INL/MIS-19-52999-Revision-0

Opportunities with NSUF for Nuclear Energy R&D

February 2019

Brenden J Heidrich

Changing the World's Energy Future

Idaho National Laboratory

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Idaho Falls, Idaho 83415

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Nuclear Science User Facilities

Opportunities with NSUF for Nuclear Energy R&D

Brenden Heidrich, Ph.D.
Irradiation Chief Scientist, NSUF

Additive Manufacturing Discussion on Collaboration Opportunities with LLNL & ISU
Idaho Falls, ID
February 27, 2019

nsuf.inl.gov

NSUF Nuclear Science User Facilities

INL/MIS-19-52999

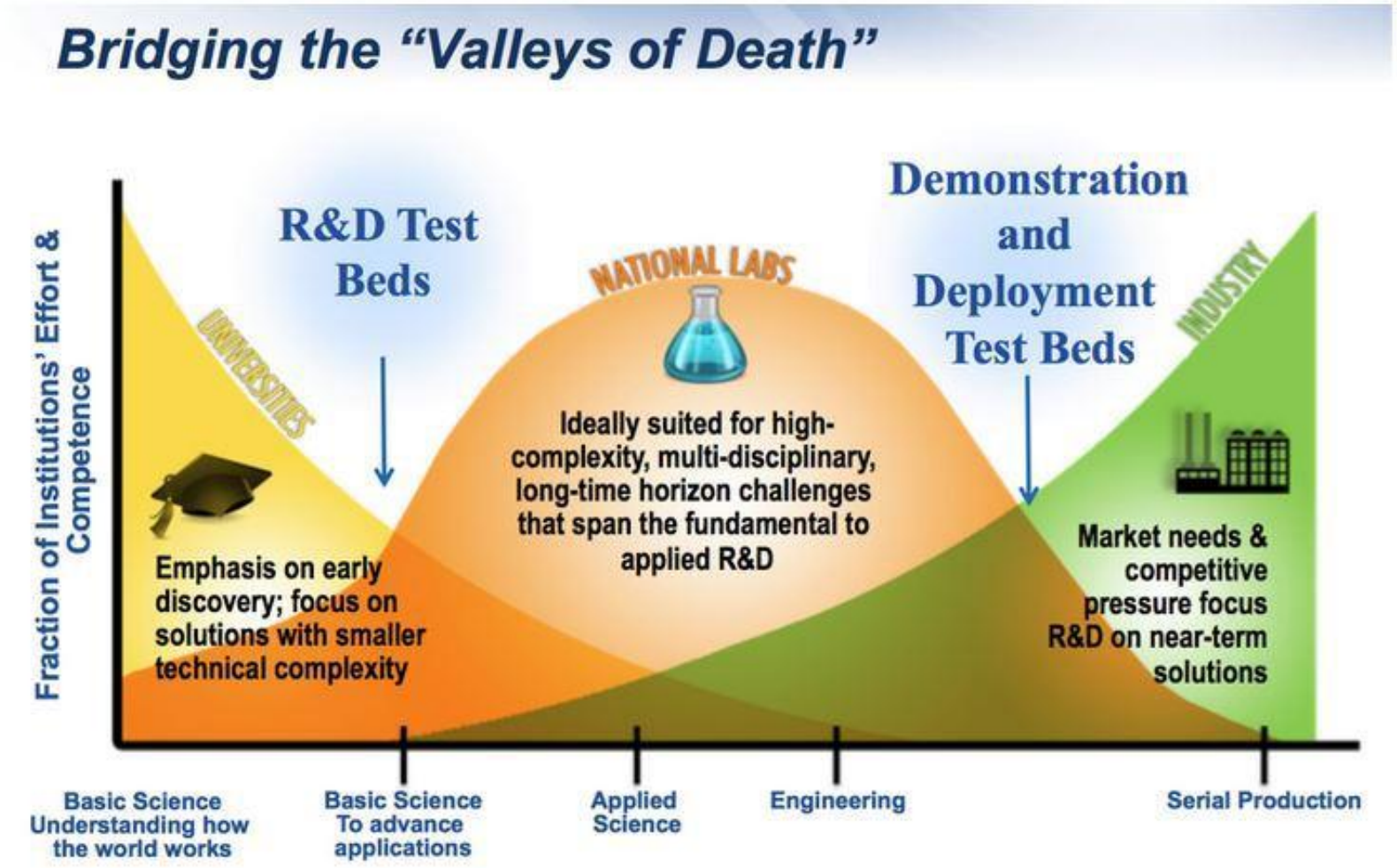
The NSUF: Pairing the best minds with the needed capability

- The Nuclear Science User Facilities (NSUF) offers unparalleled research opportunities for nuclear energy researchers.
- Users are provided access (at no cost to the researcher) to:
  - world-class nuclear research facilities,
  - technical expertise from experienced scientists and engineers, and
  - assistance with experiment design, assembly, safety analysis and examination.
- Access is awarded through a competitive peer-reviewed process.
- Submitted proposals should be consistent with the DOE-NE mission and its programmatic interests.

NSUF supports the **NE Mission Focus Areas** by offering access to capabilities that can provide the fundamental understanding to:

1. predict the long term stability of light water reactor structural materials and accident tolerant fuels to support the **existing fleet,**
2. determine the applicability of advanced materials for future reactor designs to better develop the **advanced reactor pipeline**, and
3. develop simplified materials recovery technologies, waste management, and proliferation risk reduction methods to the re-establish the **national fuel cycle infrastructure**.

Role of the National Laboratories in Nuclear Energy R&D



NSUF General

- **Established 2007 as DOE Office of Nuclear Energy first and only user facility**
  - **Initially at Idaho National Laboratory only, today INL is lead institution**
  - **Link intellectual capital with nuclear research infrastructure to fulfill mission of DOE-NE**
  - **Provide access to capabilities and expertise at no cost to user**
  - **Irradiation effects in nuclear fuels and materials**
  - **Support design, fabrication, transport, irradiation, PIE, disposition**
- **Generally select projects through open competitive proposal processes**
  - **Consolidated Innovative Nuclear Research (CINR FOA, 1 call/year)**
    - **Irradiation + PIE ($1.0M - $4.0M, up to 7 years)**
    - **PIE only (~$500K, up to 3 years)**
    - **Irradiation only ($500K - $3.5M)**
    - **Beamlines at other user facilities**

  - **Rapid Turnaround Experiments (RTE, 3 calls/year, limited $$, executed within 9 months)**
  - **Proposals welcome from University, National Laboratory, Industry, Small Business**

NSUF – A consortium

A group formed to undertake an enterprise beyond the resources of any one member

- Recognized early that needs of community exceed capacity at INL
- Partner Facilities program started in 2008
- Name changed to Nuclear Science User Facilities in 2014
- 11 Universities + 4 Universities in CAES, 8 National Laboratories, 1 industry

2007	2008	2009	2010	2011	2012	2013	2016	2017
INL Idaho National Laboratory	MIT Massachusetts Institute of Technology	CAES Center for Advanced Energy Studies	Oak Ridge National Laboratory	Cal	PNNL	Westinghouse	Argonne National Laboratory	Brookhaven National Laboratory
		125 Illinois Tech Since 1890			Purdue University			Sandia National Laboratories
		NC State University						Lawrence Livermore National Laboratory
								Los Alamos National Laboratory Est. 1943
								Ohio State
								Texas A&M University
								University of Florida
	Wisconsin University of Wisconsin-Madison	UNLV University of Nevada Las Vegas	University of Michigan					SCK•CEN Studiecentrum voor Kernenergie Centre d'Etude de l'Energie Nucléaire

NSUF

NSUF Capabilities Offer Research Opportunities

Neutron Irradiations	Ion Irradiations	Gamma Irradiations	Hot Cells & Shielded Cells	Low Activity Laboratories	Beamlines	High Performance Computing
INL Idaho National Laboratory	Wisconsin University of Wisconsin-Madison	INL Idaho National Laboratory	INL Idaho National Laboratory	INL Idaho National Laboratory	Brookhaven National Laboratory	INL Idaho National Laboratory
Oak Ridge National Laboratory	University of Michigan	Oak Ridge National Laboratory	Oak Ridge National Laboratory	CAES Center for Advanced Energy Studies	NC State University	
Massachusetts Institute of Technology	Argonne National Laboratory	Sandia National Laboratories	PNNL	Oak Ridge National Laboratory	Los Alamos National Laboratory	
NC State University	Sandia National Laboratories		Los Alamos National Laboratory	PNNL		
Ohio State	Texas A&M University		Westinghouse	Los Alamos National Laboratory		
Sandia National Laboratories	Lawrence Livermore National Laboratory		University of Michigan	Cal		
SCK•CEN Studiecentrum voor Kernenergie Centre d'Etude de l'Energie Nucleaire			SCK•CEN Studiecentrum voor Kernenergie Centre d'Etude de l'Energie Nucleaire	Wisconsin University of Wisconsin-Madison		
				NC State University		
				University of Michigan		
				Purdue University		
				UNLV University of Nevada Las Vegas		
				University of Florida		
				SCK•CEN Studiecentrum voor Kernenergie Centre d'Etude de l'Energie Nucleaire		

Visit nsuf.inl.gov for details at individual facilities

- **11 Universities**
- **CAES (4 Univ)**
- **8 National Labs**
- **1 Industry**
- **1 Int'l Affiliate**

NSUF

NSUF Support Structure Points of Contact

DOE
Mr. Shane Johnson
Mr. Mike Worley
Ms. Alice Caponiti
Ms. Tansel Selekler
Mr. Jihad Aljayoushi (ID)

Ion Beams
Prof. Gary Was (UM)
Prof. Kumar Sridharan (UW)
Dr. Meimei Li (IVEM, ANL)
Dr. Khalid Hattar (SNL)
Prof. Lin Shao (TAMU
Dr. Scott Tumey (LLNL)

Neutron Irradiation
Ms. Debra Utterback (INL)
Dr. Lin-Wen Hu (MIT)
Dr. Gordon Kohse (MIT)
Prof. Ayman Hawari (NCSU)
Mr. Kory Linton (ORNL)
Prof. Raymond Cao (OSU)
Dr. Richard Sisson (SNL)
Dr. Sven Van den Berghe (BNRC)

Beamlines
Dr. Lynne Ecker (BNL)
Prof. Ayman Hawari (NCSU)
Dr. Tarik Saleh (LANL)

Examinations
Dr. Kurt Terrani (ORNL)
Mr. Kory Linton (ORNL)
Dr. Yaqiao Wu (CAES)
Ms. Joanna Taylor (CAES)
Dr. Andrew Casella (PNNL)
Dr. David Senor (PNNL)
Prof. Ahmed Hassanein (Purdue)
Prof. Peter Hoseman (UCB)
Dr. Paula Freyer (Westinghouse)
Dr. Tarik Saleh (LANL)
Prof. James Baciak (UFla)
Dr. Thomas Hartmann (UNLV)
Prof. Kumar Sridharan (UW)
Prof. Ayman Hawari (NCSU)
Prof. Gary Was (UM)
Dr. Mitch Meyer (INL)
Dr. Sven Van den Berghe (BNRC)

And many more scientists, engineers and technical staff at all partner facilities to help get things done

Accessing the NSUF

1. **Consolidated Innovative Nuclear Research FOA**
   - For full irradiation/PIE, PIE Only, or NSLS-II projects
   - Kickoff in August, awarded the following June
   - R&D support funding can be requested
2. **Rapid Turnaround Experiment calls**
   - For small examination or beam-line projects
   - Three calls per year
   - No R&D support funding
   - XPD at NSLS-II is available
3. **DOE-NE Infrastructure Programs**
   - Reactor Upgrades
   - General Scientific Infrastructure

- NFML
- Internships
- Post-Docs
- LDRD

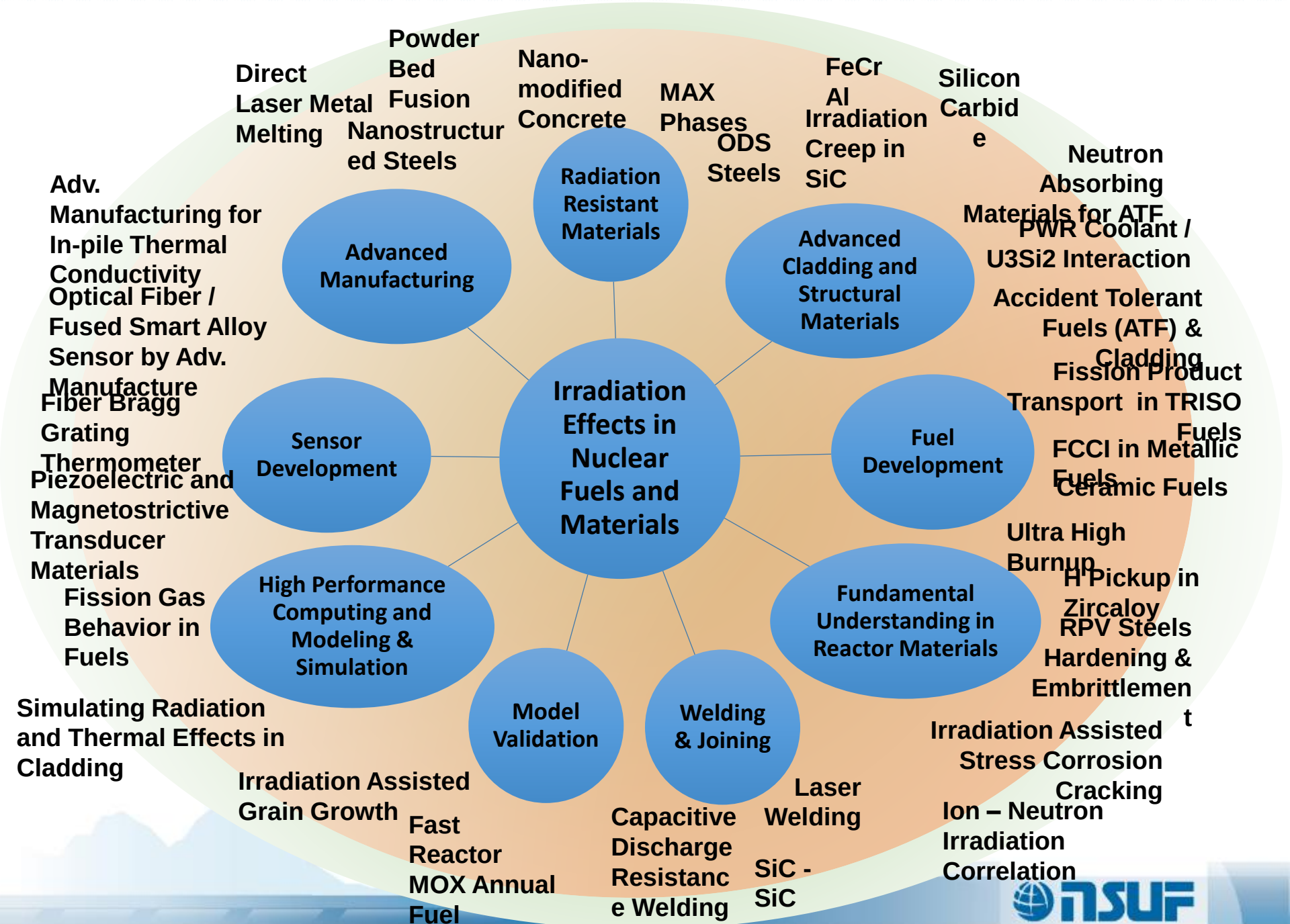
NSUF Projects Summary

FY 2007 – FY2018

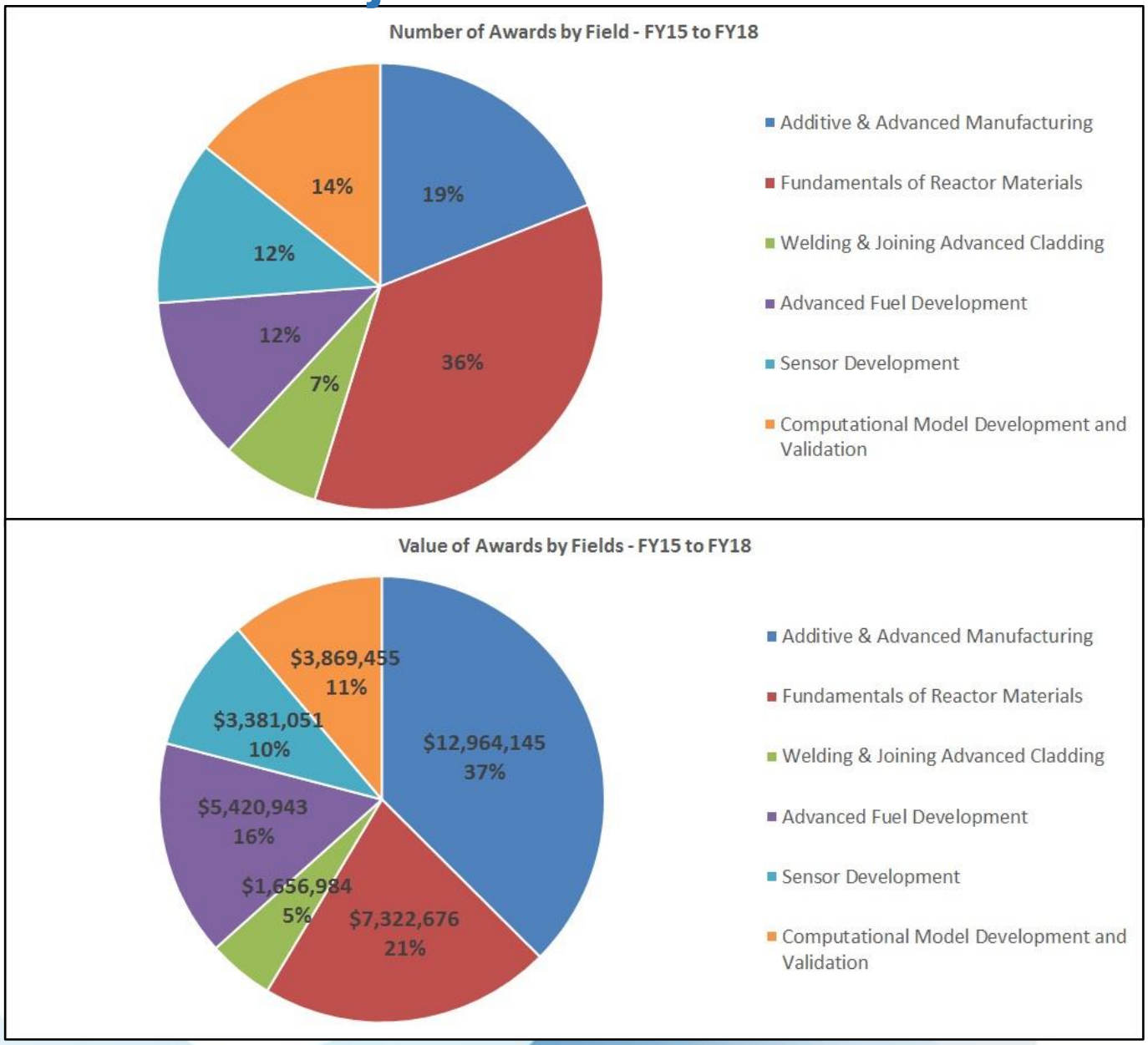
- **Total of 39 CINR type projects executed**
- **Total of 35 CINR type projects currently ongoing**
- **Total of 270 RTEs executed**
- **Total of 63 RTEs ongoing**
- **407 total projects awarded**
  - 251 projects to 45 US universities
  - 123 projects to 6 national laboratories
  - 15 projects to the US nuclear industry
  - 18 projects to 9 international universities and research laboratories

FY 2018

- **Effective FY2018 budget: ~$30M** (same as FY17 & FY16)
- **Total effective FY 2018 budget allocated to projects: ~$13.6M direct** (CINR + RTE) + ~$3.4M supporting (PIE coordination, experiment managers, experiment analyses, shipping, SCK-CEN pilot projects)
- **At any particular time, NSUF is managing 100+ projects**

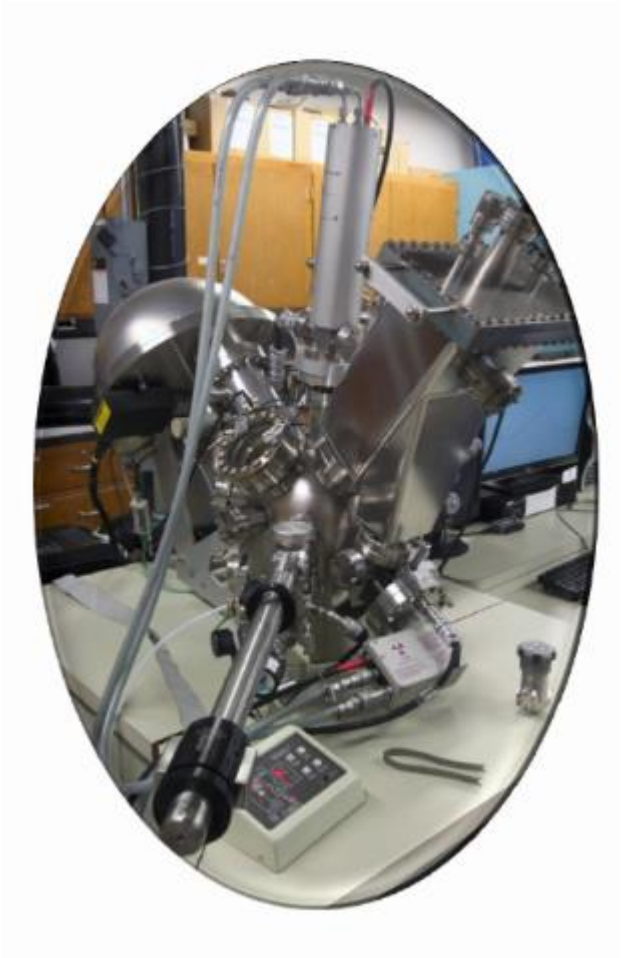

Irradiation Effects in Nuclear Fuels and Materials
Radiation Resistant Materials
Advanced Cladding and Structural Materials
Fuel Development
Fundamental Understanding in Reactor Materials
Welding & Joining
Model Validation
High Performance Computing and Modeling & Simulation
Sensor Development
Advanced Manufacturing
Direct Laser Metal Melting
Powder Bed Fusion
Nanostructured Steels
Nano-modified Concrete
MAX Phases
ODS Steels
FeCrAl
Irradiation Creep in SiC
Silicon Carbide
Neutron Absorbing Materials for ATF
PWR Coolant / U3Si2 Interaction
Accident Tolerant Fuels (ATF) & Cladding
Fission Product Transport in TRISO Fuels
FCCI in Metallic Fuels
Ceramic Fuels
Ultra High Burnup
H Pickup in Zircaloy
RPV Steels Hardening & Embrittlement
Irradiation Assisted Stress Corrosion Cracking
Ion – Neutron Irradiation Correlation
Laser Welding
SiC - SiC
Capacitive Discharge Resistance Welding
Fast Reactor MOX Annual Fuel
Irradiation Assisted Grain Growth
Simulating Radiation and Thermal Effects in Cladding
Fission Gas Behavior in Fuels
Piezoelectric and Magnetostrictive Transducer Materials
Fiber Bragg Grating Thermometer
Optical Fiber / Fused Smart Alloy Sensor by Adv. Manufacture
Adv. Manufacturing for In-pile Thermal Conductivity

CINR Awarded Projects FY 2015 – FY 2018



Graphics created by Simon Pimblott

General Scientific Infrastructure

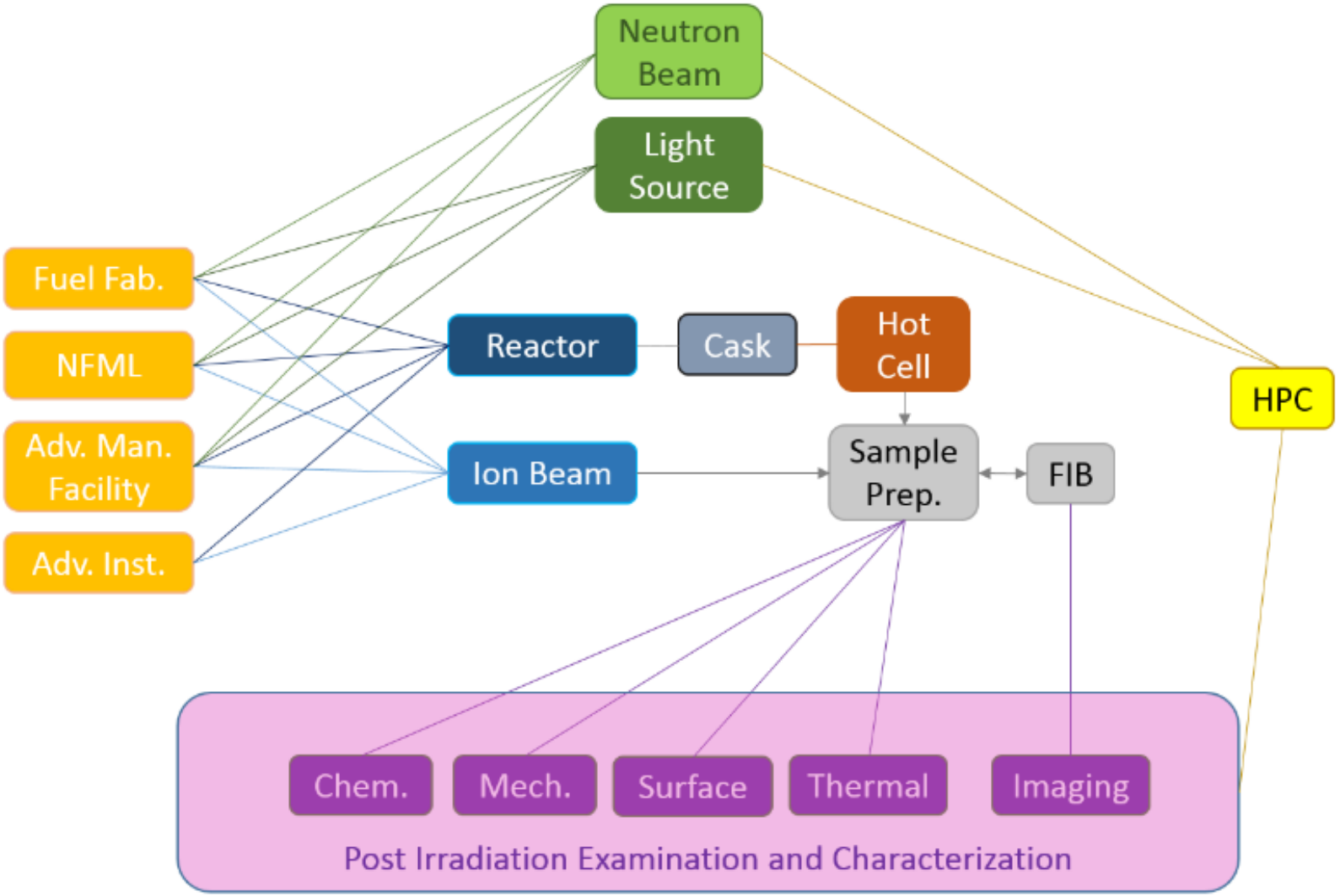


- Anticipated award size $250,000
- Universities are eligible to submit applications.
- One application per institution can be submitted.
- Cost match (1:1) required after $250,000
- Review Criteria
  - NSUF Integration (25%)
  - Scientific Impact (25%)
  - Utilization (25%)
  - Execution (25%)

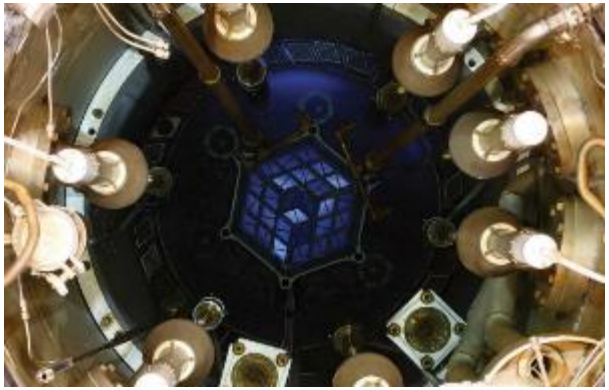
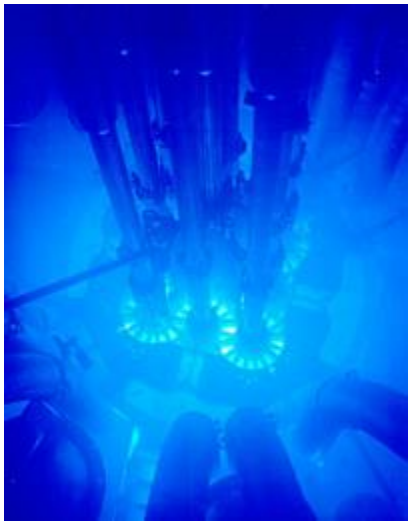
Nuclear Science User Facilities

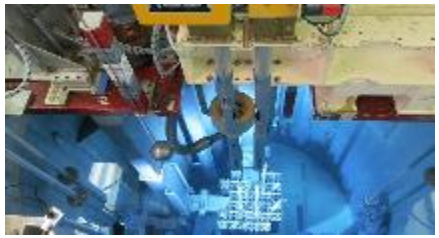
CAPABILITIES

NSUF Experiment Pathways



NSUF Neutron Irradiation Capabilities

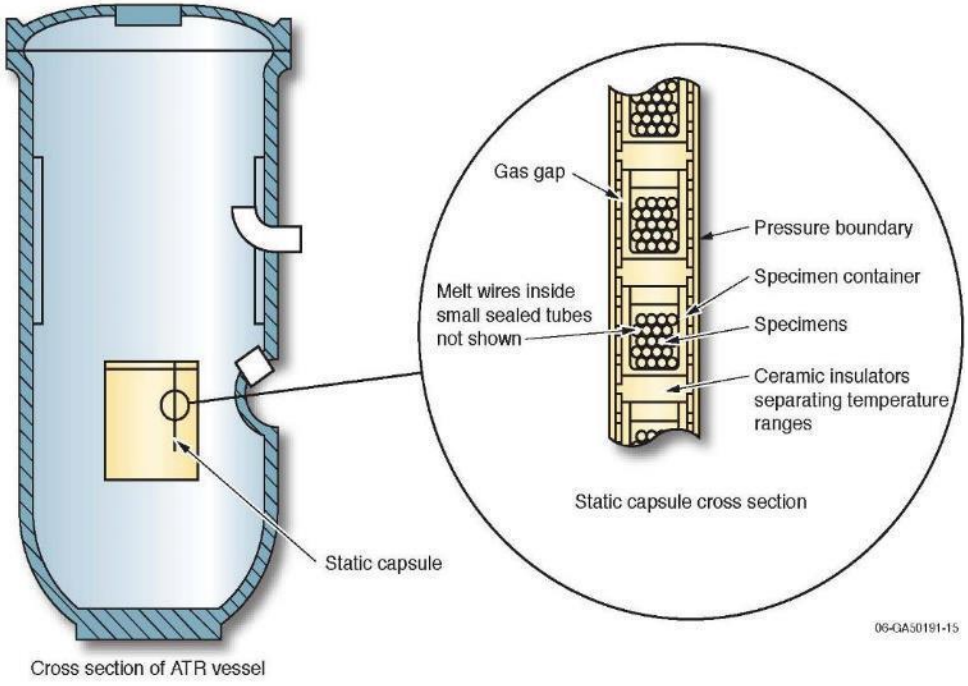


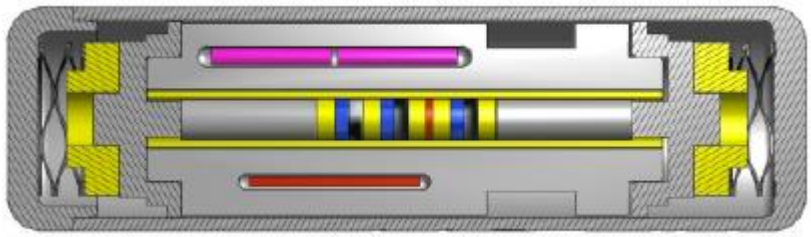




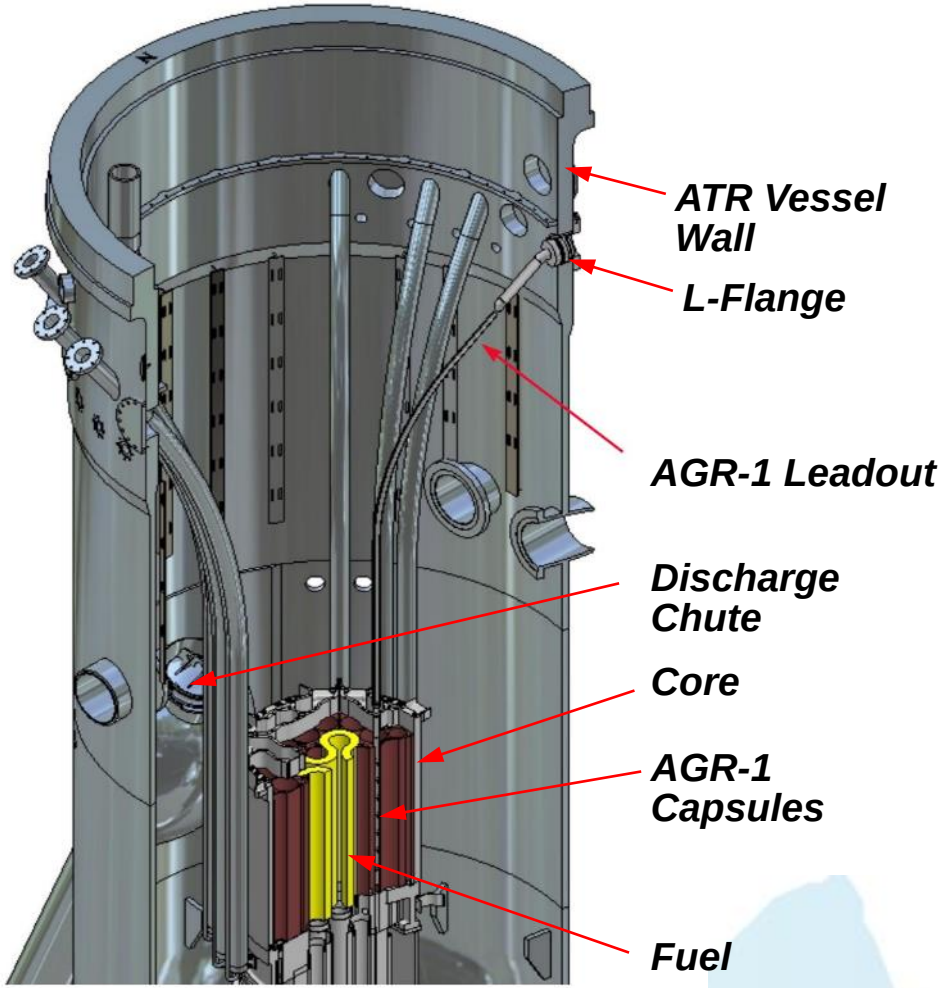
Simple Static Capsule Experiments

- Passive instrumentation (flux wires, melt wires)
- Enclosed in sealed tube, or fuel plates
- Temperature target controlled by varying gas mixture in conduction gap and with material selection
- Lengths up to 48”; diameter 0.5” – 5.0”
- Used for isotope production, fuel and material testing





Instrumented Lead Experiments



- On-line experiment measurements
- Temperature control range 250-1200°C, within +/- 5°C
- Monitoring of temperature control exhaust gases for experiment performance (e.g., fission products, leaking materials, etc.)
- Specialized gas environments (oxidizing, inert, etc.)

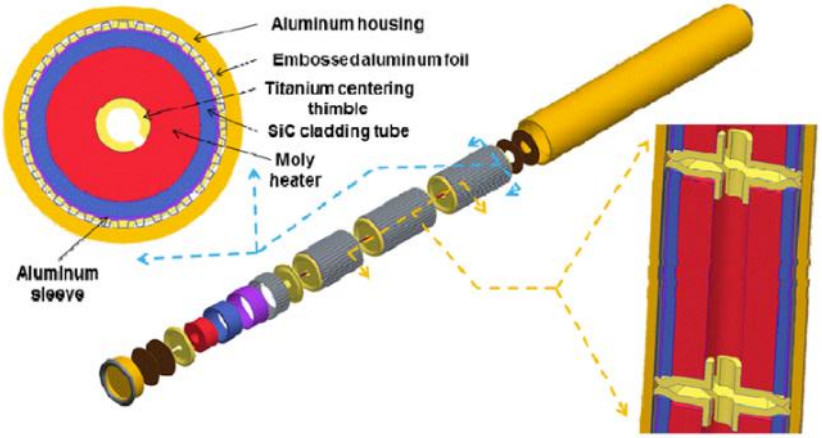
Hydraulic Shuttle Irradiation System

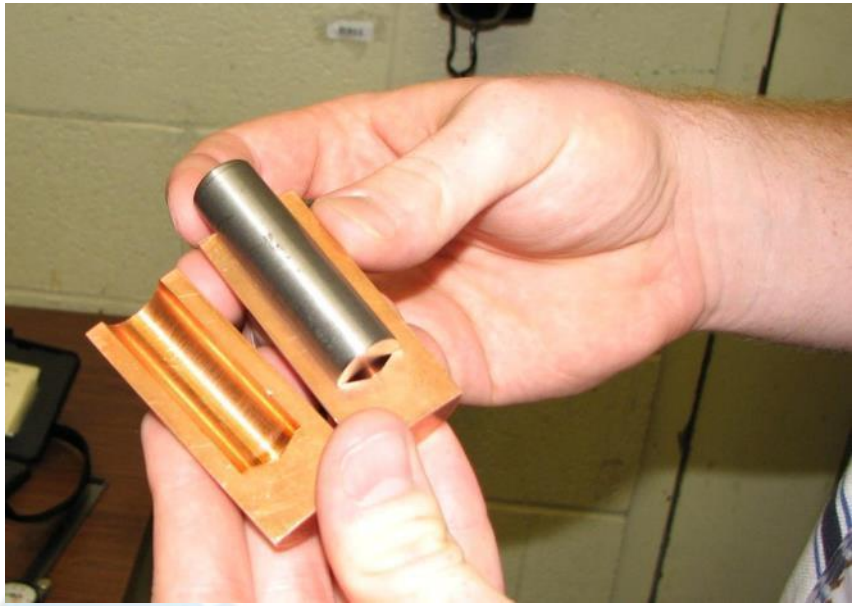
- 14 shuttle capsules
- Simultaneously irradiated

- <u>Flux, at 110 MW</u>:
  Thermal Flux: 2.5×10^{14} n/cm^2-s
  Fast (>1MeV): 8.1×10^{13} n/cm^2-s

- <u>Dimensions</u>:
  ~ 0.55” ID, ~2.1” IL
  ~ 7 cc useable volume
  ~35 gm Contents

- Can irradiate small amounts of fissile material (10mg)





NSUF – Ion Beam Irradiation Facilities

University of Michigan

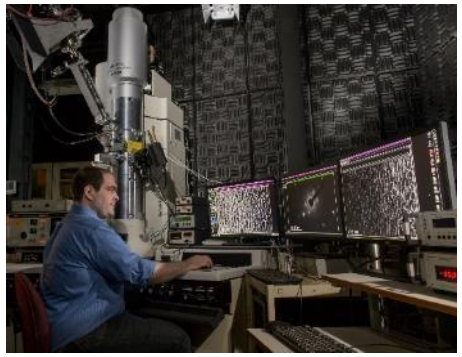
Ion Beam Laboratory

University of Wisconsin

Tandem Accelerator Ion Beam

Additional Partner Facilities:

- IVEM at the Argonne National Laboratory
- CMUXE at the Purdue University (surface science)
- Ion Beam Laboratory at the Texas A&M University
- I^{3}TEM Facility at the Sandia National Laboratory



Synchrotron Radiation

Illinois Institute of Technology
MRCAT Beamline
at Argonne National Laboratory's
Advanced Photon Source

National Synchrotron Light Source-II (NSLS-II)
radioactive materials beamline
at Brookhaven National Laboratory

Hot Cell Capabilities

Hot Fuel Examination Facility (INL)

MIT Reactor Hot Cells

Materials Center of Excellence Laboratories (Westinghouse)

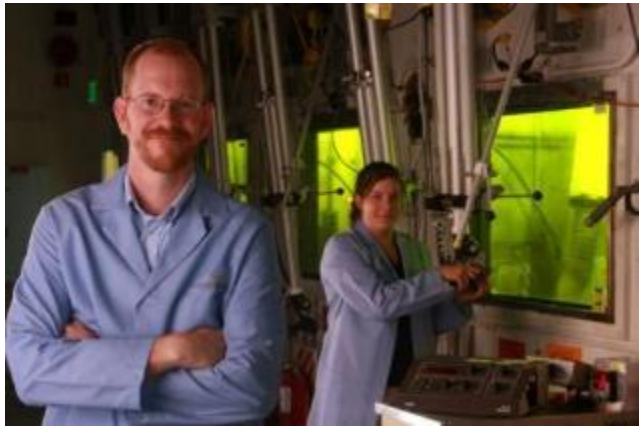
Radiochemical Engineering Development Center (ORNL)

Radiochemistry Processing Laboratory (PNNL)

NSUF Capabilities: high-radioactivity

High radiation level measurements/instrumentation

- **Neutron Radiography**
- **Elemental & Isotopic Analyses**
- **Gas Sampling and Analyses**
- **Profilometry**
- **Gamma Scanning**
- **Mechanical Testing (tensile, punch, Charpy)**
- **Micro-focus X-ray Diffraction**
- **Thermal Analyses**
- **Eddy Current**
- **Irradiation Assisted Stress Corrosion Cracking**
- **Electron Probe Micro Analysis (EPMA)**
- **Electron and Optical Microscopy**
- **Focused ion Beam (FIB)**



Idaho National Laboratory · Oak Ridge National Laboratory · PNNL · Los Alamos National Laboratory · Westinghouse · NSUF

NSUF Capabilities: low-radioactivity

Low radiation level measurements/instrumentation

- **Electron and Optical Microscopy**
  - Scanning Electron Microscopy (SEM)
  - Transmission Electron Microscopy (TEM)
- **Focused Ion Beam (FIB)**
- **Mechanical Testing**
  - Tensile
  - Hardness
  - Micro- and Nano-Indentation
- **X-ray Diffraction**
- **Photo Electron Spectroscopy**
  - X-ray Photo Electron Spectroscopy (XPS)
  - UV Photo Electron Spectroscopy (UPS)
  - Auger Spectroscopy
- **Irradiation Assisted Stress Corrosion Cracking (IASCC)**
- **Positron Annihilation Spectroscopy**
- **Atomic Force Microscopy**
- **Secondary Ion Mass Spectrometry**
- **Thermal Analysis**
  - Thermal Conductivity
  - Heat Capacity
  - Thermal Expansion
- **Nuclear Magnetic Resonance**

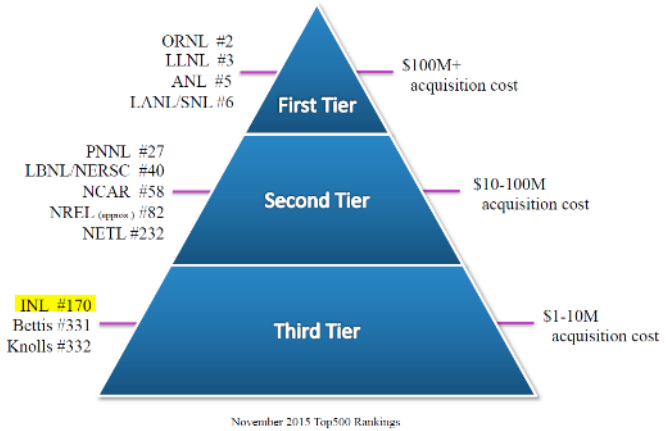
NSUF High Performance Computing Resources

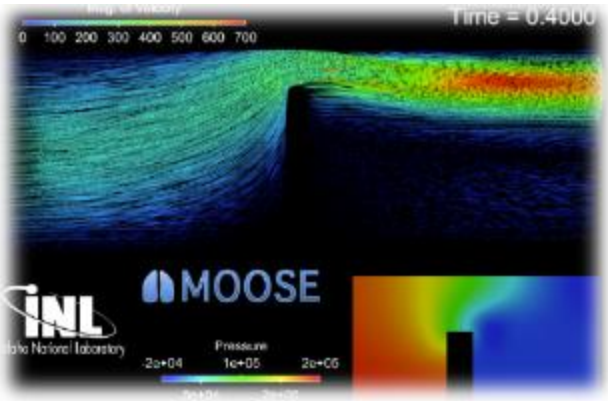
How does HPC enable DOE missions?

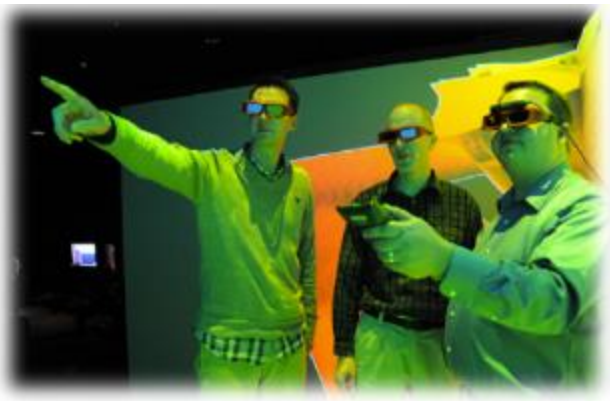
- High Performance Computing (HPC) compliments theory and informs experimental processes.
- HPC functions as a 'microscope' for researchers to better understand physics, chemistry, and engineering principles in ways not otherwise possible.
- HPC resources support NSUF, CASL, NEAMS, NEUP, and GAIN

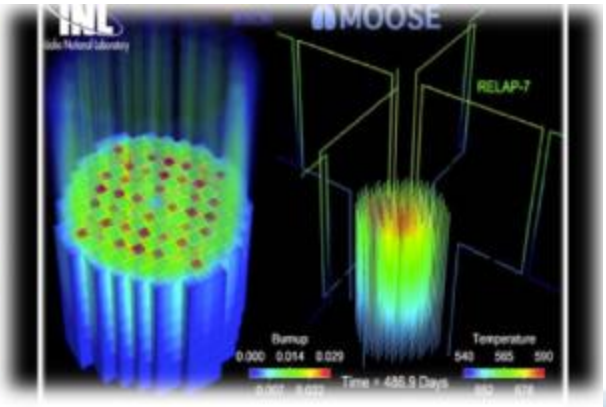
NSUF Program Support

- System already in place for quickly granting user access and prioritizing work
- Reporting and accounting systems are being modified to better capture NSUF metrics and science impact
- Implementing tools to improve and simplify user experience
- Ensuring that NSUF and related programs have needed support
  - Priority scheduling for milestones upon request
  - Supporting as-run analysis, thermal analytics, neutronics analytics
  - MOOSE support







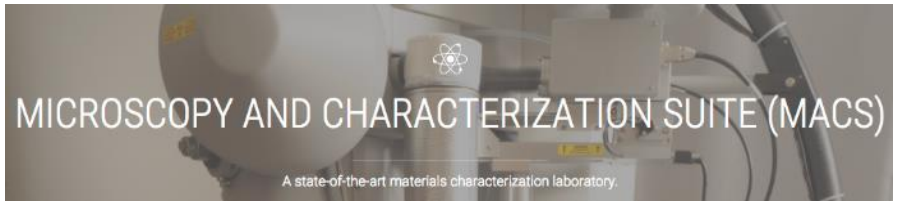


Courtesy of Eric Whiting, Director of Scientific Computing

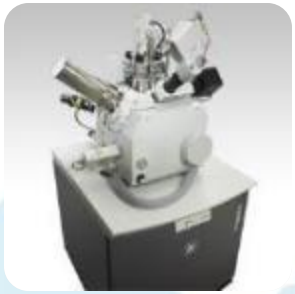
Nuclear Science User Facilities

TOOLS & DATABASES

Infrastructure Database (NEID)



FEI Quanta 3D FEG
Focused Ion Beam
SEM Microscope



Institutions

Facilities

Instruments

Database of world-wide nuclear energy R&D resources (NEID)

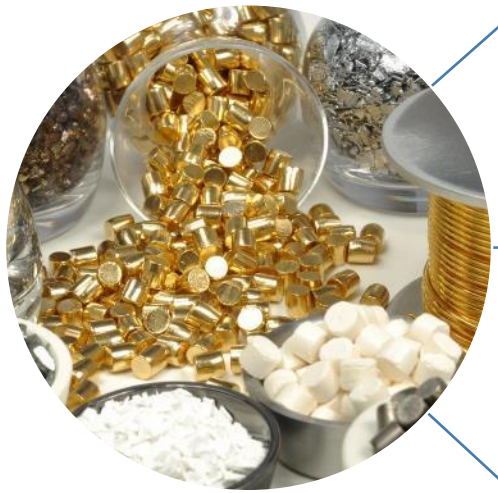
NSUF Fuels and Materials Library

Provides irradiated samples for users to access and conduct research through a competitively reviewed proposal process.

The library includes over 3500 specimens as part of the NSUF awarded research.

<u>Materials Include:</u>

- **Steels**
- **Other alloys**
- **Ceramics**
- **Pure materials**
- **Actinides**
- **Fission products**



INL Legacy materials

Volunteered materials from outside the INL

Supporting documentation related to samples

NSUF Fuels and Materials Library

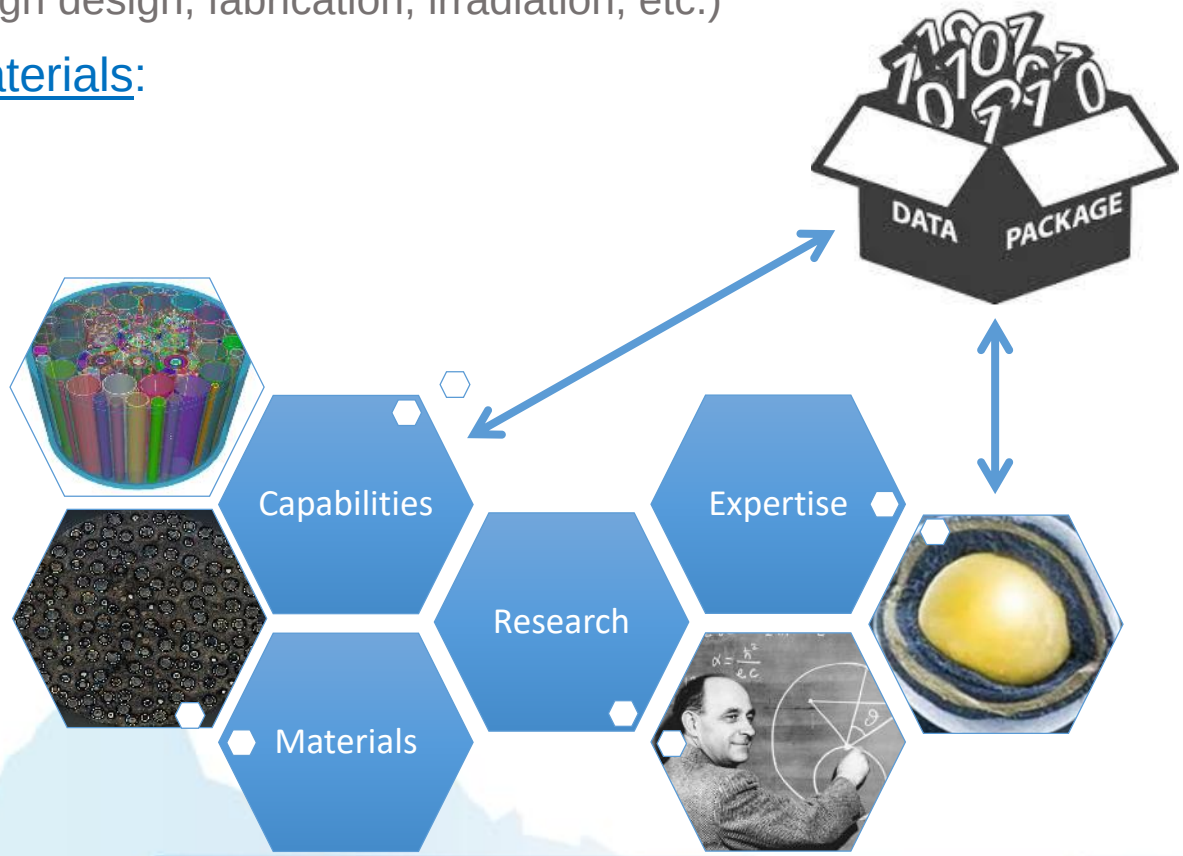
Steels	
17-4 PH SS	Fe-Cr Alloys
304 SS	HCM12-A
304 SS welds	HT-9
Super 304H	MA-956
316 SS	MA-957
347 SS	MAR-2008
416 SS	Mo-ODS
420 SS	nCr-YWT
9Cr ODS	NF616
Borated Steel	NF709
Carbon Steel	PM2000
Cast ASS	T-91
D9 ASS	Tool Steel T-1
Eurofer 97	XM-19
F82H-IEA	various model alloys

Other Alloys	Ceramics	Pure Materials
Al_3Hf	Al_2O_3	Copper
Al1100	MgO	Iron
Al6061	$MgO\text{-}ZrO_2$	Ni/Cu/Nb (DC)
Aluminum Bronze	$Mg_2\text{-}SnO_4$	Nickel
Berylco #25	$Mg0_{1.5}Al_2O_3$	Niobium
C276 Hasteloy	$MgTiO_3$	Silver
Incoloy 800H	$Nd_2Zr_2O_7$	Tantalum
Inconel X/X-750	SiC	Tungsten
Stellite	Ti_2AlC	Zirconium
	Ti_3AlC_2	
	Ti_2AlN	
	TiO_2	
	Ti_3SiC_2	

Small amounts of purified actinides and fission products in liquid form.

What can we build from NSUF Resources?

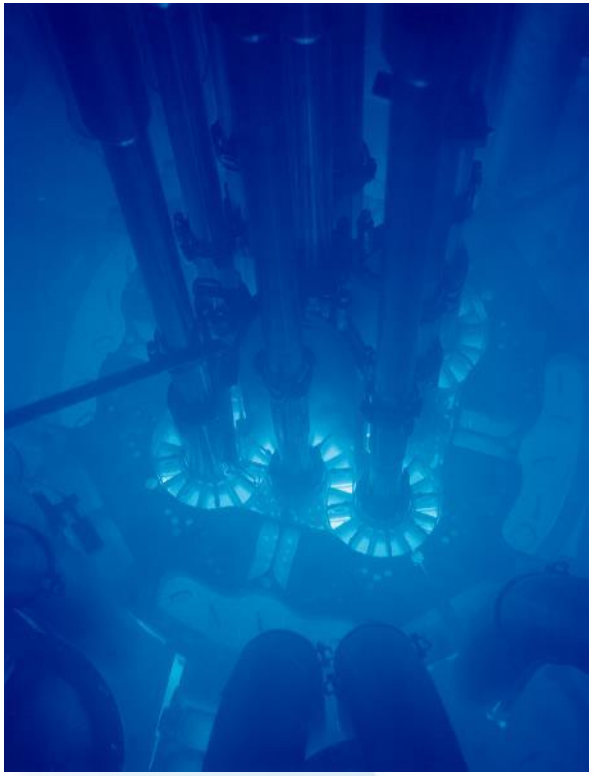
1. We can connect **facilities and instruments** as parts of a process to accomplish a research method or process, such as:
   - Microstructural characterization of irradiated fuel.
   - Irradiation experiment (through design, fabrication, irradiation, etc.)
2. We can include fuels and materials:
   - Fuels and Materials Library
   - Link to facilities utilized
   - Link to researchers
3. We can connect **research**:
   - Subject matter
   - Facilities utilized
   - PIs & collaborators
4. We can include expertise:
   - Support for **GAIN**

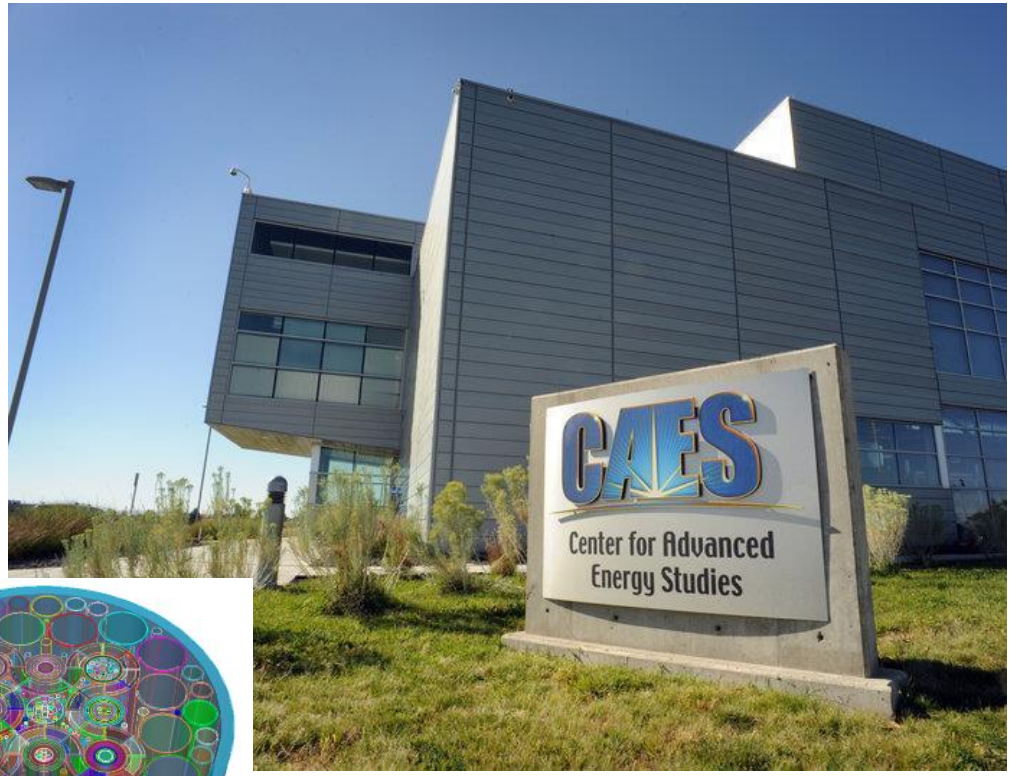


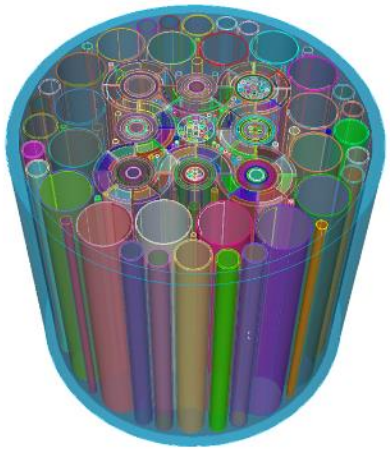
What's missing?

Contact Information for NSUF

Brenden Heidrich
(208) 526-8117
Brenden.Heidrich@INL.gov







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