November 2, 2023

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2023 ASI Program Review

Nuclear Science User Facilities Utilization for Sensor Testing and Validation

NSUF Nuclear Science User Facilities

The Nuclear Science User Facilities (NSUF)

- **Established 2007 as US DOE Office of Nuclear Energy first & only user facility**
- **Founded at Idaho National Laboratory initially intended as a single institution user facility.**
  INL remains lead and primary institution
- **NSUF operates as typical US user facility** (no cost to user, competitive proposal processes, no support or travel funding to users) but also some unique aspects

Unique aspects of NSUF

- **Consortium of facilities/capabilities, not single institution**
  9 Universities + 3 in CAES, 8 National Laboratories, 1 industry partner
- **NSUF offers multiple capabilities to a single scientific area:**
  Irradiation effects in nuclear fuels and materials.
- **Projects can last many years or be short duration.**
  Largest projects include design, fabrication, transport, irradiation, PIE, and final disposition.
- **No base funding to facilities.**
  Funding to facility is for project cost and is fully forward funded.

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	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	Argonne National Laboratory	
Massachusetts Institute of Technology	Argonne National Laboratory	Sandia National Laboratories	PNNL	Oak Ridge National Laboratory	NC State University	
NC State University	Sandia National Laboratories		Los Alamos National Laboratory	Cal	Los Alamos National Laboratory	
Ohio State	Texas A&M University		Westinghouse	PNNL		
Sandia National Laboratories	Lawrence Livermore National Laboratory		University of Michigan	Los Alamos National Laboratory		
SCK•CEN Studiecentrum voor Kernenergie Centre d'Etude de l'Energie Nucleaire			SCK•CEN Studiecentrum voor Kernenergie Centre d'Etude de l'Energie Nucleaire	NC State University; University of Michigan; Purdue University; University of Wisconsin-Madison; University of Florida		
				SCK•CEN Studiecentrum voor Kernenergie Centre d'Etude de l'Energie Nucleaire		

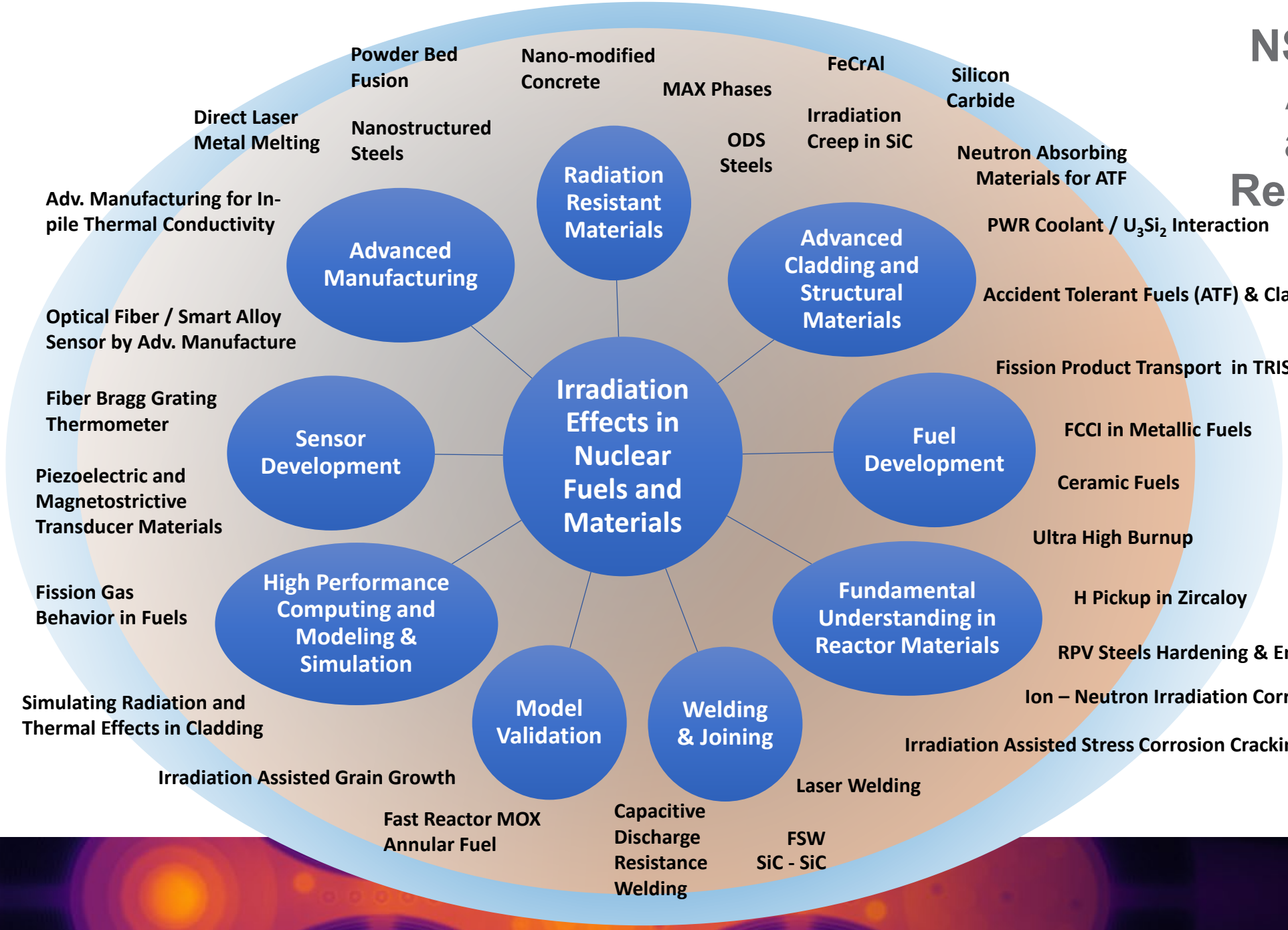
Pending Capability Additions:

- **Texas Austin: Prompt Gamma Neutron Activation Analysis 2023**
- **Penn State: Radiation Science and Engineering Center 2023**
- **ANL: APS AML HEXM beamline 2024**

Visit nsuf.inl.gov for details of individual facilities

NSUF Nuclear Science User Facilities

NSUF Research Areas Cover all Technical Readiness Levels (TRLs)



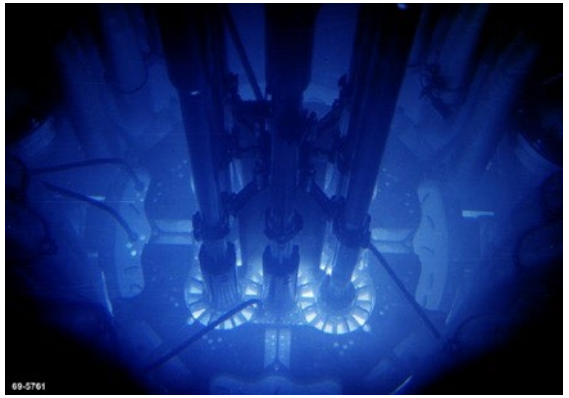
NSUF Nuclear Science User Facilities

The Nuclear Science User Facilities

Projects are selected through open competitive proposal processes

- **Rapid Turnaround Experiments** (RTE, 3 calls/year, limited $$, executed within 9 months)
- **Consolidated Innovative Nuclear Research** (CINR FOA, 1 call/year)
  - Projects include design, analyses, fabrication, transport, irradiation, disassembly, PIE, disposition
  - Possibility to also receive user R&D funding on limited number of work scopes

Neutron Irradiation + PIE	$0.5M - $4.0M	≤7 years
Neutron Irradiation only	up to ~$750K	3 years
PIE only	up to $250K	3 years
Ion or Gamma Irradiation + PIE	up to $250K	3 years
Ion or Gamma Irradiation only	up to $100K	3 years
Beamlines at other user facilities		3 years



- Proposals welcome from university, government laboratory, industry, and small business researchers.
  - Only non-proprietary projects accepted. All awarded projects are fully forward funded.

NSUF Projects Summary

FY 2007 – FY2023

- 68 CINR type projects executed
- 35 CINR type projects currently ongoing
- 525 RTEs executed
- 71 RTEs ongoing

724 total projects awarded

- 441 projects to 56 US universities
- 217 projects to 8 national laboratories
- 30 projects to 13 industry
- 36 projects to 19 international
- Total NSUF Access Award Funding: $124MM

* Data valid through 6/30/2023

CINR Funding Opportunity Announcement FY24

FINANCIAL ASSISTANCE

FUNDING OPPORTUNITY ANNOUNCEMENT

U. S. Department of Energy

Idaho Operations Office

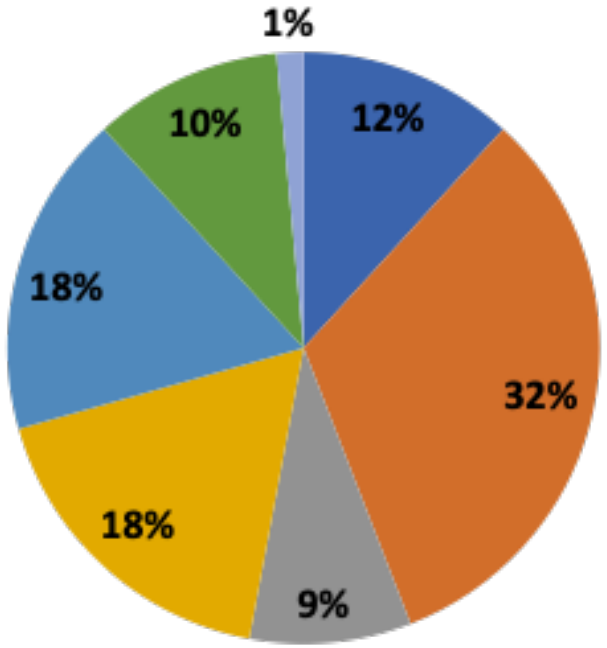
Fiscal Year 2024 Consolidated Innovative Nuclear Research

Funding Opportunity Announcement:
DE-FOA-0003038

NSUF-1.2: TESTING OF ADVANCED MATERIALS FOR SENSORS **(ELIGIBLE TO LEAD: UNIVERSITIES ONLY; UP TO 7 YEARS AND $1,000,000)** **(NSUF READINESS REQUIREMENTS APPLY)**
Applications are sought for irradiation testing and post-irradiation examination that support the development of advanced sensor materials, and the development of advanced instrumentation or measurement systems to support NE's mission to enhance the long-term viability and competitiveness of the existing fleet, and to develop an advanced reactor pipeline, and to implement and maintain national strategic fuel cycle and supply chain infrastructure. For this topic, areas of interest include irradiation testing and post irradiation examination of candidate sensor materials and candidate instrumentation systems. Proposed projects can include irradiations and post-irradiation examination to address fundamental and applied technology gaps.

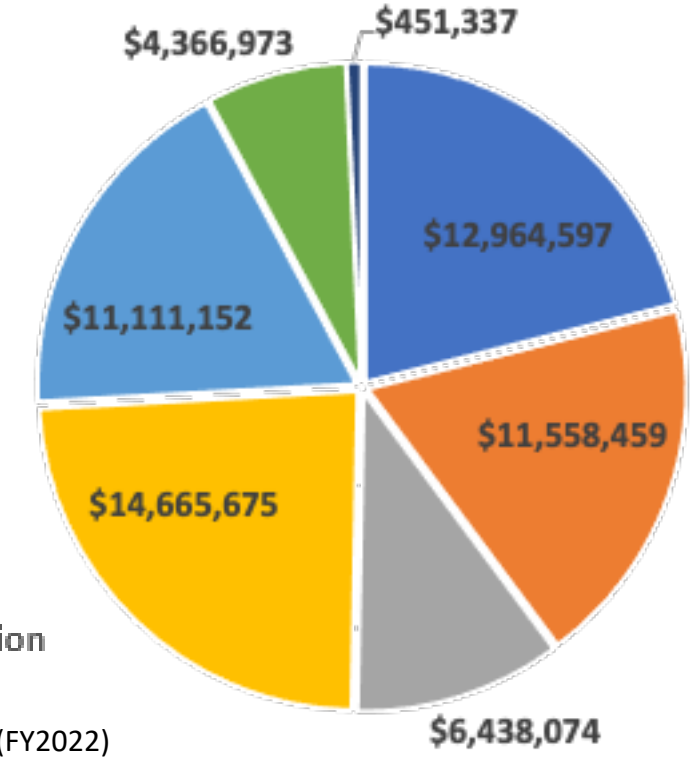
CINR Awarded Projects FY 2015 – FY 2022

Number of Awards by Field



- Additive & Advanced Manufacturing
- Fundamentals of Reactor Materials
- Welding & Joining Advanced Cladding
- Advanced Fuel Development
- Sensor Development
- Computational Model Development and Validation

Value of Awards by Field



Note, the remaining 1% is for gamma irradiation of seismic dampers (FY2022)

Graphics created by Simon Pimblott

CINR Awarded Projects

Focus on Key Technologies and Understanding

Sensor Development

Completed in:
FY17
FY18
FY19
FY20
FY21
FY22

FY	Title	Institution	Funding
2015	Ultrasound-Based Sensors for Enhanced Monitoring of Irradiation Testing	INL	$957
2017	Additive manufacturing of thermal sensors for in-pile thermal conductivity measurement	BSU	$536
	Radiation Effects on Optical Fiber Sensor Fused Smart Alloy Parts with Graded Alloy Composition Manufactured by Additive Manufacturing Processes	UPitt	$775
	Monitoring Of Temperature Of Reactor Experiments – MOTORE	SCK-CEN/INL	$100
	Benchmarking of Ultrasonic Thermometer and Fiber Bragg Grating Thermometer	SCK-CEN/INL	$140
2018	High-performance nanostructured thermoelectric materials and generators for in-pile harvesting	UND	$655
	Irradiation Behavior of Piezoelectric Materials for Nuclear Reactor Sensors	OSU	$458
2019	High Fluence Active Irradiation and Combined Effects Testing of Sapphire Optical Fiber Distributed Temperature Sensors	INL	$1,206
	Irradiation of Optical Components of In-Situ Laser Spectroscopic Sensors for Advanced Nuclear Reactor Systems	UMich	$406
	Neutron Radiation Effect on Diffusion between Zr (and Zircaloy) and Cr for Accurate Lifetime Prediction of ATF	OSU	$1,134
2020	Irradiation of Sensors and Adhesive Couplants for Application in LWR Primary Loop Piping and Components	EPRI	$635
2021	Understanding irradiation behaviors of ultrawide bandgap Ga2O3 high temperature sensor materials for advanced nuclear reactor systems	NCSU	$490
	Deployment and In-Pile Test of an Instrument for Real-Time Monitoring Thermal Conductivity Evolution of Nuclear Fuels	INL	$1,080
			$8,572

CINR Awarded Projects table created by Lindy Bean

NSUF Nuclear Science User Facilities

NSUF CINR Awards

PI	Year	Title	Institution	NSUF Capabilities	Award Budget
Joe Palmer	2020	Demonstration of Self-Powered Neutron Detectors Performance and Reliability	Idaho National Laboratory	MITR	$705,400
James Wall	2020	Irradiation of Sensors and Adhesive Couplants for Application in Light Water Reactor (LWR) Primary Loop Piping and Components	Electric Power Research Institute	PULSTAR/NCSU, LAMDA/ORNL	$635,255
Ge Yang	2021	Understanding Irradiation Behaviors of Ultrawide Bandgap Ga_2O_3 High Temperature Sensor Materials for Advanced Nuclear Reactor Systems	North Carolina State University	PULSTAR/NCSU, CAES	$490,660
Zilong Hua	2021	Deployment and In-Reactor Test of an Instrument for Real-Time Monitoring Thermal Conductivity Evolution of Nuclear Fuels	Idaho National Laboratory	MITR, INL	1,080,000

CINR FY2021: Deployment and In-Pile Test of an Instrument for Real-time Monitoring Thermal Conductivity Evolution of Nuclear Fuels

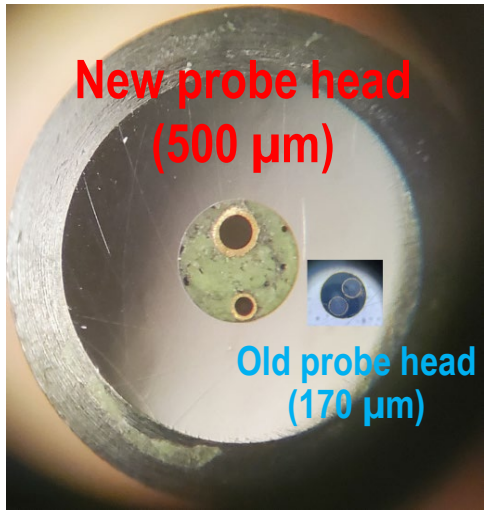
Work Scope	ID	Lead Institute	PI	Assess Value, ($k)	Duration	Collaboration Institute	Technical lead Institute	Capabilities
NSUF-1.1	24335	INL	Zilong Hua	1,080	2 years	MIT	MIT	Irradiation and PIE at MITR

Objective

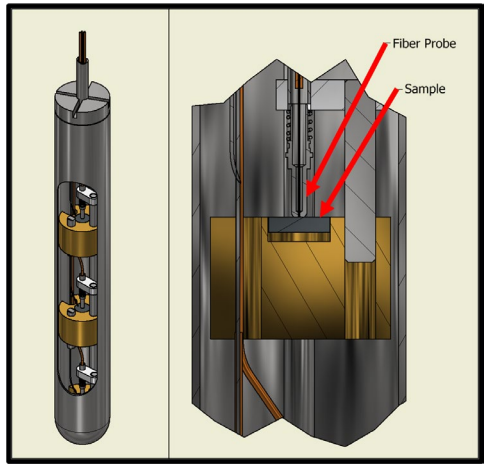
- Deploy a recently developed fiber-optic-based instrument in the MITR to perform in-reactor thermal conductivity measurements of fuels and materials

Outcome/Impact

- The developed tools will provide unique insights and a better understanding of defect generation and evolution in nuclear fuels during operation and the corresponding temporal and spatial thermal conductivity variation
- This knowledge will benefit the advanced fuel performance codes and the development of next-generation fuels



Sensor output head, with the fibers for heating and for detection



Design diagram of the instrument packages

CINR FY2020: Demonstration of Self-Powered Neutron Detectors Performance and Reliability

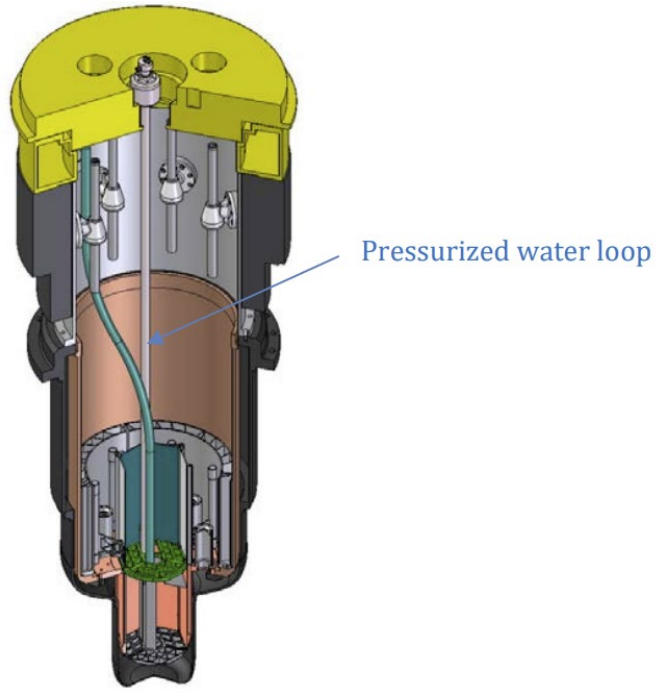
Work Scope	ID	Lead Institute	PI	Assess Value, ($k)	Duration	Collaboration Institute	Technical lead Institute	Capabilities
NSUF-2.3	19178	INL	Joe Palmer	705	3 years	MIT	MIT	Irradiation at MITR

Objective

- Demonstrate by in-pile testing in a high-power test reactor the operation and reliability of Self-Powered Neutron Detectors (SPNDs) produced commercially by a domestic source

Outcome/Impact

- Enable the adoption of Self-Powered Neutron Detectors (SPND) technology by DOE-NE programs that perform experiments in ATR
- Demonstrate the technology applicability to advanced reactor concepts MITR irradiation highly impacted the fulfillment of DOE-NE programs objectives



Cutaway 3-D model of the MITR showing in-core water loop installed in the reactor core (fuel elements removed for clarity)

CINR FY2019: High Fluence Active Irradiation and Combined Effects Testing of Sapphire Optical Fiber Distributed Temperature Sensors

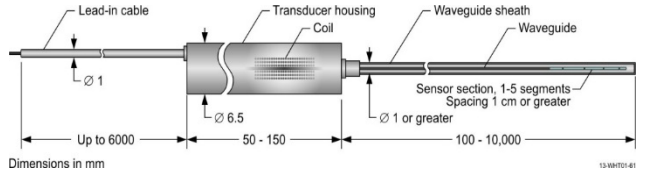
Work Scope	ID	Lead Institute	PI	Assess Value, ($k)	Duration	Collaboration Institute	Technical lead Institute	Capabilities
NSUF-1.1	16380	INL	Joshua Daw	1,206	3 years	MIT, OSU, NETL, ORNL	MIT, OSU	Sensor fabrication and in-pile testing at OSU Out-of-pile testing at INL and NETL Irradiation at MITR

Objective

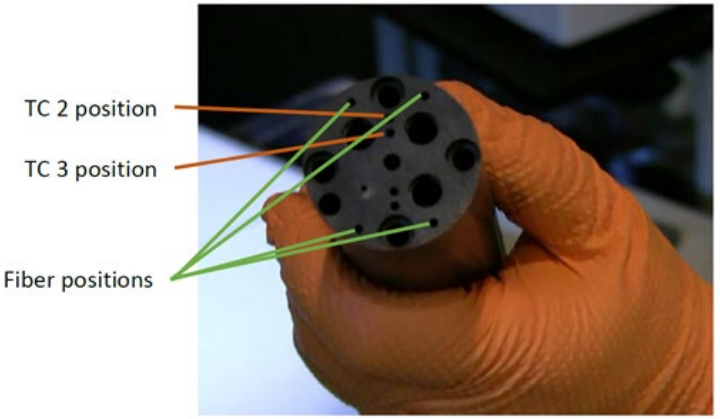
- Investigate the in-pile performance of sapphire optical fiber temperature sensors
- Develop clad sapphire optical fibers for in-pile instrumentation

Outcome/Impact

- Deliver the capability of applying modern optical fiber sensing techniques used in other extreme environment applications for the testing of nuclear fuel and materials
- Allow the access to operational data with spatial resolution during irradiation testing
- Greatly reduce the time and cost associated with developing, demonstrating, and licensing new nuclear due to the accurate online monitoring of test parameters



Schematic diagram of magnetostriction based ultrasonic thermometer.



Evaluate the lifetime and sensing performance of the sensor under irradiation to high neutron fluence

CINR FY2017: Additive Manufacturing of Thermal Sensors for In-pile Thermal Conductivity Measurement

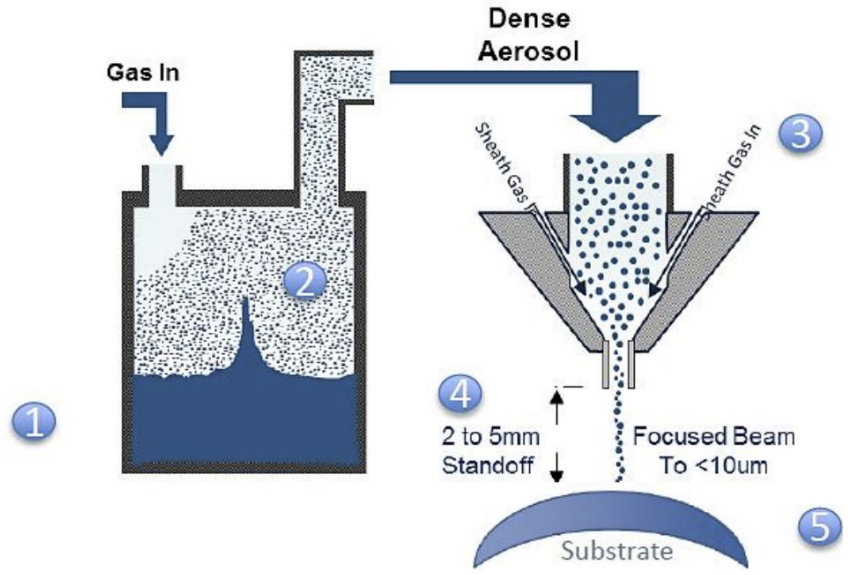
Work Scope	ID	Lead Institute	PI	Assess Value, ($k)	Duration	Collaboration Institute	Capabilities
NSUF-1.2A	12527	Boise State Univ	Yanliang Zhang	535	3 years	NCSU, MIT	Irradiation at MITR and NCSU PULSTAR, PIE at CAES

Objective

- Print sensors onto conforming surfaces
- Evaluate sensor performance with characterization, testing, & modeling
- Evaluate sensor in-pile performance and irradiation effect
- Validate the performance of printed sensors using other independent methods

Outcome/Impact

- Advance scientific knowledge of the in-pile performance for sensors fabricated using additive manufacturing
- Accelerate the deployment of additive manufacturing to fabricate a broad range of sensors and instrumentation for both in-pile and out-of-pile measurements



Schematic showing use of an aerosol jet printer to fabricate a sensor that conforms to a 3D substrate

FY 2022 RTE Highlights

Awards Valuation of $1.4M

77 proposals submitted from 28 institutions

(79/32 in FY21, 168/44 in FY20, 185/51 in FY19)

- 13 US Universities
- 6 National Laboratories
- 3 Foreign Institutions
- 6 Industry

30 experiments awarded PIs from 20 institutions

(29/20 in FY21, 56/29 in FY20, 99/38 in FY19)

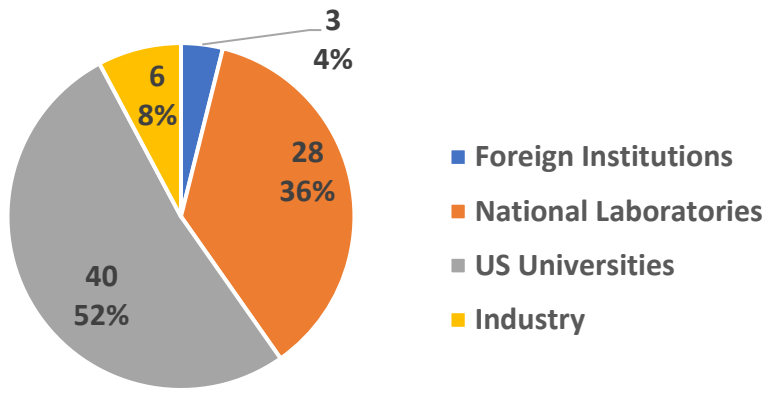
- 20 US Universities
- 10 National Laboratories
- 0 Foreign Institutions
- 0 Industry

9 NSUF facilities to perform experiments

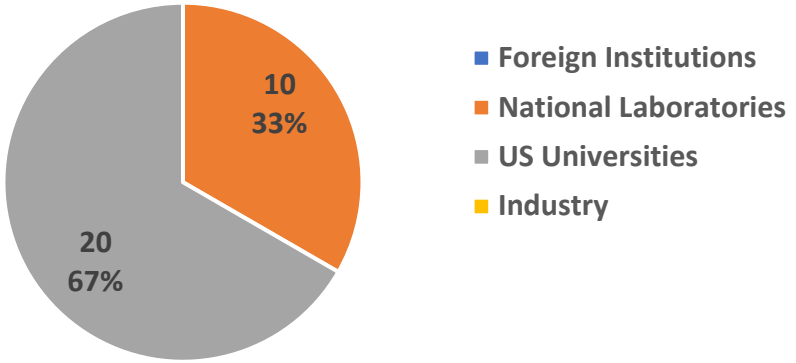
(10 in FY21, 14 in FY20, 12 in FY19)

- 9 INL
- 5 ANL/IVEM, 5 ORNL/LAMDA, 2 BNL/NSLS-II, 1 PNNL
- 4 Michigan, 2 TAMU, 2 OSU
- 7 CAES

Submitted Proposal Institution Type



Distribution of RTE Awards



NSUF RTE Awards 2023

PI	Title	Institution	NSUF Capabilities
Jack Lanza	Irradiation of Radiation-hard GaN Transistors for Mixed Gamma and Neutron Field Under High Temperature	The Ohio State University	The Ohio State University Research Reactor
Emily Hutchins	Neutron Irradiation of Updated In-Pile Steady State, Extreme Temperature Experiment (INSET)	University of Tennessee-Knoxville	The Ohio State University Research Reactor
Frederick Reed	Neutron Irradiation of a radiation resistant digitizer at PULSTAR	Oak Ridge National Laboratory	PULSTAR (North Carolina State University)
Zhibin Yu	Irradiating a novel thin-film scintillator for neutron radiography	Florida State University	The Ohio State University Research Reactor
Stephen Taller	Increasing the Sensitivity of Passive SiC Thermometry Through Nanocalorimetry Experiments	Oak Ridge National Laboratory	Michigan Center for Materials Characterization (University of Michigan)

NSUF RTE Awards 2023

PI	Title	Institution	NSUF Capabilities
Ge Yang	Investigation of evolution of defects in β-Ga2O3 under irradiation and high temperature	North Carolina State University	Intermediate Voltage Electron Microscopy (IVEM)-Tandem Facility (Argonne National Laboratory
Angela Di Fulvio	Testing of ex-core monitoring configurations at the Ohio State University Research Reactor (OSURR)	University of Illinois at Urbana-Champaign	The Ohio State University Research Reactor
Mauricio Pereira da Cunha	In-Situ Irradiation and RF Characterization of Langasite-Based Surface Acoustic Wave Sensors for Advanced Nuclear Reactor Applications	University of Maine	The Ohio State University Research Reactor
Connor Harper	Time-Resolved Neutron Damage Characterization using In Situ Positron Annihilation Spectroscopy	Idaho State University	The Ohio State University Research Reactor
Biswajit Ray	Characterization of the Total-Dose Effect on State-of-the-Art Static Random-Access Memory	The University of Alabama in Huntsville	The Ohio State University Research Reactor


NSUF
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