



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

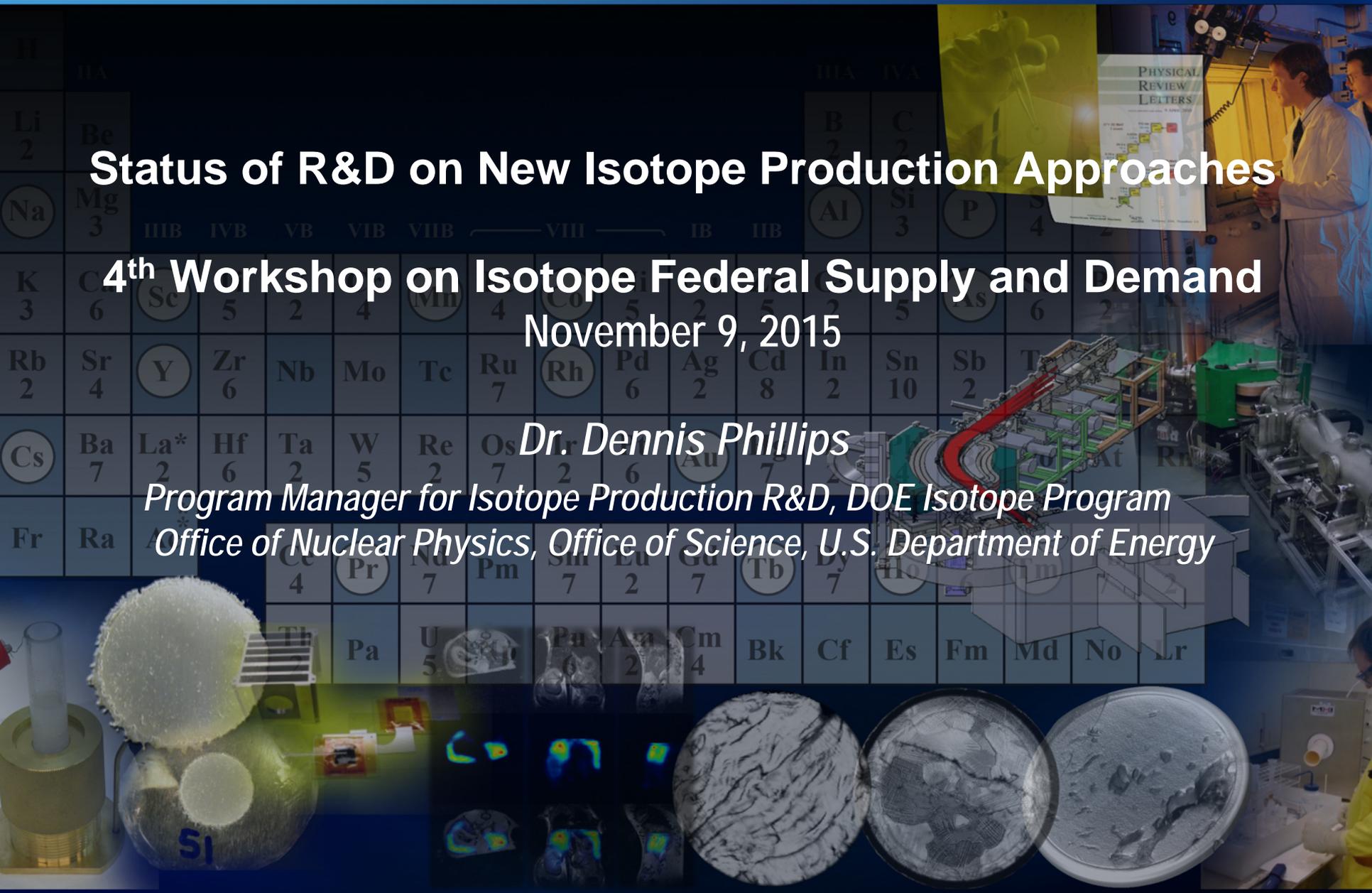
# Status of R&D on New Isotope Production Approaches

4<sup>th</sup> Workshop on Isotope Federal Supply and Demand  
November 9, 2015

*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*



## ■ Isotope Program Appropriated Funding

- Core R&D
  - Directly stewarded activities at Labs and Universities
  - Support R&D using unique capabilities and expertise to support IP mission
  - Facilitates responsiveness to requests for isotopes
  - Important to recruiting and retention of workforce at our key facilities
- Competitive R&D
  - Gives opportunities to Labs and Universities that have facilities and expertise in isotope production (all labs and academic institutions are eligible to submit proposals)
  - Helps us identify interests and needs in the broader community
  - Helps enable development of future workforce
- SBIR/STTR for small businesses.

## ■ Workforce Development

- Support travel bursaries for post docs and students to attend conferences/symposia
- Collaboratively support Nuclear Chemistry and Radiochemistry Summer Schools
- Participation in SC Early Career Award Program
- Participation in SC Graduate Student Research Program

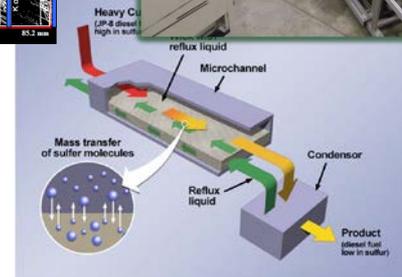
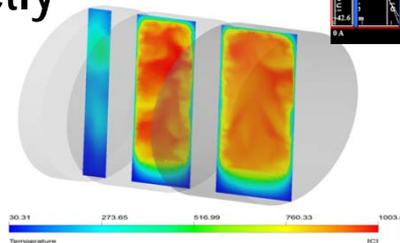
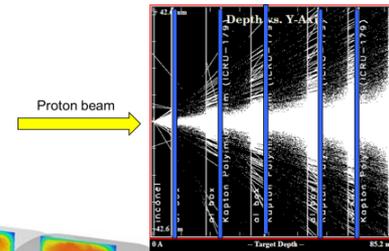
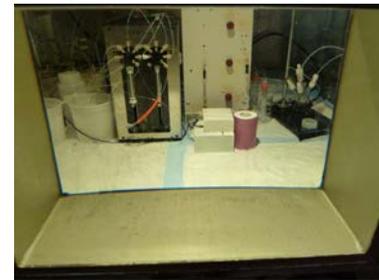
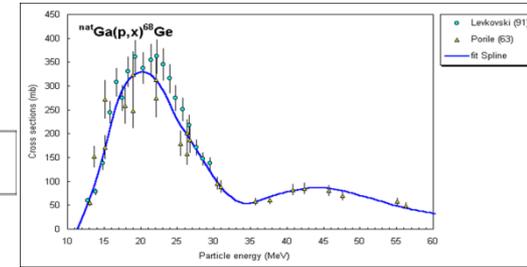
# Key Areas of Research

- 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
- Other?
  - Application research NOT directly supported by 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]

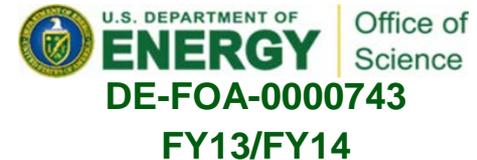
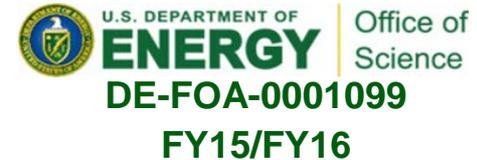
	$\alpha, 3n$	$\alpha, 2n$		
		$^3\text{He}, n$		
	p,2n	p,n	d,n	t,n
			$^3\text{He}, np$	$\alpha, np$
		p,pn	<b>Original Nucleus</b>	$^3\text{He}, p$
		n,2n	<b>Z,N</b>	d,p
				n, $\gamma$
		p, $\alpha$	n,t	t,np
			d, $\alpha$	n,p
			n,nd	t, $^3\text{He}$
			n, $\alpha$	
			n, $n^3\text{He}$	n,pd

Z  
N



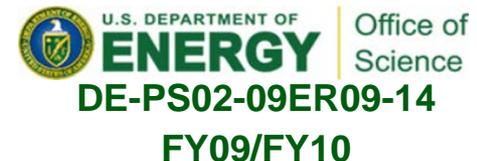
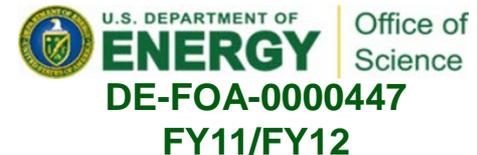
- **Funding Opportunity Announcements (\$30.2 to date)**

- Held biannually for academic and national laboratories
- Support research to provide the scientific and technical foundation to enable availability of critical isotopes for research and applications for the nation
- Evaluation of proposals done under rigorous peer review; funding decisions strongly guided by community needs

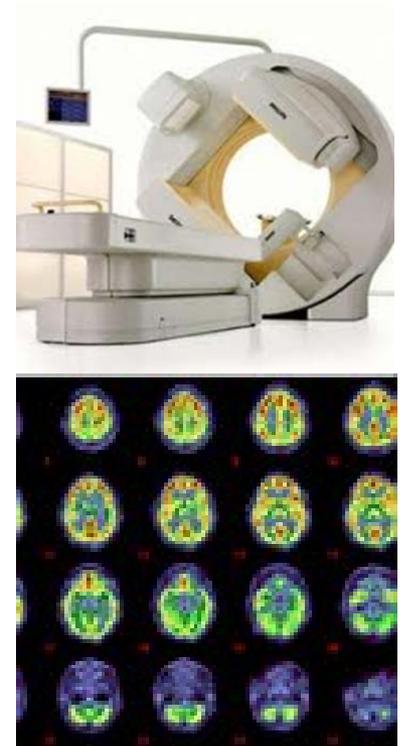
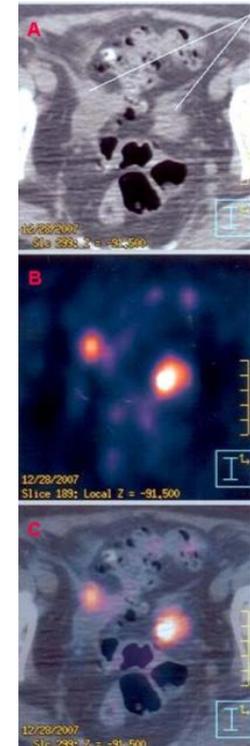


- **Next FOA will issue early spring for FY17/18 appropriation**

- Posting in March 2016
- Proposals Due May 2016
- Review July-August 2016
- Selection by August-September 2016
- FY17 funded University efforts would start January, 2017;  
Labs start October-November, 2017
- <http://science.energy.gov/np/funding-opportunities/>



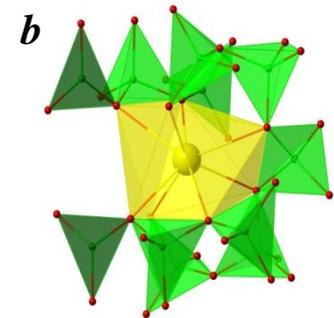
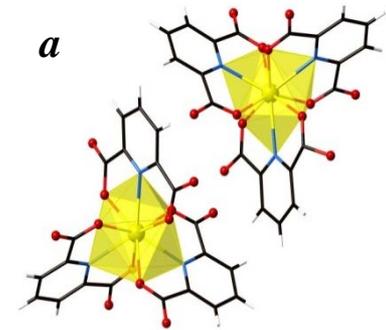
- Alpha emitters for targeted therapy
  - Ac-225/Bi-213, At-211, Rn-211, Ac-227/Th-227/Ra-223, Ra-224/Pb-212, U-230/Th-226
- Beta and Auger electron emitters
  - Sc-47, Cu-67, As-77, Re-186, W-188/Re-188, HSA Sm-153, Rh-105, Ru-106, Lu-177, Ho-166, Pm-149, and other radiolanthanides, Te-119/Sb-119, Pt-193m,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



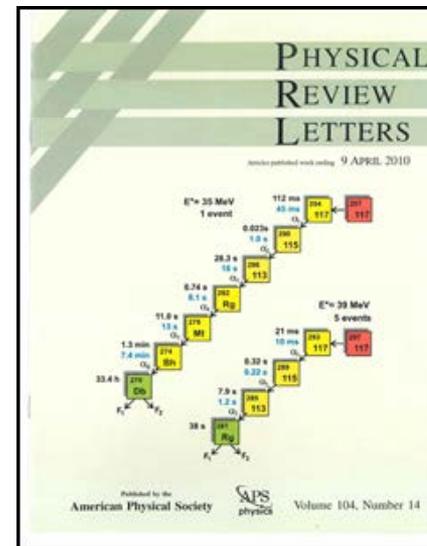
- Np-236/Pu-236
  - Mass spectroscopy isotope dilution standards
  - Collaborative effort between LANL and U. Washington
  - Accelerator production on uranium targets
- Actinides for **Heavy Element Chemistry** and **Super Heavy Element Discovery**
  - Am-243, Pu-244, Cm-248, Cf-249/Cf-251, Bk-249  
**Es-253/Es-254, Fm-257**  
U-238, 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



$Bk[B_6O_8(OH)_5]$



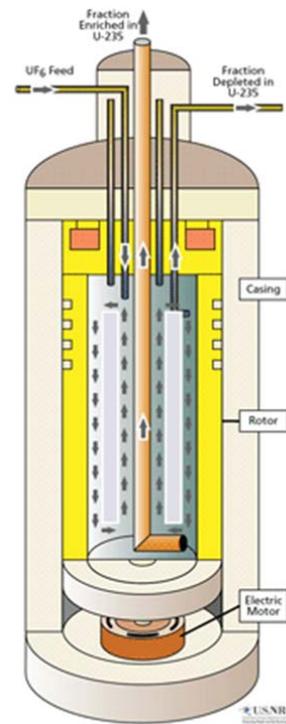
$^{249}Bk(DPA)_3$



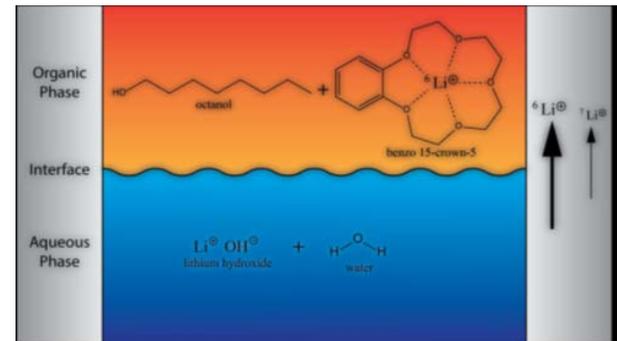
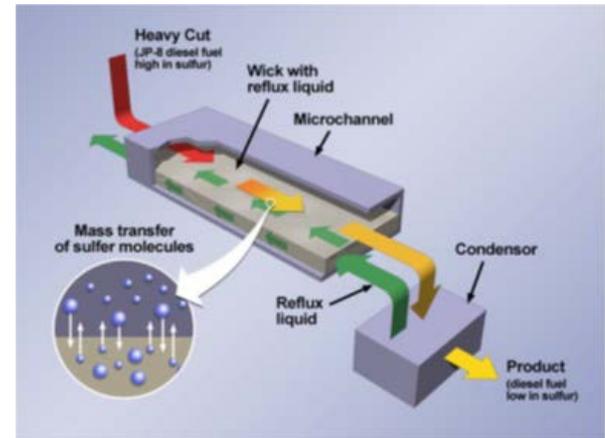


- Technologies currently under development

- New electromagnetic and gas centrifuge technologies
- Microchannel distillation for Ge-76 enrichment
- Environmentally friendly Li-7 production based upon crown-ether solvent extraction and/or chromatography



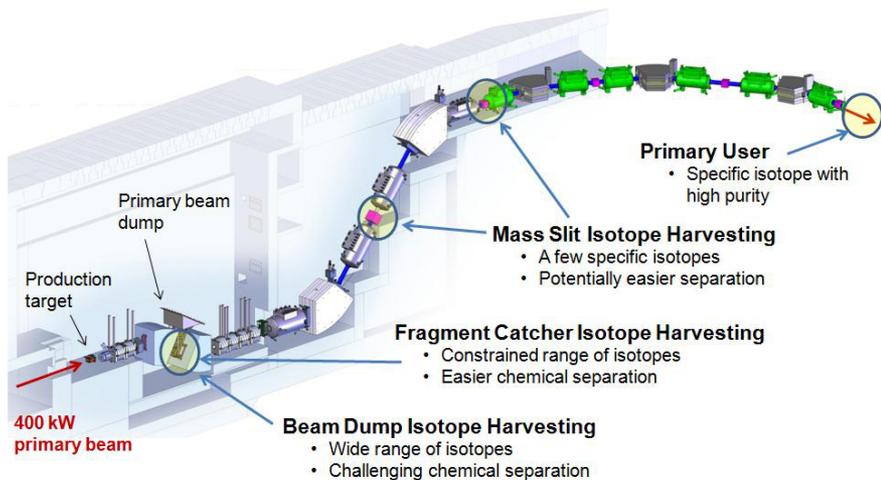
Schematic of a centrifuge



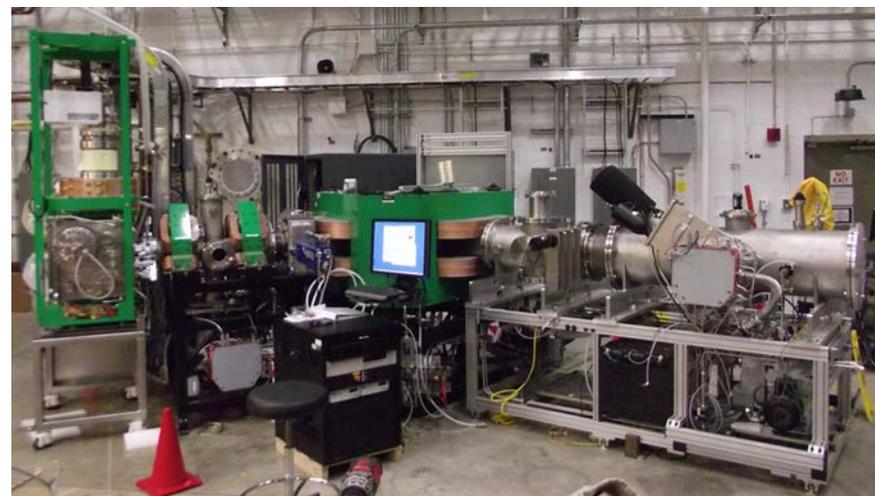


# Broad Scope Developments

- 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
- Harvesting isotopes from the Facility for Rare Isotope Beams
- Development of 100 mA ion source for electromagnetic stable isotope enrichment

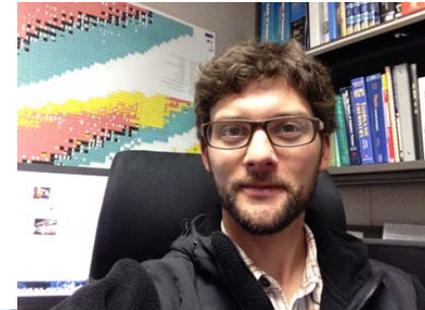


FRIB Isotope Harvesting Strategies



100 mA EMIS Upgrade Assembly

- Core research funding at Laboratories may support students and post-docs
- Funded several grants with significant training components (training emphasis will continue)
  - MURR/LANL/BNL
  - Penn State University
  - University of Washington/PNNL
  - Hope College/Washington University
  - Texas A&M University
- Provided FY15/16 funding to support 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 has been successful!**
  - Significant publishable advances that may lead to 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 must remain a priority for the Isotope Program**
  - NSACI LRP Recommendations
    - We recommend a significant increase of funding for Research and Development