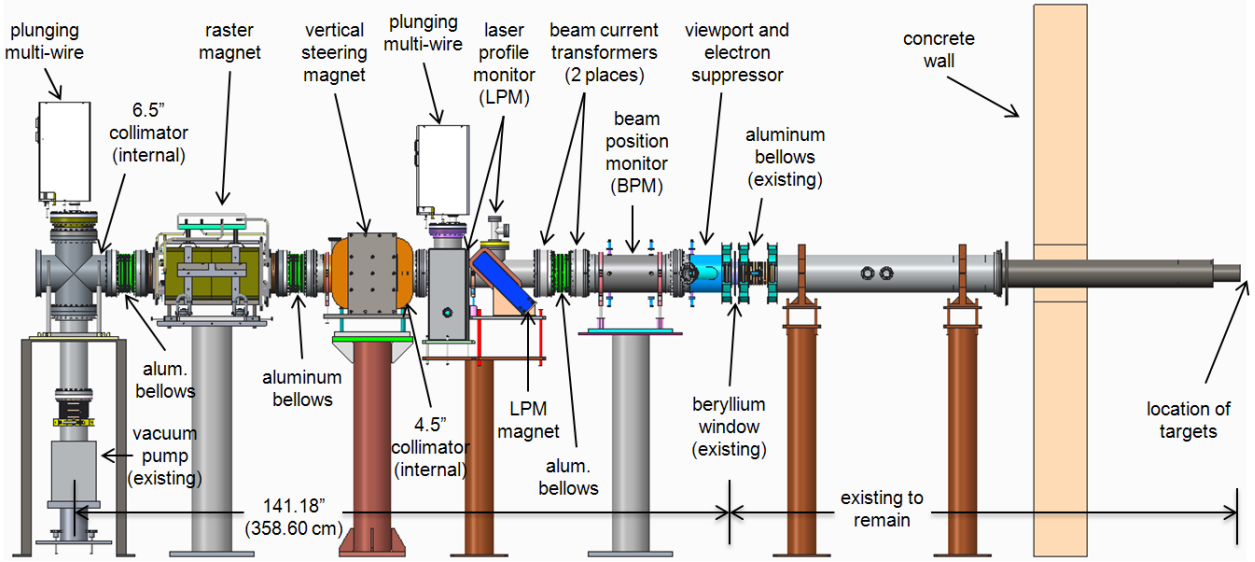
- BLIP beam raster system development
  - Reduction in localized target heating
    - Enables increase in beam current from 100 μA to 165 μA (greater isotope yields)
    - Greatly lowers possibility of target failures
- BNL linac intensity upgrade
  - Phase 1 (Complete) Changes pulse shape to effectively increase current from 125 μA to 165 μA
  - Phase 2 (Proposed)
    Increases current to 250 μA by increasing pulse length
- All Inclusive Isotope Production Facility
  - Refurbish 3 hot-cells
    - Decontaminate
    - Install new instrumentation
  - Enables $^{225}$Ac processing at MIRP

**Unrastered heat profile**



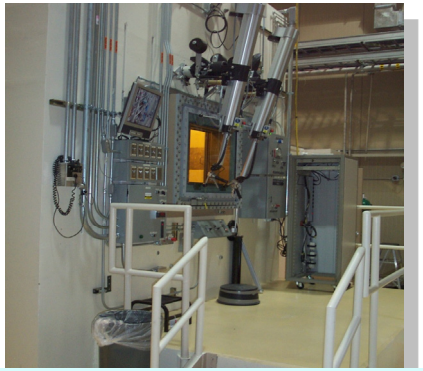

**Rastered heat profile**

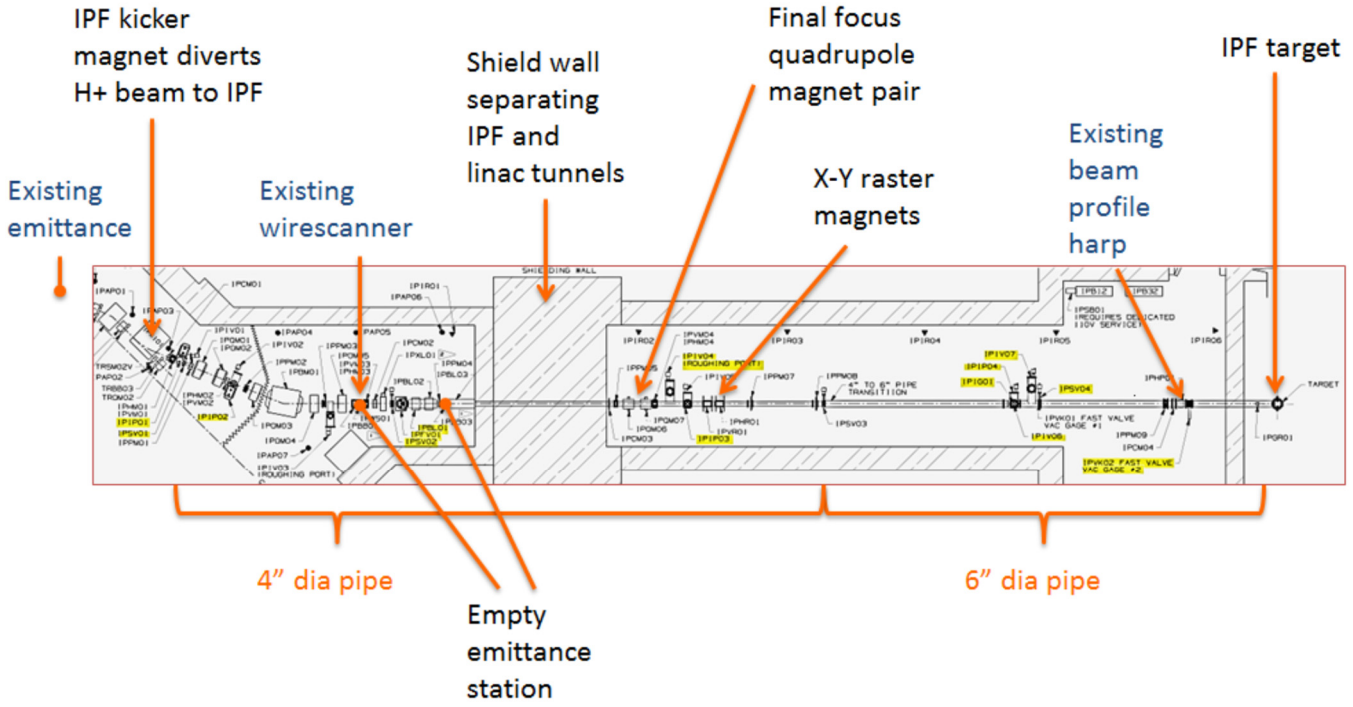


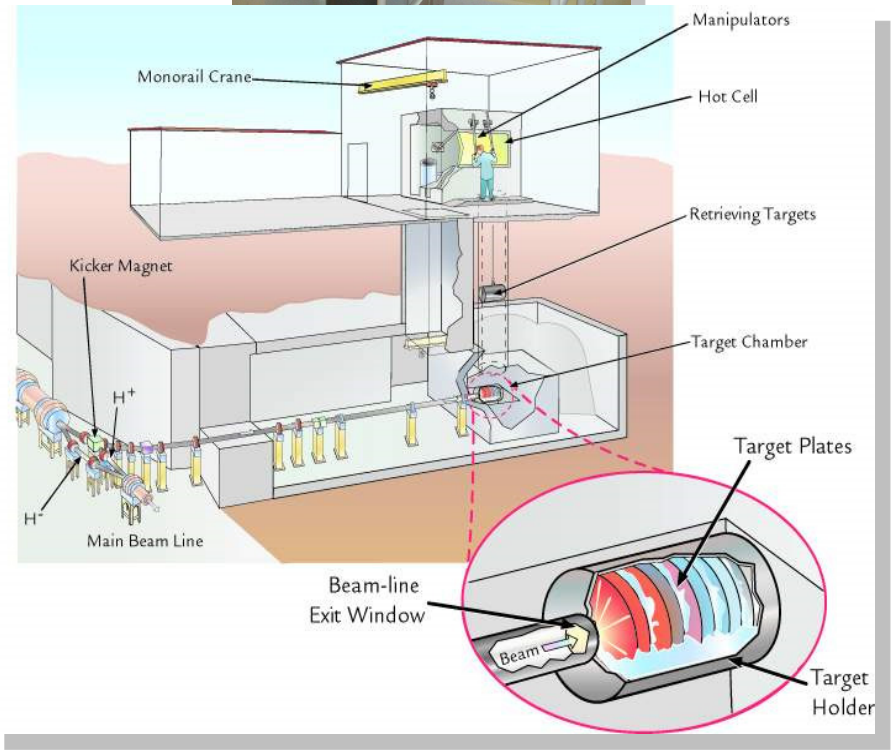



# IPF at LANL

- IPF operations started in 2004
- $H^+$ beam from LANSE injector diverted into IPF transport line
  - IPF is the only user of $H^+$ beams
- Energies up to 100 MeV
- $^{82}Sr$, $^{68}Ge$, $^{22}Na$, $^{73}As$, $^{88}Y$
- Operate out-of-phase with BLIP@BNL for full 12 month coverage

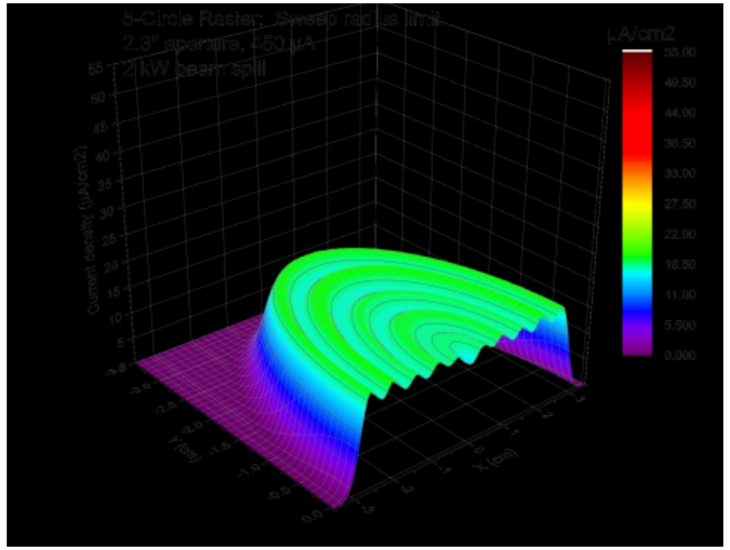


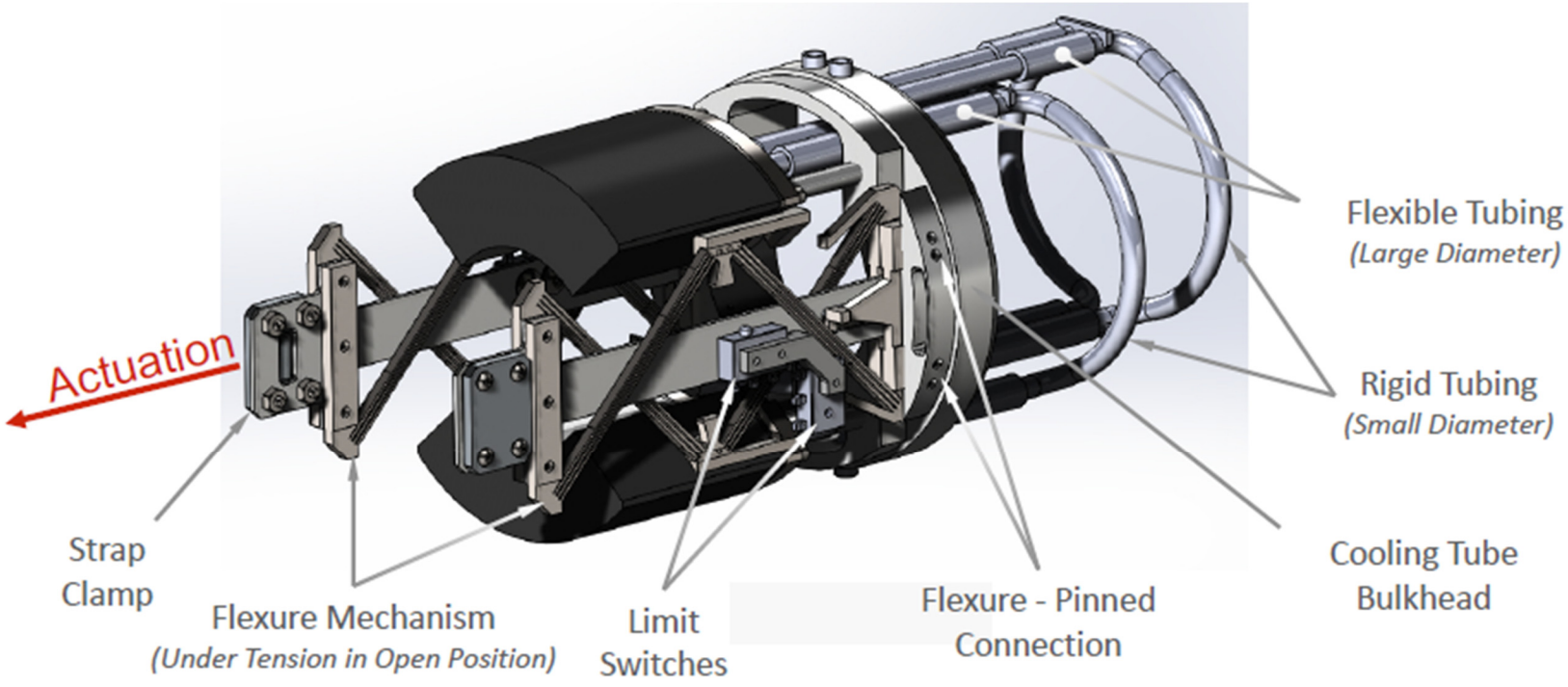


# IPF Upgrades (Adjustable collimator)

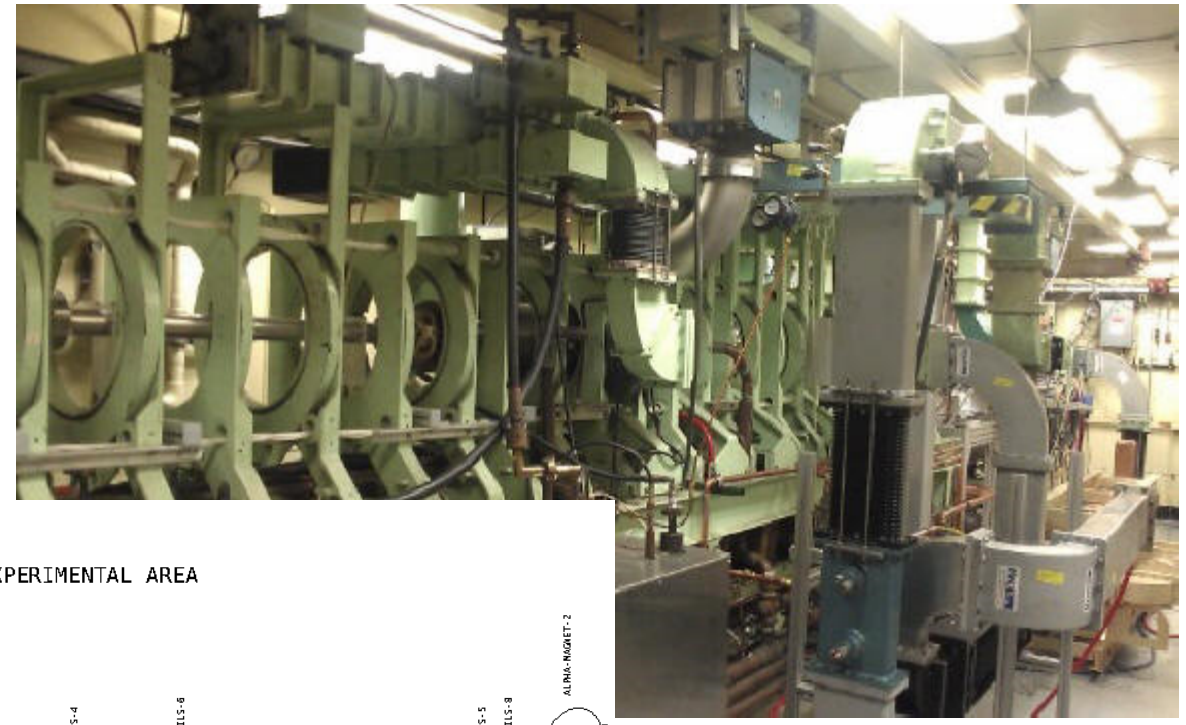
- Water cooled, with simultaneous temperature and current measurement in four independent segments
  - Beam position monitor
- Adjustable aperture
- First in the world; enables multiple target configurations
- New beam raster

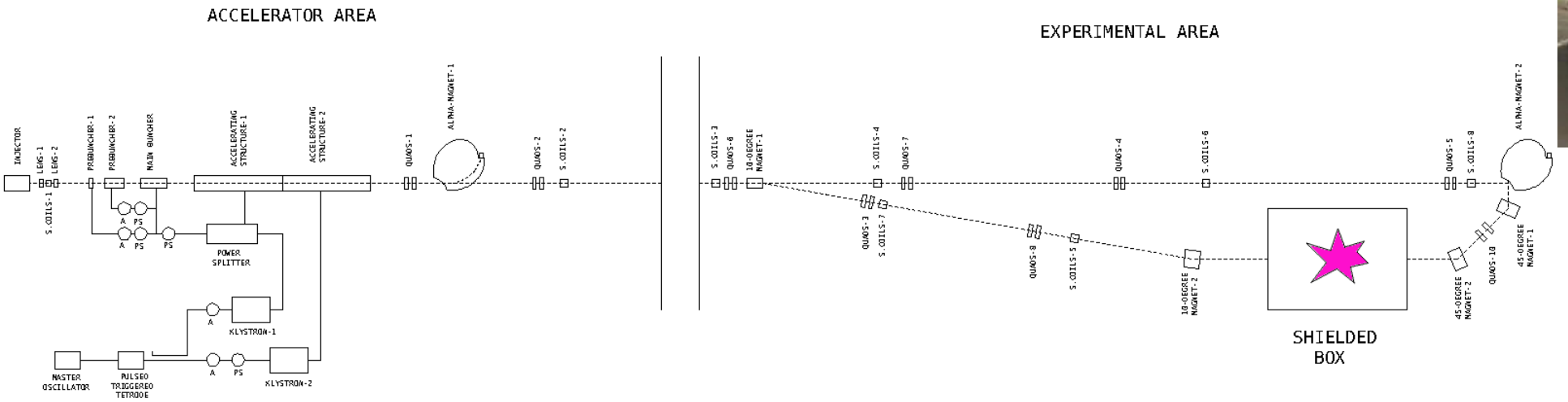


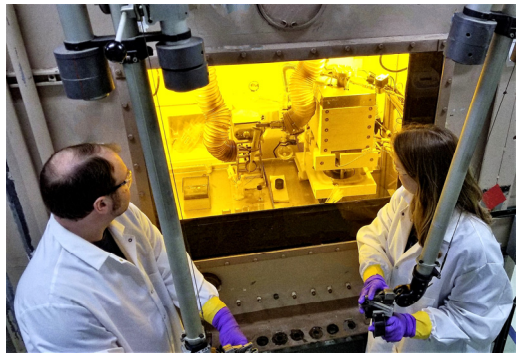



# LEAF at ANL

- Active R&D on isotope production via a bremsstrahlung beam:
  - up to 50 MeV $e^-$ beam incident on radiator -> γ
  - < 1 kW of beam power at 50 MeV
- Developing $^{67}Cu$ for medical research (transitioning to production soon)
  - $^{68}Zn(\gamma,p)^{67}Cu$



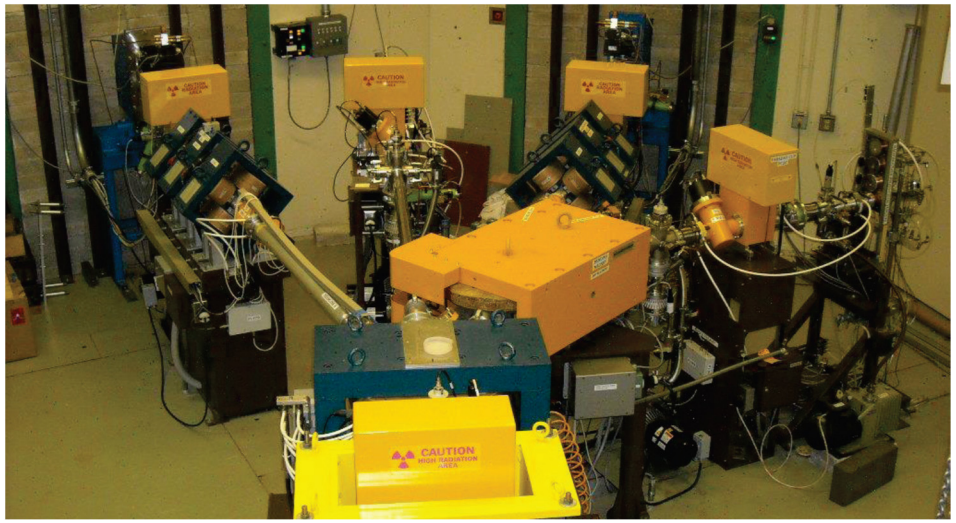


# University Accelerator Facilities

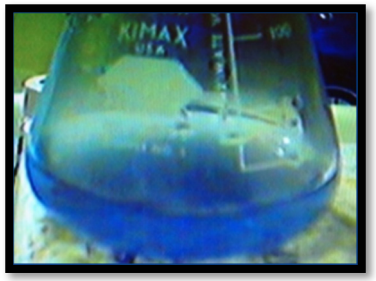
- Unique capabilities and expertise
- Invest R&D and develop capabilities
- Workforce development
- Cost-effective
- Regional networks
  - Enables effectiveness of short-lived isotopes via local production and distribution
- University of Washington; University of Wisconsin; Duke University; Washington University; UC Davis; Texas A&M

- In 2016, University of Washington became part of Isotope Program isotope production network:
  - Cyclotron
  - $^{211}$At production via $\alpha$ beam
- Since 2018, DOE stewarding UW Isotope Capabilities

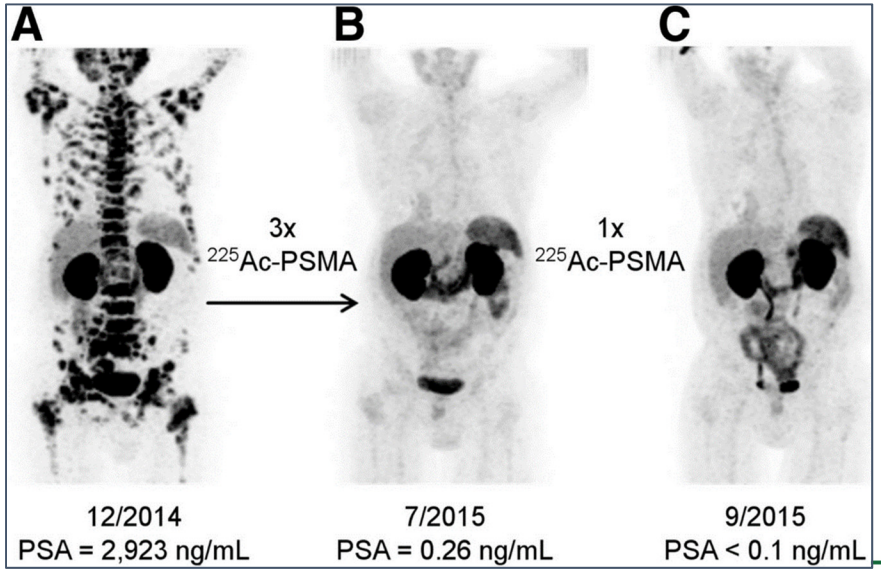


# $^{225}$Ac

- High priority for NIH for decades
- **ORNL extracts $^{225}$Ac from $^{229}$Th recovered from $^{233}$U: 1,200 mCi per year - entire U.S. supply and more than half the worldwide supply.**
- Supply **cannot adequately support** clinical trials or therapy
- IP has developed accelerator production route- full scale production can meet **clinical and therapy demands**
- **Accelerator (BLIP and IPF) production started 2017**







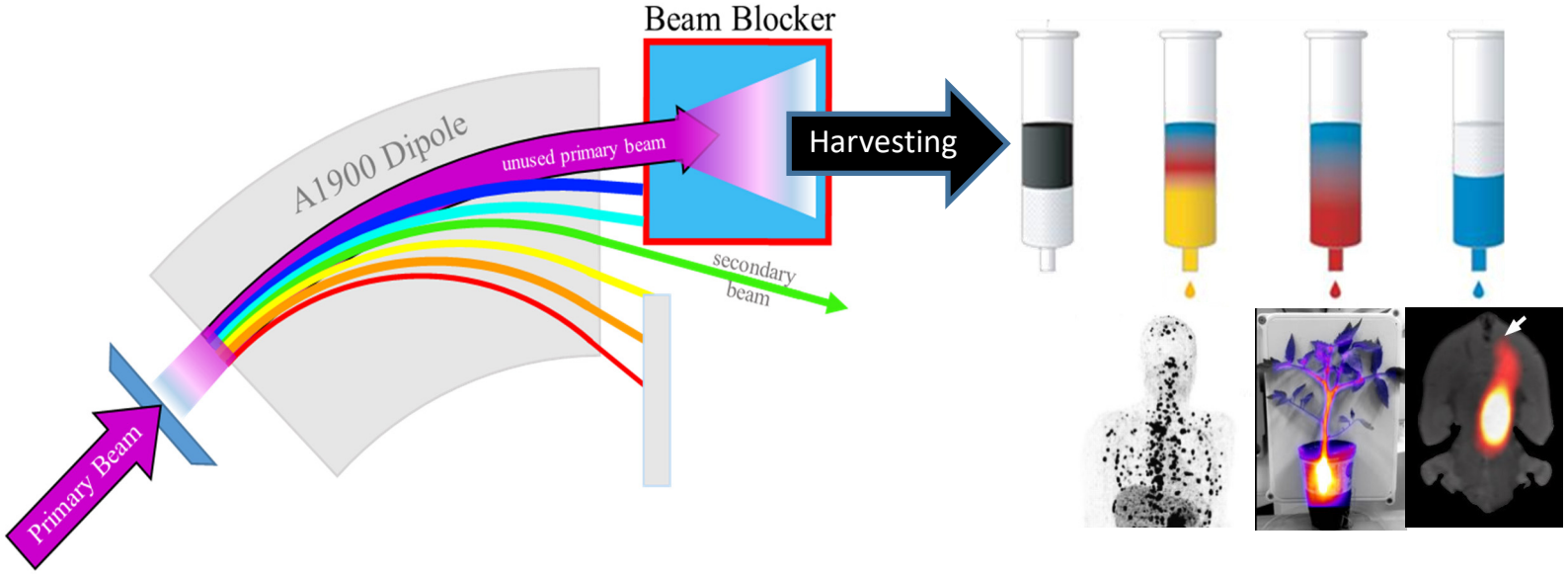

- Completed Stage 1: 5-50mCi/B
- Stage 2: jan 18: 10-100mCi/B ; already 150mCi
- Stage 3: 100-1000mCi/B
- IP strategy includes other production routes
  - reactor production of $^{229}$Th,
  - extraction of $^{229}$Th from legacy $^{233}$U
  - low-energy cyclotron production
  - electron accelerator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

# FRIB Isotope Harvesting

- NSCL-scale beam dump for R&D efforts:
  - Beam dump water purification system is tested and ready for routine use.
  - R&D irradiations and processing have successfully extracted $^{47}$Ca and $^{76}$Kr, parent radionuclides for nuclear medicine generators.
- FRIB beam dump design supports harvesting of isotopes
- Conceptual design complete:
  - Beam dump water and gas processing system
  - Radiochemistry processing hot-cells and infrastructure
- Proposal submitted to DOE-NP Isotope program:
  - 3-year design, construction, commissioning period
  - Complete Q4FY22

**2015 NSAC Isotope Program Long Range Plan Recommendation**:

***Infrastructure for isotope harvesting at FRIB*** – During routine operation for its nuclear physics mission, FRIB will produce a broad variety of isotopes that could be harvested synergistically without interference to the primary user.




Purifying radionuclides using chemistry instead of magnets.

# Summary

- DOE Isotope program responsible for the production and distribution of isotopes that are not available commercially
- Isotope production is a three prong effort
  - Reactors: low energy neutrons
  - Separation facilities:  electromagnetic and centrifugal
  - Accelerators: protons (up to 200 MeV) and electrons (up to 50 MeV)
- DOE-IP supports an active R&D to develop new production capabilities of new isotopes for research (medical, physics,…)
  - $^{225}Ac$
  - $^{67}Cu$
  - $^{211}At$
  - …
- DOE-IP R&D to develop and maintain US based isotope production that are presently only available from foreign suppliers