



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

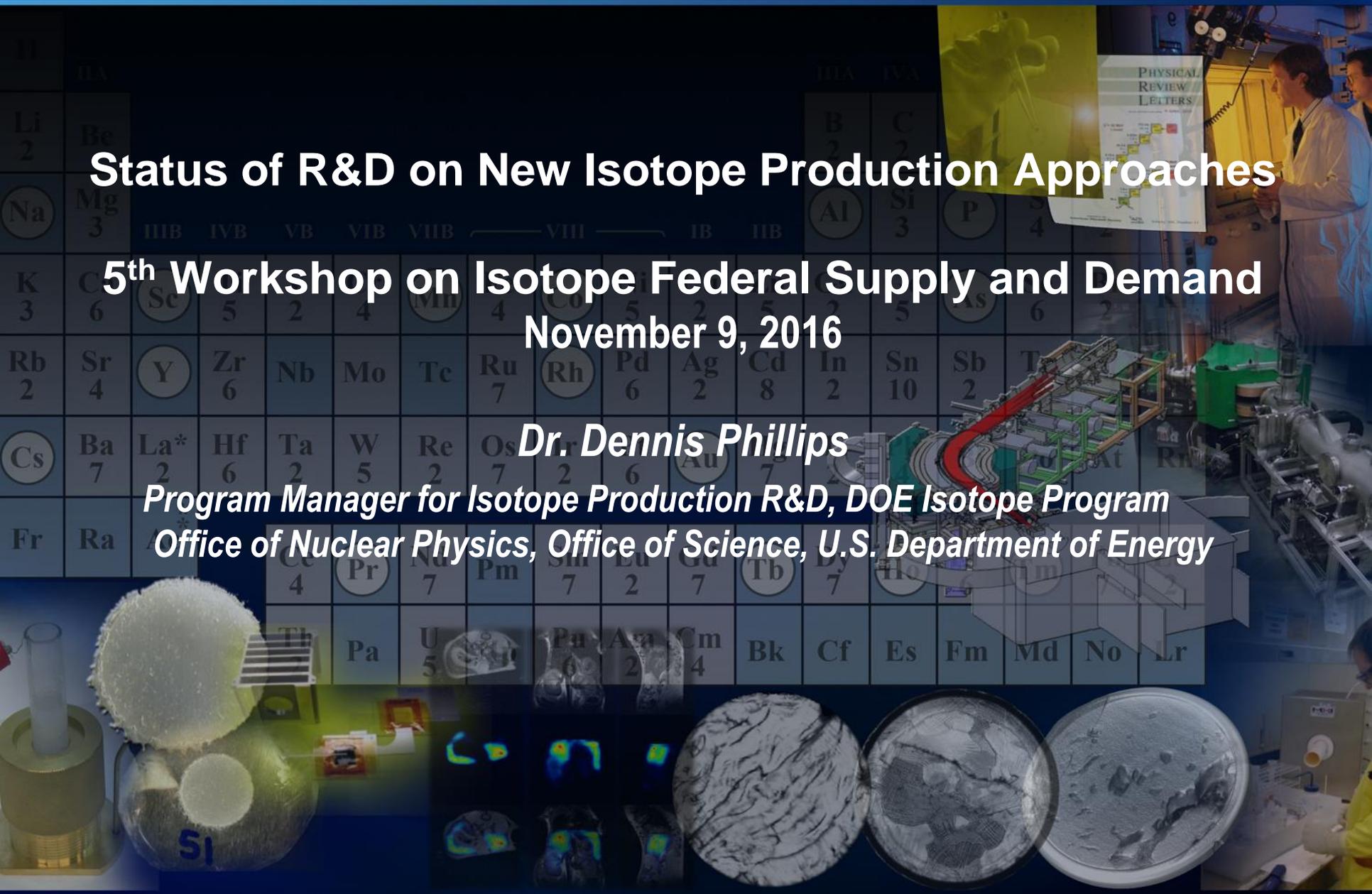
# Status of R&D on New Isotope Production Approaches

5<sup>th</sup> Workshop on Isotope Federal Supply and Demand  
November 9, 2016

*Dr. Dennis Phillips*

*Program Manager for Isotope Production R&D, DOE Isotope Program*

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



## ■ Core R&D

- Maintains core scientific expertise at stewarded labs and universities in isotope production and processing
- Supports R&D using unique capabilities and expertise to support IP mission
- Supports R&D to optimize ongoing isotope production at Labs and Universities
- Supports R&D to develop new production and processing techniques
- Facilitates responsiveness to requests for isotopes
- Important to recruiting and retention of workforce at our key facilities

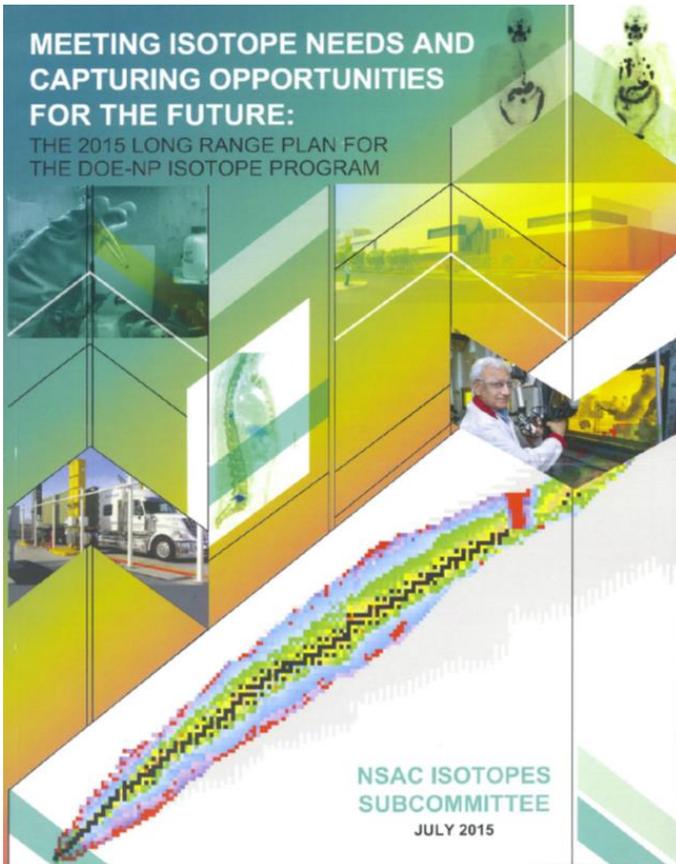
## ■ Competitive R&D

- Eligible to all labs and academic institutions
- Proposals are peer-reviewed – strong competition
- Targeted to demands identified by community (such as federal surveys)
- Helps us identify interests, opportunities and needs in the broader community
- Helps enable development of future workforce

## ■ SBIR/STTR for small businesses



- **Recommends a significant increase of R&D funding to optimize program (See Chapters 3 and 4)**
  - Continue support for R&D on the production of alpha-emitting radioisotopes
  - Support R&D into the production of high specific activity theragnostic radioisotopes
  - Continue support for R&D on the use of electron accelerators for isotope production
  - Support for R&D on production of isotopes important to basic research, national security, other applied research
  - Support R&D on the development of irradiation materials for targets exposed to extreme environments
  - Infrastructure development including facility upgrades, harvesting of isotopes at FRIB, automation, high capacity stable isotope enrichment, radioisotope separator
  - Investments in workforce development should continue to be a priority



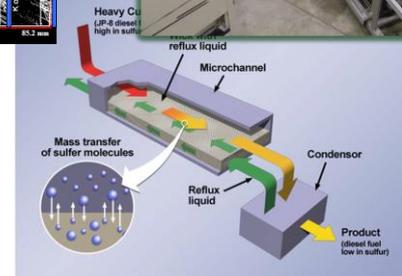
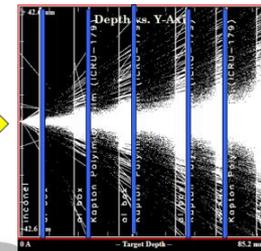
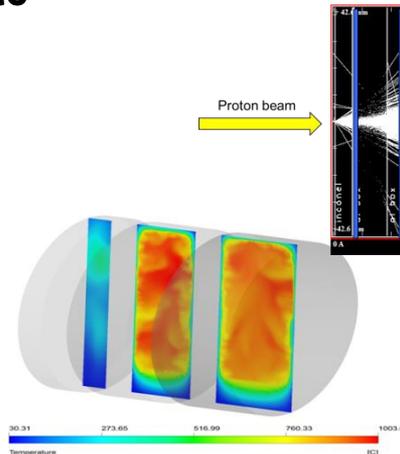
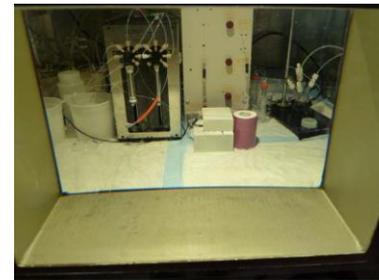
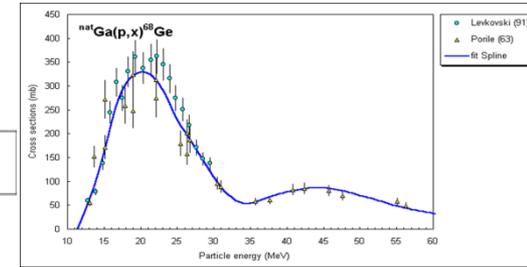
# Key Areas of Research

- **Transmutation (neutrons, charged particles, high energy gamma photons)**
- **Targetry (thermal hydraulics, materials, nuclear data, particle transport modeling)**
- **Mass-separation for enriched stable isotopes and HSA radioactive isotopes**
- **Processes for recovery and purification of radioisotopes; remote handling/automation**
- **Application research NOT generally supported by the DOE Isotope Program**

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

	$\alpha, 3n$	$\alpha, 2n$		
		$^3\text{He}, n$		
	p,2n	p,n	d,n	t,n
			$^3\text{He}, np$	$\alpha, np$
				$^3\text{He}, p$
		p,pn	<b>Original Nucleus Z,N</b>	d,p
		n,2n		n, $\gamma$
				t,np
	p, $\alpha$	n,t	n,np	n,p
		d, $\alpha$	p,2p	
		n,nd	n,d	t, $^3\text{He}$
		n, $\alpha$	n, $^3\text{He}$	
		n,n $^3\text{He}$	n,pd	

Z ↑  
N →



- **Funding Opportunity Announcements (\$30.2M supporting 46 research projects)**

- Held biannually for academic and national laboratories
- Evaluation of proposals done under rigorous peer review
- Funding decisions strongly guided by community needs

**DE-PS02-09ER09-14  
FY09/FY10**

**DE-FOA-0000447  
FY11/FY12**

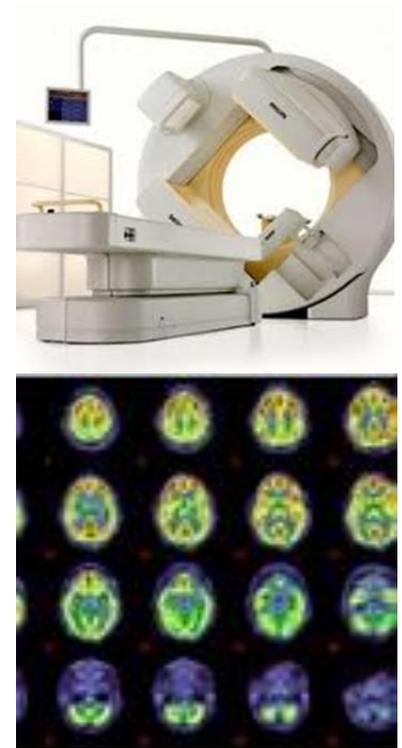
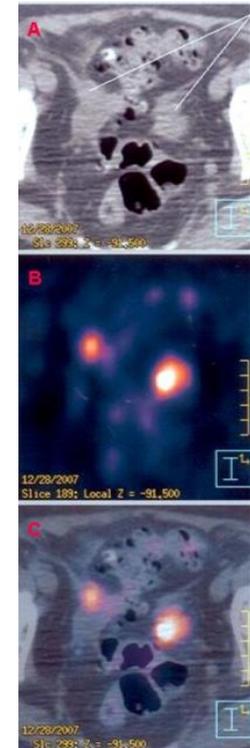
**DE-FOA-0000743  
FY13/FY14**

**DE-FOA-0001099  
FY15/FY16**

- **DE-FOA-0001588 FY17/FY18**

- ~\$3.5M per year
- 6 -10 new awards

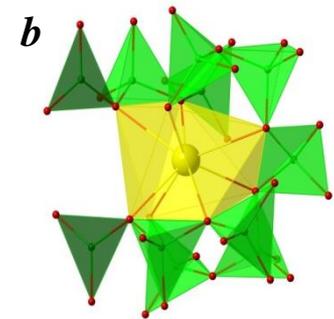
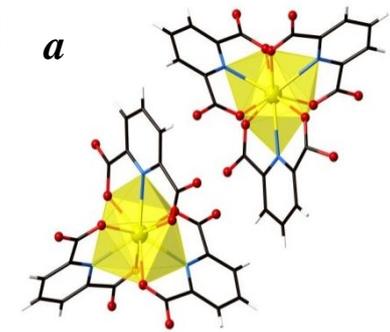
- **Alpha emitters for targeted therapy**
  - Ac-225/Bi-213, At-211, Rn-211, Ac-227/Th-227/Ra-223, Ra-224/Pb-212, U-230/Th-226
- **Beta and Auger electron emitters**
  - Sc-47, Cu-67, As-77, Re-186, W-188/Re-188, HSA Sm-153, Rh-105, Ru-106, Lu-177, Ho-166, Pm-149, and other radiolanthanides, Te-119/Sb-119, Pt-193m, Pt-195m
- **PET isotopes**
  - Sr-82, Se-72/As-72, Ti-44/Sc-44, Sc-47, Cu-64, Zr-89, Mn-52, Nb-90
- **SPECT and planar gamma imaging**
  - Direct Tc-99m production, Cu-67
- **Theragnostic isotopes**
  - Y-86/Y-90, As-72/As-76 or As-77, Cu-64/Cu-67, Cu-67, Sc-44/Sc-47, Sn-117m, Pt-193m
- **Bimodal imaging**
  - PET/CT (Ga-68)
  - PET/MRI (Mn-52)



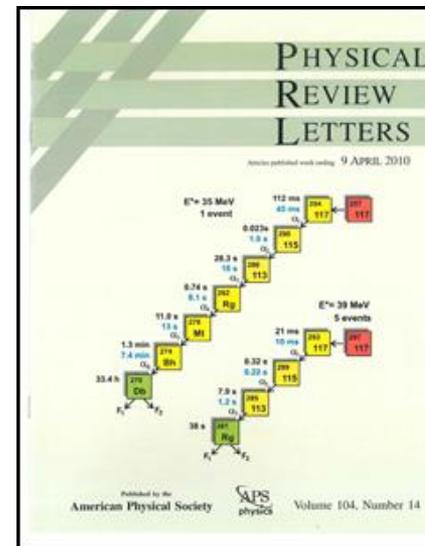
- **Np-236/Pu-236 for nuclear forensics**
  - Mass spectroscopy isotope dilution standards
  - Collaborative effort between LANL and U. Washington
  - Accelerator production on uranium targets
- **Actinides for Heavy Element Chemistry, Super Heavy Element Discovery, and Forensics**
  - Am-243, Pu-244, Cm-248, Cf-249/Cf-251, Bk-249  
Es-253/Es-254, Fm-257  
U-238, Np-236, Np-237, Pu-239/Pu-240/Pu-242
  - Harvested from legacy materials and/or co-produced in production of Cf-252
  - “Experimental Validation of the Optimization of Transcurium Isotope Production Model”
- **Environmental Tracers**
  - Si-32 for oceanographic research
  - As-73 for environmental toxicology
- **Isotopes for Nuclear Physics Research**
  - Ho-163 and Al-26 for astrophysics
  - Ge-76 for neutrino research



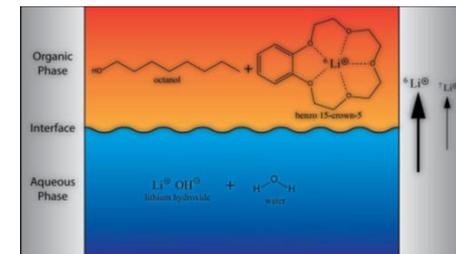
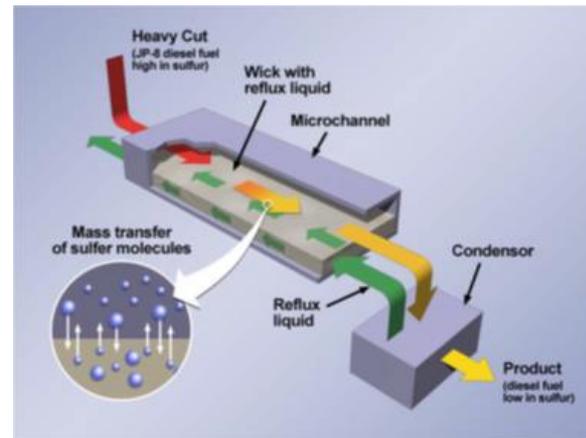
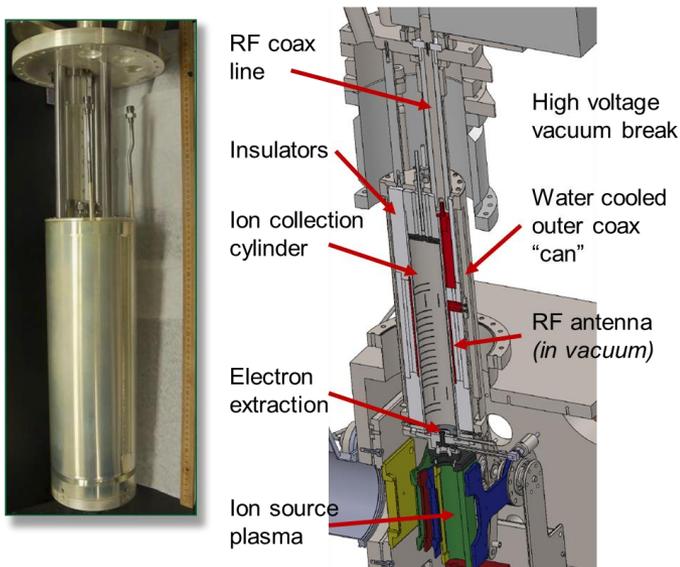
$Bk[B_6O_8(OH)_5]$



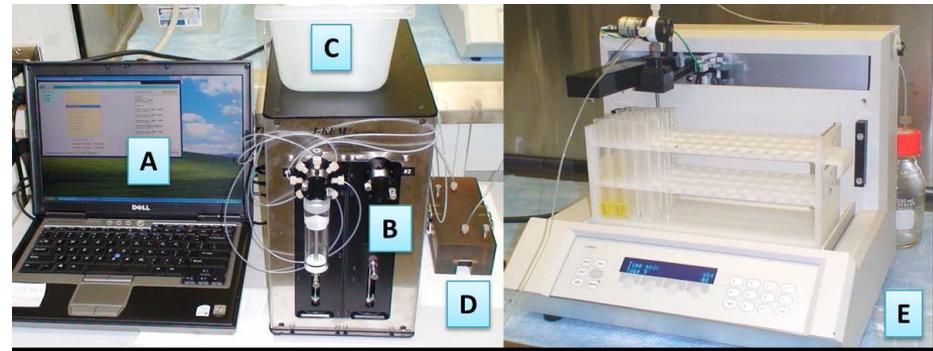
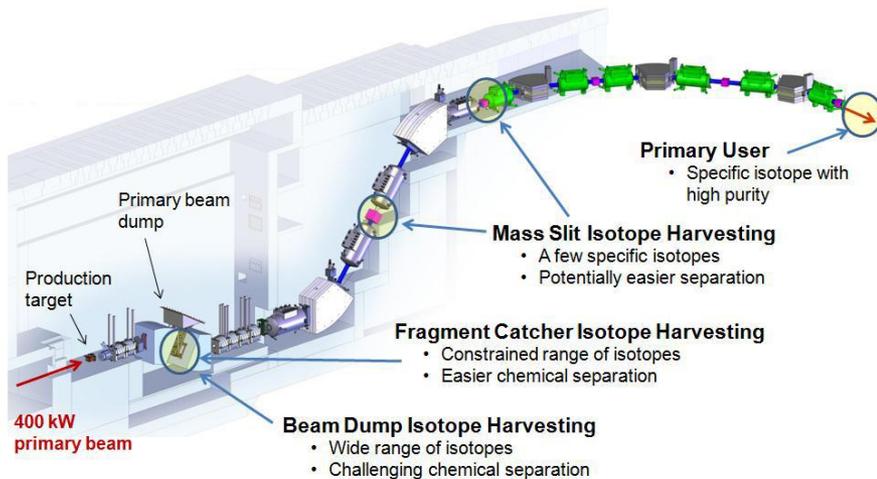
$^{249}Bk(DPA)_3$



- R&D for new production technology
  - Development of 100 mA ion source for electromagnetic stable isotope enrichment— ongoing (Grimm presentation)
  - Microchannel distillation for Ge-76 enrichment – NDBB
  - Environmentally friendly Li-7 production based upon crown-ether solvent extraction and/or chromatography – R&D to support ability to meet specifications for industry

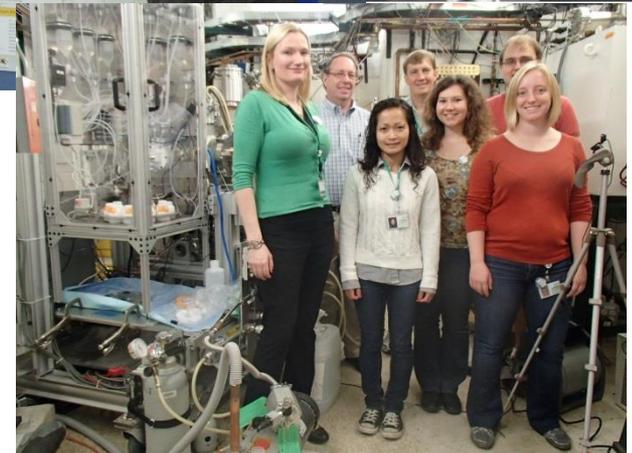


- New technologies for chemical separations of lanthanides and actinides for isotope production
- Automation of isotope recovery and purification technologies
- Radioisotope production using photo-transmutation reactions in electron accelerators
- Production of radioisotopes using high energy neutrons
- Selective gaseous extraction of valuable fission isotopes from low-enriched uranium targets – refer to NNSA Mo-99
- Harvesting isotopes from the Facility for Rare Isotope Beams



FRIB Isotope Harvesting Strategies

- Core research funding at Laboratories supports students and post-docs
- Training components in funding)
  - MURR/LANL/BNL
  - Penn State University
  - University of Washington/PNNL
  - Hope College/Washington University
  - Texas A&M University
- Summer Schools in Nuclear Chemistry and Radiochemistry
- Workforce Development for Teachers and Scientists,  
<http://science.energy.gov/wdts/>
  - DOE Office of Science Graduate Student Research (SCGSR) Program
  - SULI Program (Science Undergraduate Laboratory Internships)
- OSC Early Career Research Program
  - <http://science.energy.gov/early-career/>



- **The R&D program is successful**
  - Significant publishable advances toward new or improved production capability
  - Numerous students and postdocs have been engaged in the work supported by the program
  - The existence of the R&D program increases the ability to recruit and retain a skilled and vibrant workforce
- **R&D is a priority for the Isotope Program**
  - NSACI LRP Recommendations
    - We recommend a significant increase of funding for Research and Development
- **IP is prepared to conduct R&D on isotope production relevant to your mission**