Brenden Heidrich,
Director

Irradiation Testing User Development Workshop

May 20, 2024

Opportunities for Universities in Material Science with the Nuclear Science User Facilities



INL/MIS-24-77373

- **NSUF Overview**
  - Program Office
  - Partners
  - Outreach
- **Competitive Access Awards**
  - Rapid Turnaround Experiments (RTE)
  - Consolidated Innovative Nuclear Research (CINR)
  - Research Areas
- **Capability Development**
  - Nuclear Fuels and Materials Library (NFML)
  - Collaborations and SAM
  - Instrument Scientist Support

The Nuclear Science User Facilities (NSUF)

- **Established in 2007 as the United States Department of Energy Office of Nuclear Energy (DOE-NE)'s first & only user facility**
- **Founded at Idaho National Laboratory (INL)** (initially intended as a single institution user facility)
  - INL remains lead and primary institution



- **NSUF operates similarly to other U.S. user facilities** (no cost to user, competitive proposal processes, no travel funding to users, etc.)

Unique aspects of NSUF

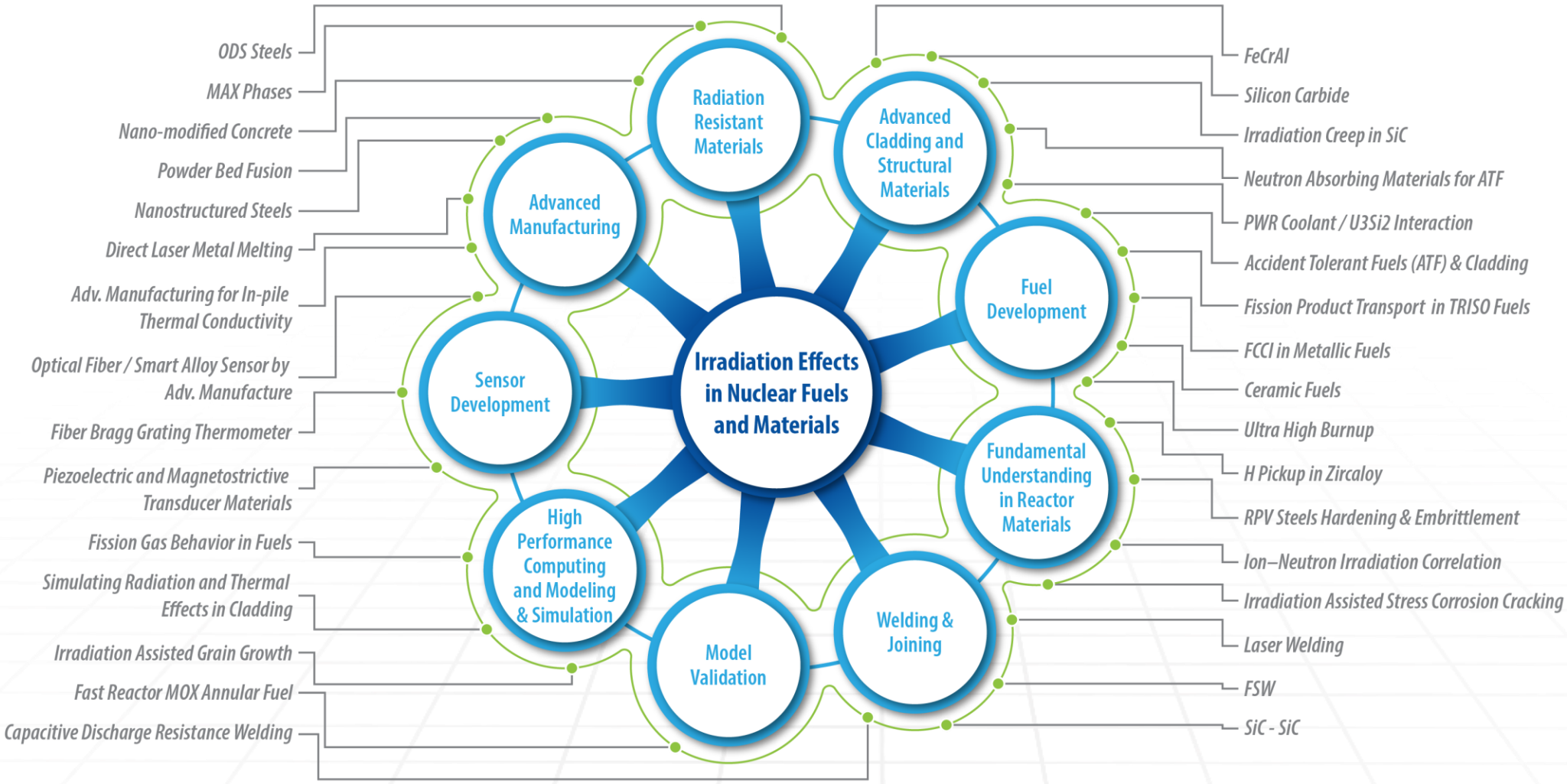
- **Consortium of facilities/capabilities, not single institution (21 Institutions)**
  - 11 Universities + 3 Univ. in CAES, 8 National Laboratories, 1 industry partner
- **NSUF offers multiple capabilities to a single scientific area**
  - Irradiation effects in nuclear fuels and materials
- **Projects can last many years or have a short duration**
  - Largest projects include design, fabrication, transport, irradiation, post irradiation examination (PIE), and final disposition
- **No base funding to facilities**
  - Funding to facility is for project cost and is fully forward funded



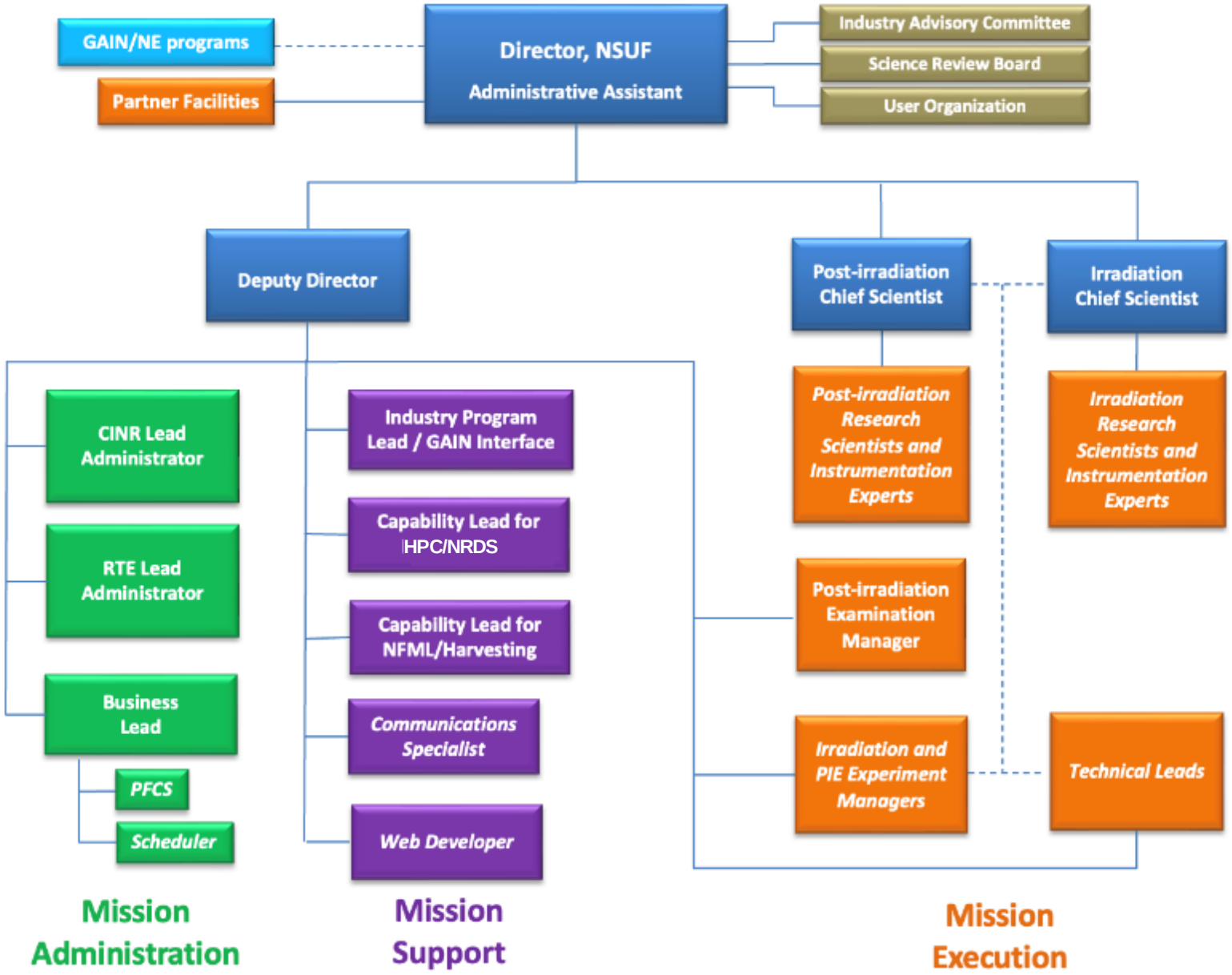
The Nuclear Science User Facilities (NSUF)

- **Vision**
  - Continue U.S. leadership in nuclear energy research with cutting edge resources.
- **Mission**
  - Coordinate a consortium of institutions to provide no-cost access to unique and highly specialized nuclear research facilities and technical expertise.
- **Goal**
  - Produce the highest quality research results that increase understanding of advanced nuclear energy technologies important to DOE-NE and industry while creating new innovative concepts.
- **Strategy: Strategic Research and Development (R&D) Support**
  - Provide mechanisms for research organizations to conduct irradiations and post irradiation analyses and utilize computing and experimental resources not normally accessible to these organizations.

NSUF Research Areas Cover all Technical Readiness Levels (TRLs)



NSUF Program Office Structure



NSUF Points of Contact

DOE-NE 72

Ms. Alice Caponiti
Ms. Suibel Schuppner
Dr. Christopher Barr
Ms. Willettia Amos (ID)

Ion Beams/Gamma Irradiation

Prof. Kevin Field (UM)
Prof. Adrien Couet (UW)
Dr. Wei-Ying Chen (IVEM, ANL)
Dr. Michael Starr (SNL)
Prof. Lin Shao (TAMU)
Dr. Scott Tumey (LLNL)
Dr. Michael Starr (SNL)
Prof. Raymond Cao (OSU)

Neutron Irradiation

Dr. Keith Jewell (INL)
Dr. Gordon Kohse (MIT)
Prof. Ayman Hawari (NCSU)
Mr. Kory Linton (ORNL)
Prof. Raymond Cao (OSU)
Dr. Richard Sisson (SNL)
Dr. Joris Van den Bosch (BNRC)
Prof. Kenan Ünlü (PSU)

Beamlines

Dr. Simerjeet Gill (BNL)
Dr. Xuan Zhang (ANL)
Prof. Ayman Hawari (NCSU)
Dr. Tarik Saleh (LANL)
Dr. Jon Almer (ANL)
Prof. William Charlton (UTA)

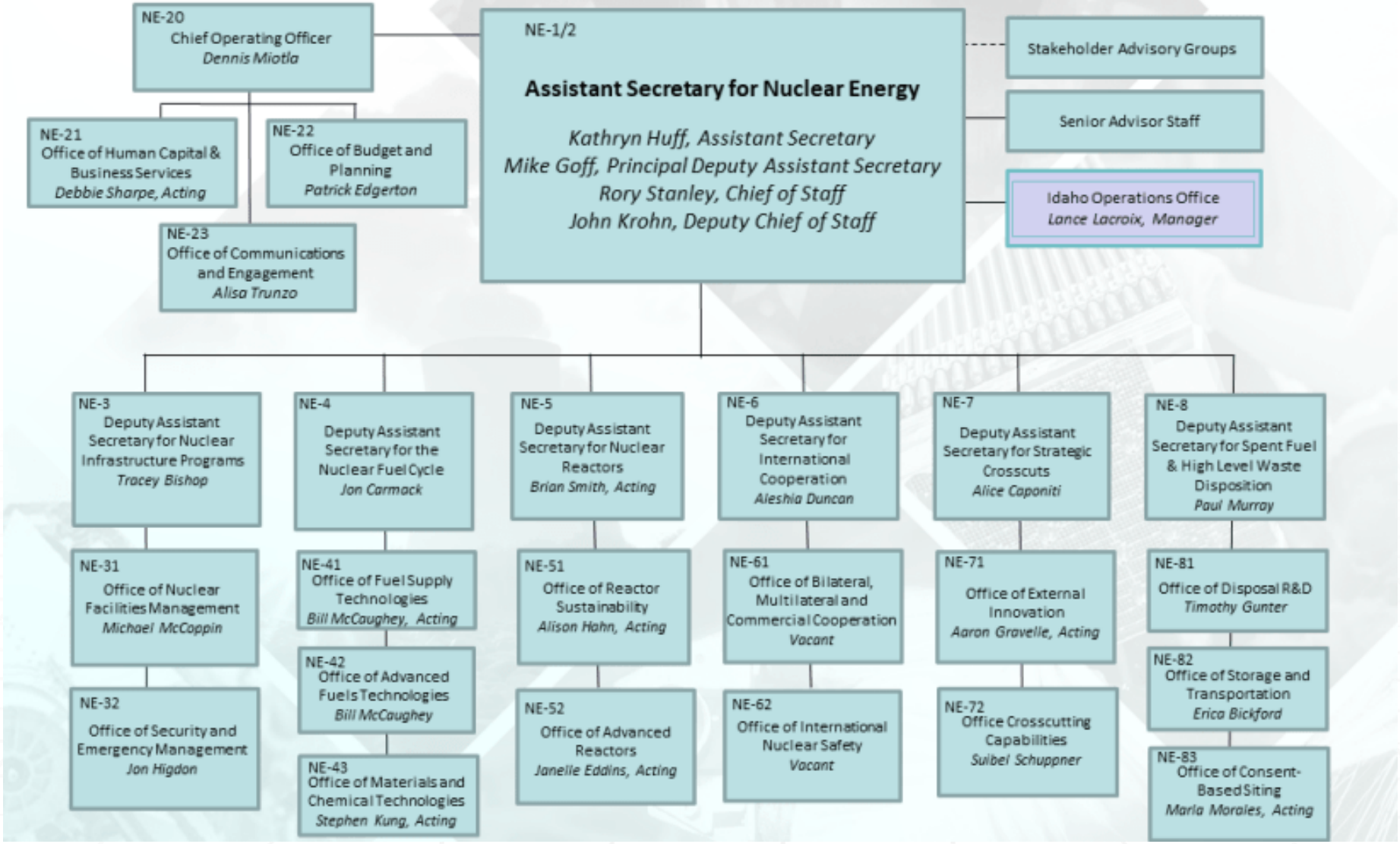
Examinations

Dr. Colin Judge (INL)
Dr. Rongjie Song (INL)
Dr. Jeffrey Giglio (INL)
Mr. Kory Linton (ORNL)
Dr. Yaqiao Wu (CAES)
Dr. Stu Maloy (PNNL)
Prof. Ahmed Hassanein (Purdue)
Prof. Peter Hosemann (UCB)
Ms. Catou Cmar (Westinghouse)
Dr. Alexander Long (LANL)
Prof. Yong Yang (UFla)
Prof. Kumar Sridharan (UW)
Prof. Ayman Hawari (NCSU)
Prof. Kevin Field (UM)
Dr. Joris Van den Bosch (BNRC)

… and many more scientists, engineers, and technical staff at INL and all partner facilities

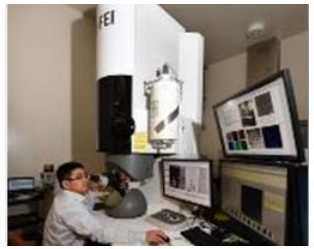
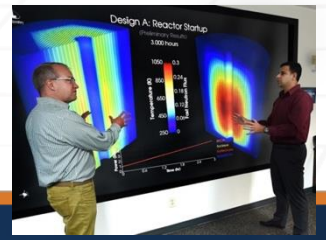
U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

April 7, 2024



The Best Capabilities across the Nation



Neutron Reactors		12 reactor facilities at national laboratories and universities including the Advanced Test Reactor at INL
Gamma & Ion Irradiation		7 gamma irradiation facilities and 7 ion beam facilities at national laboratories and universities
Post-Irradiation Examination		Multiple hot cell and broad post-irradiation examination facilities including advanced characterization methods
Beamlines		Synchrotron and neutron beamlines for nuclear fuel and materials studies
Computational Resources		Scientific high-performance computing capabilities for advanced modeling and simulation at INL

NSUF Nuclear Science User Facilities

Cutting-Edge Resources: Access to infrastructure and associated capabilities across 21 partner sites

Open access: Available to industry, academia, and national labs for non-proprietary R&D

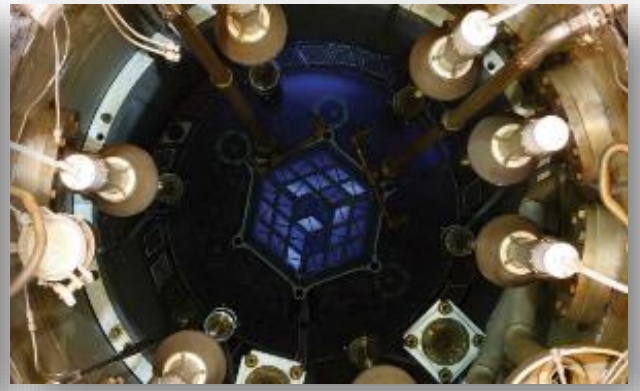
Education and training: Workshops and hands-on skill development

Impact: Increase understanding to drive innovation across nuclear energy technologies

Graphics courtesy of Christopher Barr

Neutron Irradiation Capabilities












Hot Cell Capabilities



Idaho National Laboratory



Idaho National Laboratory



Massachusetts Institute of Technology



Westinghouse Churchill Laboratories



Oak Ridge National Laboratory



Pacific Northwest National Laboratory

High Performance Computing (HPC) Resources

- NSUF HPC systems support a wide range of users and programs as a shared-use resource for national laboratories, universities, and industry
- **Bitterroot (2024)**
  - 374 nodes, 41,888 cores
  - Will be delivered March 16, 2024
- **Hoodoo (2021)**
  - **Machine Learning Cluster**
  - **108 A100 GPUs**
- **Sawtooth (2020)**
  - 6 Petaflops performance
  - 2,079 compute nodes, 99,972 compute cores
  - #37 on November 2019 TOP500 list
- **Lemhi (2018)**
  - 1 Petaflop performance
  - 504 compute nodes, 20,160 compute cores
  - #427 on November 2018 TOP500 lst

Bitterroot



Sawtooth

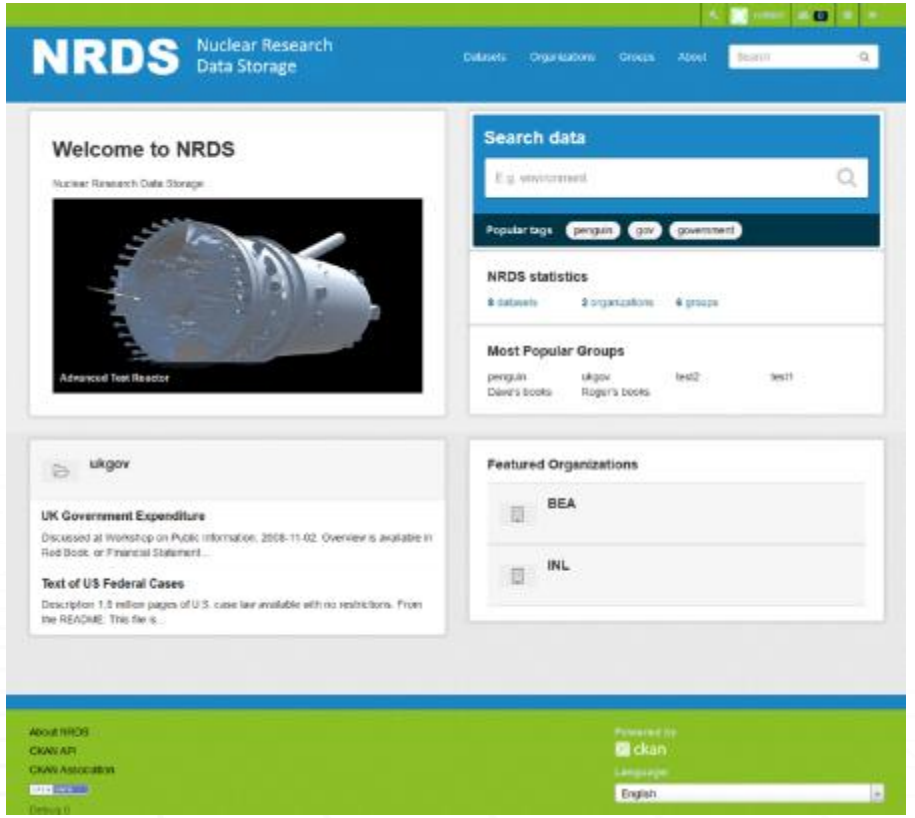


Lemhi



NSUF Nuclear Research Data System (NRDS): https://nrds.inl.gov

- **NRDS:** a place for public data to be stored and accessible in perpetuity
- **Near real-time analysis**
  - Stored close to HPC systems, allows data to be analyzed in near real time
- **Artificial Intelligence/Machine Learning (AI/ML) analysis toolsets**
  - Super resolution
  - Active detection
- **Publicly available**
  - Data co-located with projects
  - Easy to find via search and tags
  - Traceable
  - Digital Object Identified (DOI) for projects
  - Variety of licenses for PIs to choose for their data
- **FpAIRe data**
  - Findability, Peekable, Accessibility, Interoperable, Reusable, Extensible





Nuclear Science User Facilities

New Partner Capabilities: Activated Materials Laboratory at APS-U

- NSUF funded construction of the Activated Materials Laboratory (AML) in FY 2022 as part of the Advanced Photon Source Upgrade (APS-U) project to create a new capability for NSUF users.
- The collaboration is planned to provide access to NSUF users at the High-Energy X-ray Microscope beam station for **irradiated fuels and materials** research.
- AML staff at APS held a workshop, sponsored by NSUF for potential AML users in November 2023.
- This capability is planned to be available in FY2025.





Credit: Argonne National Laboratory

New Partner Capabilities: Penn State Reactor Facility

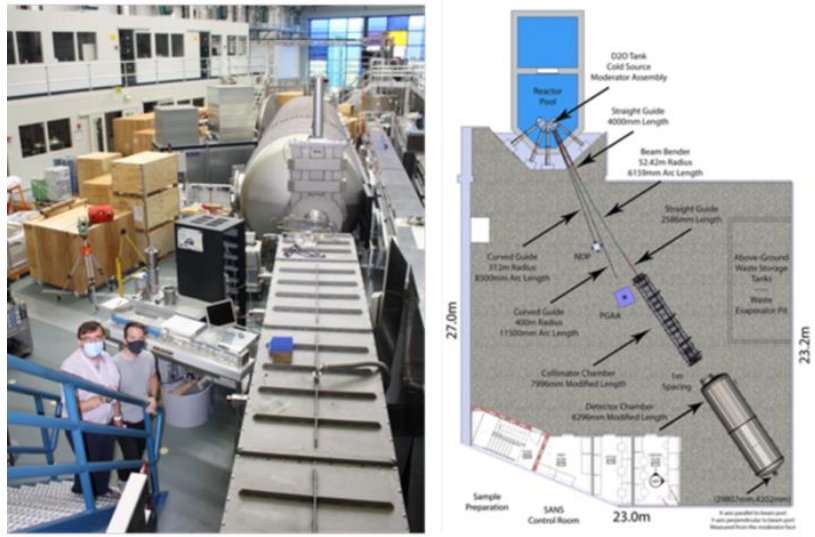
Radiation Science & Engineering Center (RSEC) Neutron Beam Laboratory

Five core neutron beam ports provide seven new neutron beam lines for the beam experimental facilities.

- BP#1 is an epithermal neutron beam facility
- BP#2 is thermal beam that will be used for exploratory research projects
- BP#3 is designated for neutron transmission projects
- BP#4 is dedicated for Neutron Imaging Facility
- Cold Neutron Beam port (three beam lines)

The Small Angle Neutron Scattering facility (SANS) has three overarching themes:

- Materials under extreme conditions (e.g., nuclear fission/fusion materials, radiation hardening, corrosive-resistant materials, etc.)
- Design of complex soft and hard matter (e.g., glassy metals, non-crystalline solids, porous metals, natural biopolymers, radiation-hardened high-entropy alloys, and electronic materials)
- Dynamics of biological matter (e.g., cell-material interactions, protein-surface interactions, neuron cell-water interactions)



Credit: Penn State University

"The addition of new neutron beam port facilities including a SANS instrument that is donated by The Helmholz-Zentrum Berlin, time-of-fight neutron depth profiling, new prompt gamma activation analysis system and new neutron imaging system in the existing RSEC capabilities, will expose students to a range of important applications."

New Partner Capabilities: University of Texas at Austin Reactor

Nuclear Engineering Teaching Laboratory

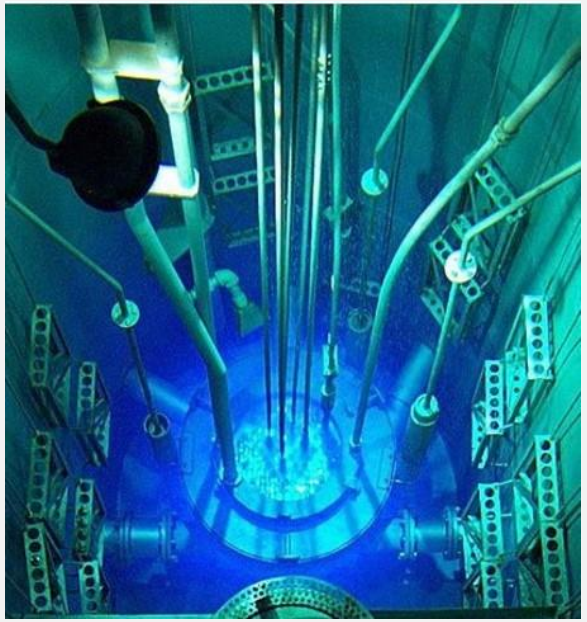
Prompt Gamma Neutron Activation Analysis Capability (PGNAA)

The PGNAA facility is currently being used to:

- Assay boron concentration for an ongoing research project
- Determine mercury content in scale and corrosion layers inside steel pipe
- Measure hydrogen content in steel for correlation to stress cracking phenomena
  - Hydrogen concentrations less than 20 ppm in steel have been measured to date

- Plans for PGNAA upgrades:
  - Automated (sample) motion controls
  - Shielding optimization
  - Environmental chamber for reduction of humidity (in progress)
  - Development of fluorine-based neutron (detector) shielding (in progress)

A proposal to acquire equipment supporting cross calibration for measurements of hydrogen in metal is in review.





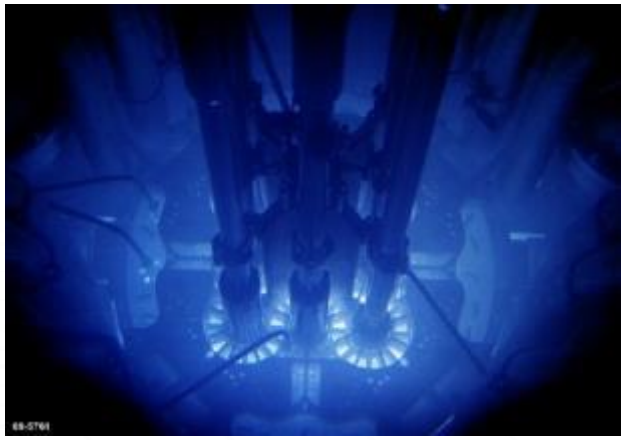
Credit: University of Texas at Austin

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NSUF Funding Calls

- **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	(cost included)	3 years



- **Rapid Turnaround Experiments (RTE, 3 calls/year +1 special call)**
  - Limited funding, executed within 9 months
- Projects are selected through open competitive proposal processes
- 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 – 2023)

- **Total NSUF Access Award Funding: $124M**
- **751 total projects awarded**
  - 77 CINR type projects executed
  - 24 CINR type projects currently ongoing
  - 553 RTEs executed
  - 71 RTEs ongoing
- **Awards distribution by institution type**
  - 449 projects to 67 U.S. universities
  - 233 projects to 8 national laboratories
  - 30 projects to 14 industrial users
  - 39 projects to 13 international users



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NSUF Rapid Turnaround Experiments FY 2023

The 1st RTE call opened in October 2022. Awards were made in February 2023.
The 2nd RTE call opened in February 2023. Awards were made in June 2023.
The 3rd RTE call opened in June 2023. Awards were made in September 2023.

The NSUF awarded 74 of the 150 proposals evaluated (49%).

- The RTE budget estimate for the 74 awarded proposals for FY 2023 is $4,719,961 (52%).
  - The average cost of the awarded RTEs in FY 2023 is $63,783
- The RTE budget estimate to award all 150 proposals for FY2023 is $8,996,909.
  - The average cost of all proposed RTEs in FY 2023 is $59,979

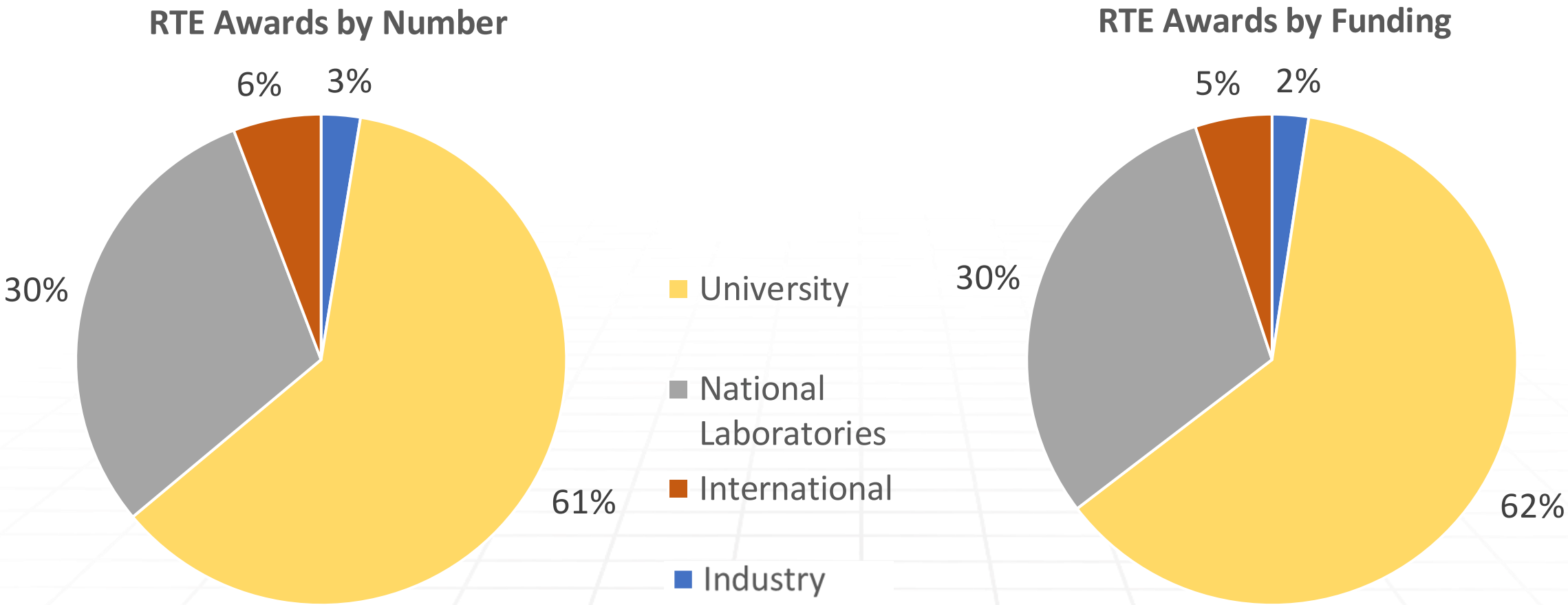
The metrics for the three FY 2023 RTE Calls are as follows:

- 43 awards (out of 88 submitted) to PIs from **U.S. universities** (49%)
- 27 awards (out of 45 submitted) to PIs from **U.S. national laboratories** (60%)
- 2 awards (out of 11 submitted) to PIs from **U.S. Industry** (18%)
- 2 awards (out of 10 submitted) to PIs from **international institutions** (20%)
- 3 awards (out of 5 submitted) to **minority serving institutions** (60%)
- 17 awards (out of 37 submitted) to **female PIs** (46%)



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RTE Awarded Projects up to FY 2023: by Institution Type



NSUF Rapid Turnaround Experiments (small projects)



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NSUF FY 2023 CINR Access Awards

Lead Institution	PI	Value, $M	Duration	Title
University of Texas at San Antonio	Prof. Elizabeth Sooby	$2.5	6 years	UN multi-design irradiation campaign: a critical assessment of accelerated burnup and main correlations for mechanistic fuel performance modeling

Objective:

To produce a robust array of uranium mononitride (UN) irradiated samples to serve post irradiation examination (PIE) and demonstrate the significant performance margins and safety of UN. The proposing team, which is comprised of fuels experts from the academic, national laboratory, and industry sectors, aims to probe the impact of fabrication impurities and fuel density as a function of both temperature and burn-up.

Collaborators:

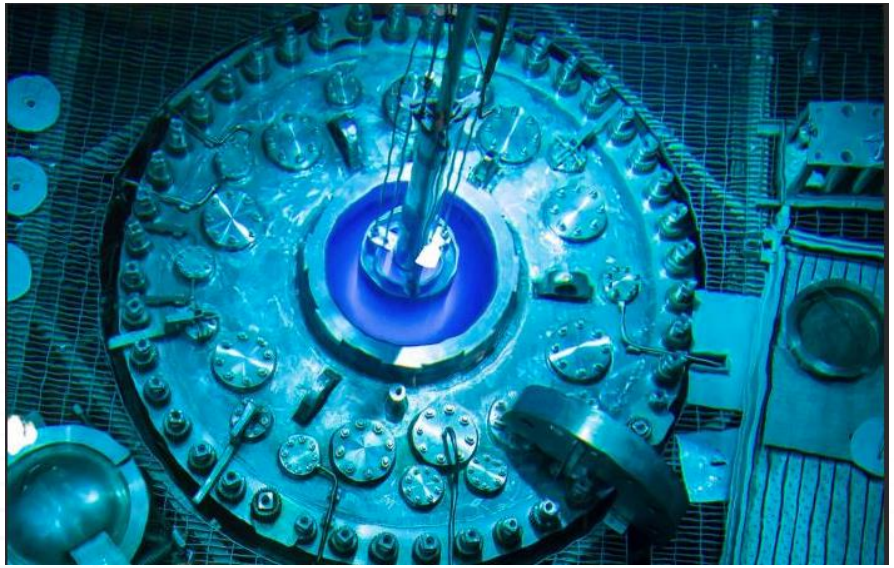
Drs. Joshua White, Michael Cooper - LANL
Drs. Jason Harp, Nathan Capps - ORNL
Drs. Denise Lopes, Luke Olson - Westinghouse

Technical Lead:

Mr. Kory Linton, ORNL

Capabilities:

ORNL - High Flux Isotope Reactor (HFIR), Irradiated Fuels Examination Laboratory (IFEL), and Low Activation Materials Development and Analysis (LAMDA) facilities



NSUF-1.1: Core and Structural Materials and Nuclear Fuel Behavior and Advanced Nuclear Fuel Development

Graphics courtesy of Lindy Bean

NSUF FY 2023 CINR Access Awards, continued

Lead Institution	PI	Value, $M	Duration	Title
Purdue University	Prof. Janelle Wharry	$2.3	5 years	Irradiation-Corrosion of Alumina-Forming Austenitic Stainless Steels in Static Lead

Objective:

Investigate the performance of alumina-forming austenitic stainless steels in coupled extremes of neutron irradiation and static lead. The results of this work will inform the extent of liquid metal embrittlement of this leading candidate material for lead fast reactor designs. A novel irradiation-corrosion capsule for miniature tensile specimens will be utilized, and post-irradiation/corrosion examination will include structural, chemical, and mechanical characterizations.

Collaborators:

Drs. Bruce Pint, Tim Graening, Timothy Lach, Yukinori Yamamoto and Mr. Kory Linton - ORNL
Prof. Ahmed Hassanein - Purdue
Dr. Michael Ickes - Westinghouse

Technical Lead:

Mr. Kory Linton, ORNL
Prof. Ahmed Hassenein, Purdue University

Capabilities:

ORNL - High Flux Isotope Reactor (HFIR), Irradiated Material and Testing (IMET), and Low Activation Materials Development and Analysis (LAMDA) facilities.

Purdue University's Interaction of Materials with Particles and Components Testing (IMPACT) Laboratory.





NSUF-1.1: Core and Structural Materials and Nuclear Fuel Behavior and Advanced Nuclear Fuel Development

Graphics courtesy of Lindy Bean

NSUF FY 2023 CINR Access Awards, continued

Lead Institution	PI	Value, $M	Duration	Title
Oak Ridge National Laboratory	Dr. Maxim Gussev	$1.6	3 years	Elemental Effects on Radiation Damage in Tempered Martensitic Steels Irradiated to High Doses at Fast Reactor Relevant Temperatures

Objective:

During several testing campaigns of irradiated materials (past and current), it has been observed that highly irradiated (>10 dpa) austenitic stainless steels can undergo intergranular brittle fracture at ambient conditions. This project is intended to support continued operation of light water reactors via analyzing and mitigating this phenomenon.

Collaborators:

Prof. Gary Was, University of Michigan
Ms. Catherine Cmar, Westinghouse

Technical Leads:

Mr. Kory Linton, ORNL
Prof. Kevin Field, University of Michigan
Ms. Catherine Cmar, Westinghouse

Capabilities:

ORNL's Low Activation Materials Development and Analysis (LAMDA) facility

University of Michigan's Irradiated Material Testing Laboratory

Westinghouse Churchill Laboratory Services

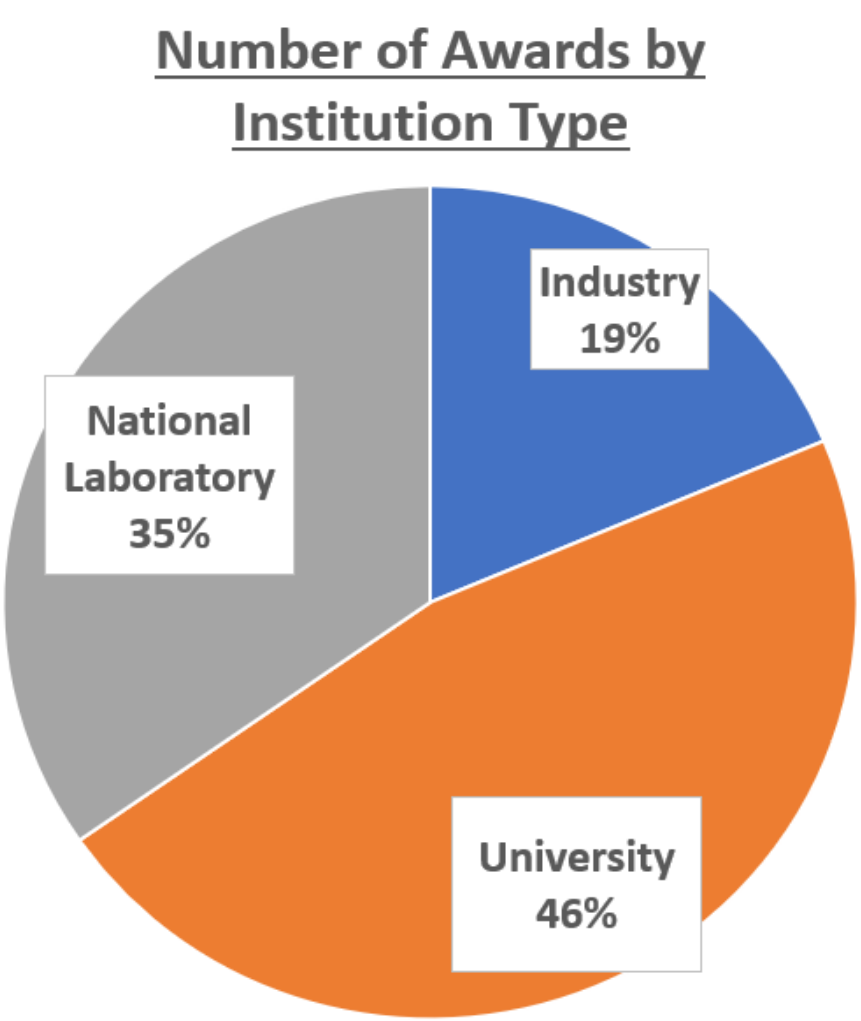
NSUF-1.1: Core and Structural Materials and Nuclear Fuel Behavior and Advanced Nuclear Fuel Development

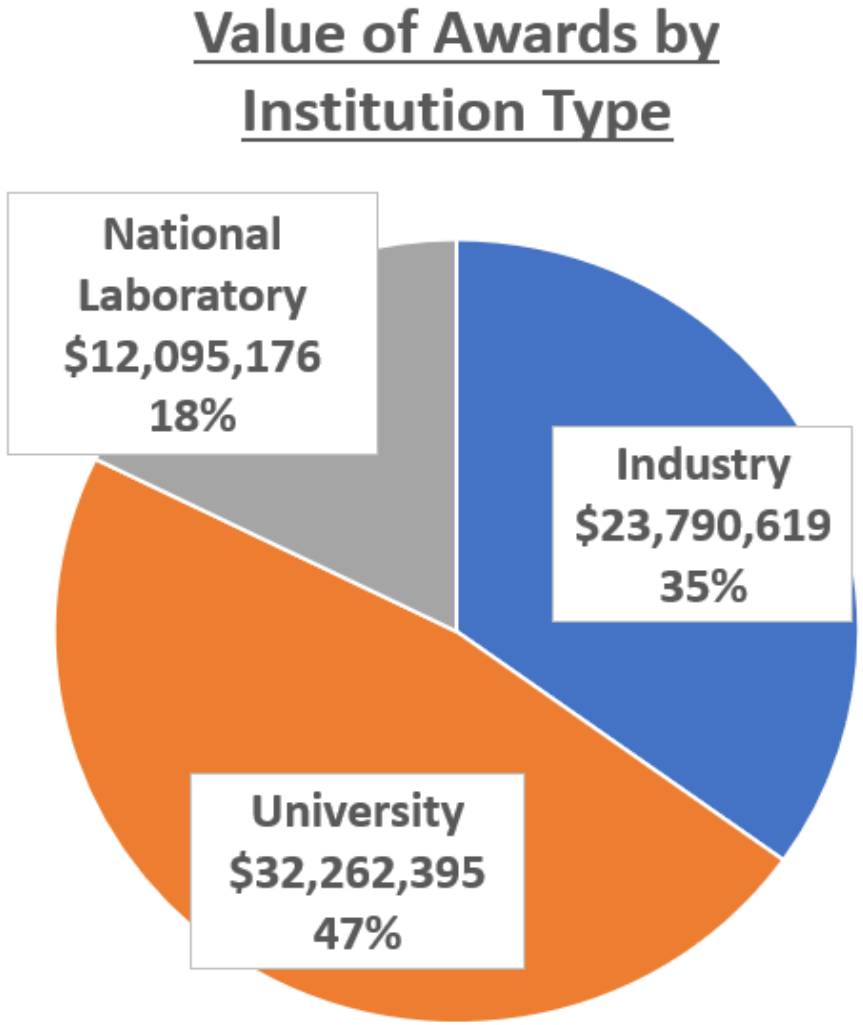




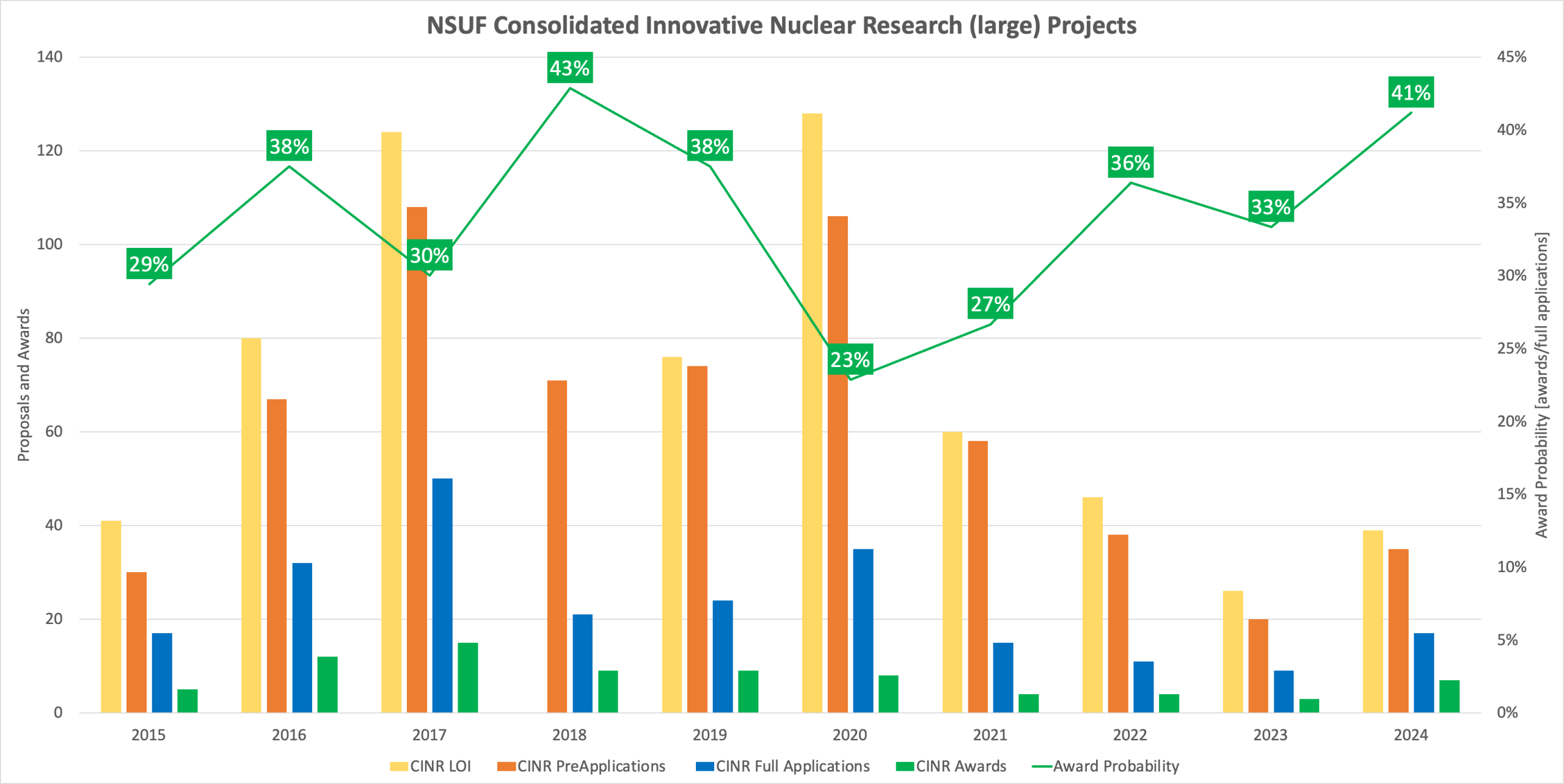
Graphics courtesy of Lindy Bean

CINR Awarded Projects FY 2015–FY 2023



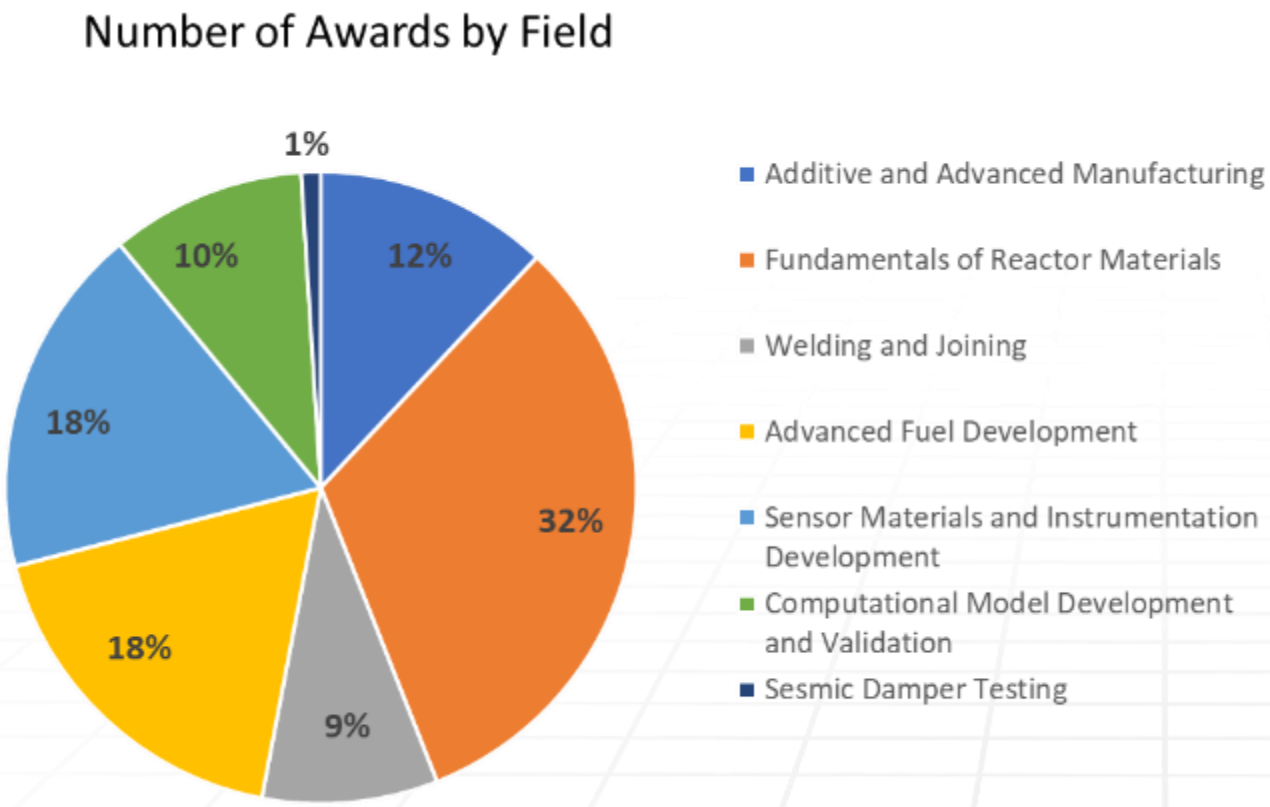


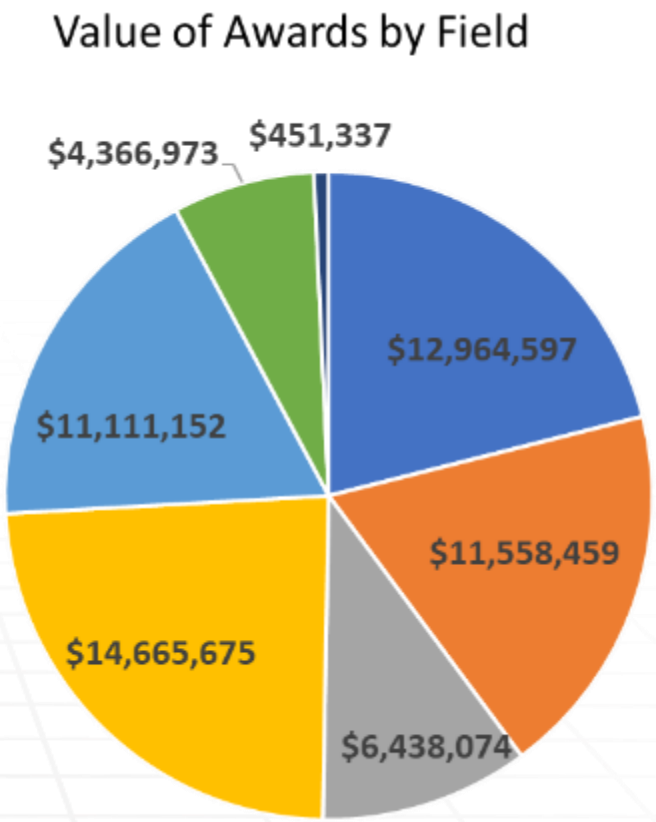
Graphics created by Lindy Bean


NSUF Consolidated Innovative Nuclear Research (large) Projects
Proposals and Awards
Award Probability [awards/full applications]
140
120
100
80
60
40
20
0
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
29%
38%
30%
43%
38%
23%
27%
36%
33%
41%
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
CINR LOI
CINR PreApplications
CINR Full Applications
CINR Awards
Award Probability

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NSUF CINR Awarded Projects up to FY 2023: by Research Field





Summary of CINR work in various technical areas

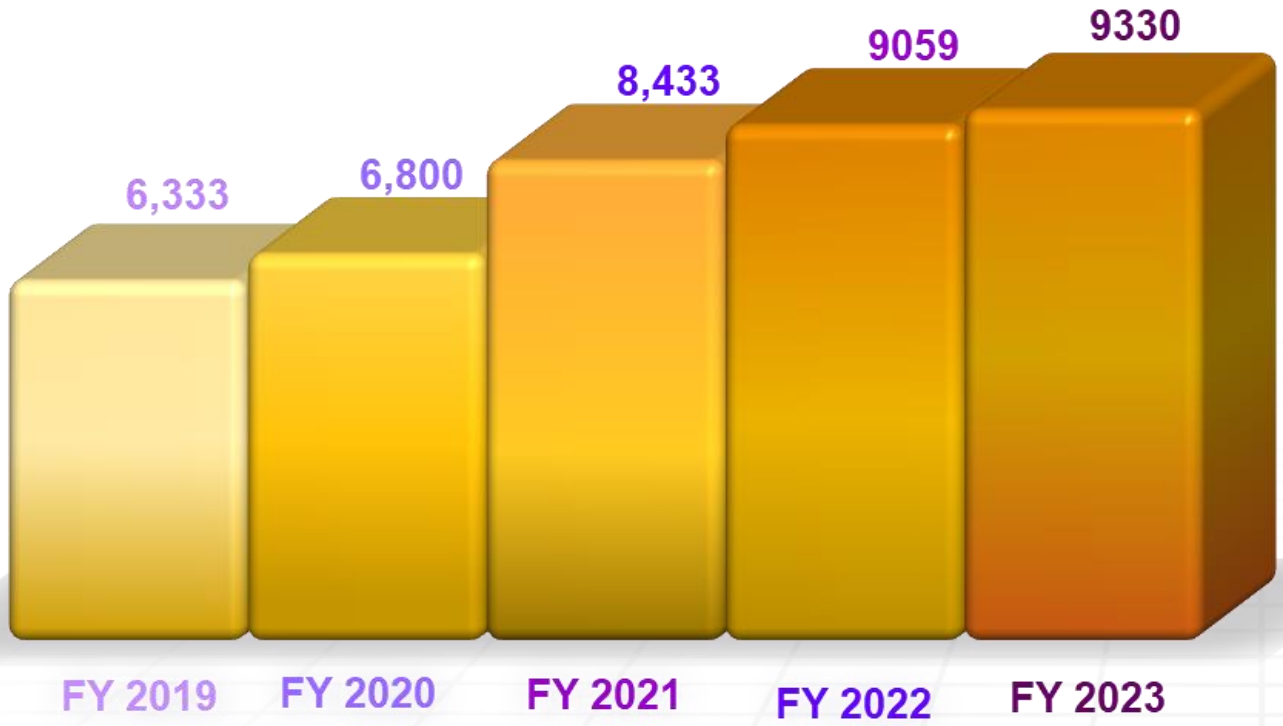
Technical Areas	Number of CINR Awards	Award Years	Access Funding
Fundamentals for Reactor Materials	30	FY15, 16, 17, 18, 19, 20, 21,22, 23	$22,450,554
Additive / Advanced Manufacturing	10	FY15, 16, 17, 18, 19, 21	$15,264,025
Advanced Fuel Development	11	FY15, 16, 17, 19, 20, 23	$14,494,994
Sensor Development	13	FY15, 17, 18, 19, 20, 21	$8,571,664
Computational Model Development and Validation	6	FY17, 18	$4,714,455
Welding & Joining Advanced Cladding	3	FY16, 17	$1,656,984
Nuclear Materials Discovery & Qualification Initiative	2	FY20, 21	$995,514

NSUF Awards Related to Advanced Manufacturing

- **24 awarded projects**
  - 14 of RTE awards
  - 10 of CINR awards
- **Awards related to types of advanced manufacturing**
  - 11 projects related to LPBF
  - 8 projects related to DED
  - 6 projects related to PM-HIP
  - 1 project related to electron beam welding
  - 2 projects related to cold spray
- **Awards related to materials**
  - ODS, Fe-based, Ni-based, Zircaloy, Fiber sensor embedded titanium components
- **NIFT-E "Neutron Irradiation as a Function of Temperature – Experiment**
  - Alumina-forming austenitic (AFA) steels, Al_2O_3 coated, Oxide coated F/M, AM Grade 91, HEAs, Hetero Nano-composites

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The NSUF Nuclear Fuels and Materials Library



The NFML is the largest global open archive of high-value irradiated fuels and material from test, commercial, and decommissioned power reactors, and valuable donations from other sources.

Most samples in the library are neutron irradiated:

- **EBR-II** (INL), **ATR** (INL), **HFIR** (ORNL), **FFTF** (PNNL)
- José Cabrera Nuclear Power Station, commercial NPPs (in process)

A smaller number were proton irradiated:

- LANSCE (Los Alamos National Laboratory)

In the past, NSUF was in ***acquisition mode***.

Now we are in ***curation mode***.

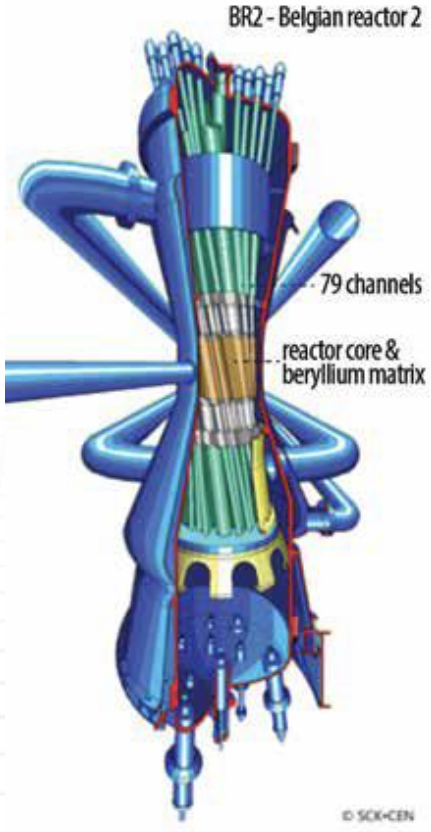
Future plans include:

- Forming a working group to inform new acquisitions. Tied in with UK collaborators.
- Planning for specific irradiation campaigns to populate the NFML with desirable material.

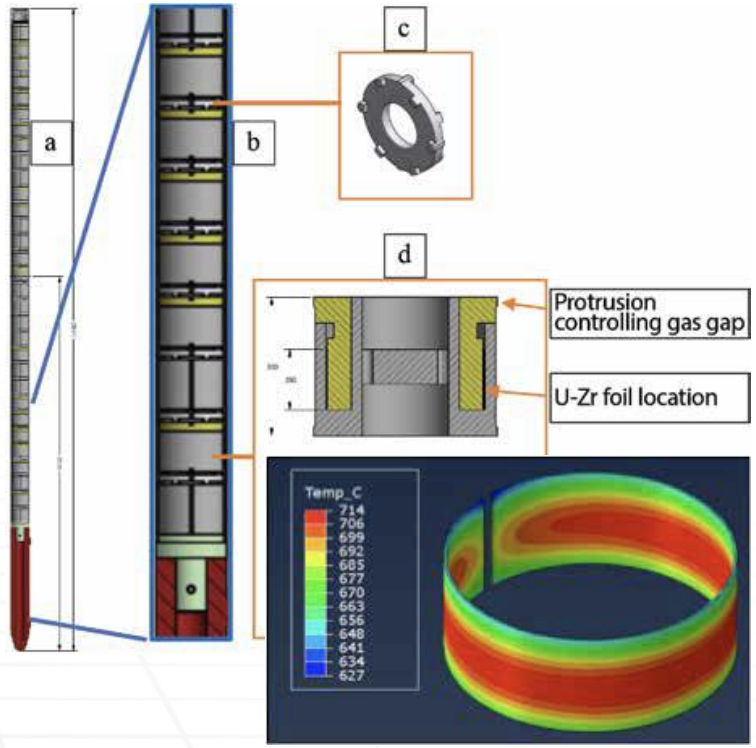
International Collaborations – NSUF BR-2 Project

DISECT "*Disc Irradiation for Separate Effects testing with Control of Temperature*"

- The research involves a collaborative effort with the **SCK-CEN in Belgium** and the NSUF utilizing capabilities at INL and the Belgian Nuclear Research Center.
- The DISECT project includes the design and fabrication of a uniquely instrumented, separate effects testing vehicle; specimen fabrication and pre-characterization; irradiation; and post-irradiation examination to enable a more comprehensive understanding of in-pile phenomena.
- **Uranium-Zirconium** (U-Zr) alloy fuel is the reference fuel for any future U.S. fast test reactors.
- Furthering the understanding of the U-Zr system can be used to provide the basis for increasing fuel burn-up beyond the current 10 atomic percent (at%) for fuels and 20 at% for experiments or extrapolating the effect of minor design modifications.



The Belgian BR2 reactor at SCK-CEN.



a) In-core portion of the test vehicle.
b) Enlarged section of vehicle illustrating the stack-up of specimen holders separated by insulators.
c) Insulators utilizing gas gaps to isolate specimen holders.
d) Specimen holders for the U-Zr alloy foils.

International Collaborations – NSUF ATR Project

NIFT-E "**N**eutron **I**rradiation as a **F**unction of **T**emperature – **E**xperiment

Strategic Objectives

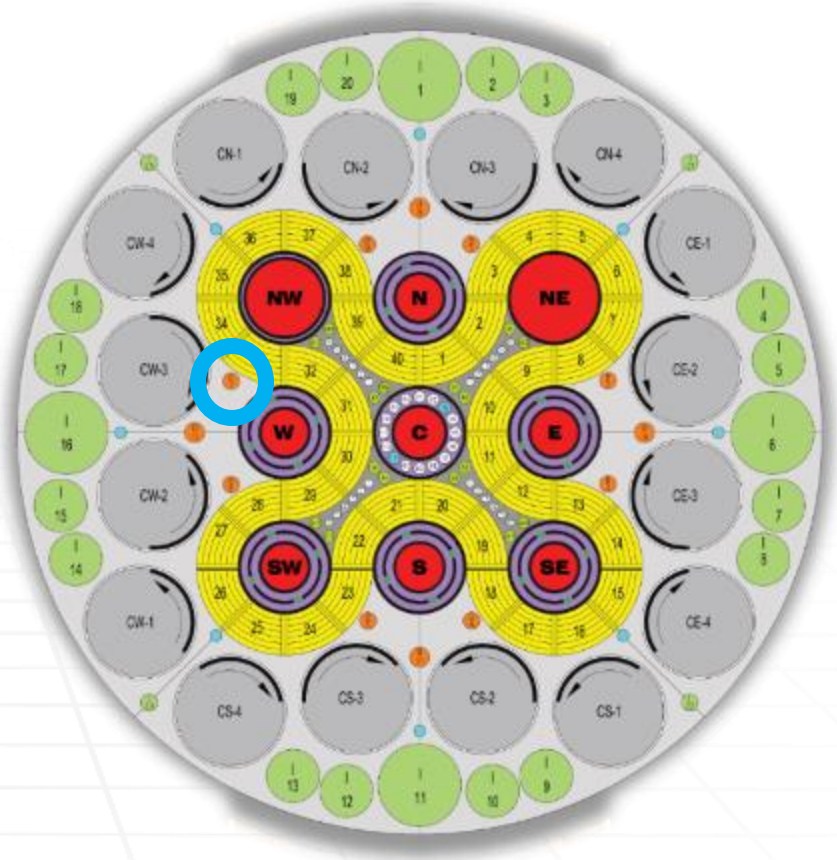
- Explore sharing of nuclear facilities between the United States and the UK
- Further nuclear energy research collaboration

Technical Objectives

- Capture effects of neutron irradiation as a function of temperature on dose on nuclear graphite and on alumina-forming austenitic (AFA) steels
- Targets microstructure and mechanical property plus corrosion behavior

Stakeholders

- **U.S.:** NSUF plus INL, PNNL, Purdue University, Westinghouse
- **UK:** NNUF plus UK NNL, Univ. of Manchester, Univ of Oxford, Univ. of Sheffield, UKAEA

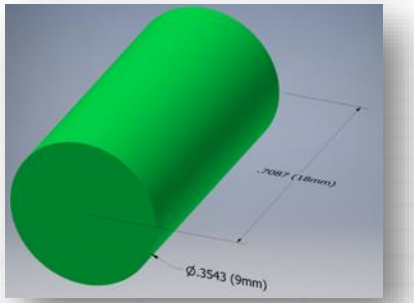


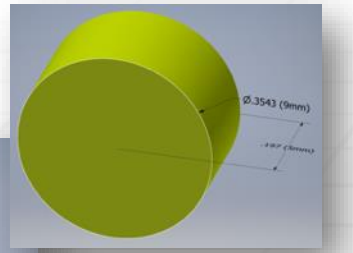
Specimens & Capsules

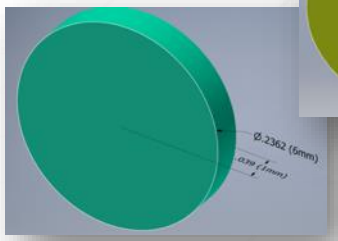
Alumina-Forming Alloys
GA05 SA
GA05 HT
GA05 20Ni SA
GA05 20Ni HT
AISI Type 304L SS 3 µm Al2O3 coated
AISI Type 304L SS 1.5 µm FeCrAl 1.5 µm Al2O3 coated

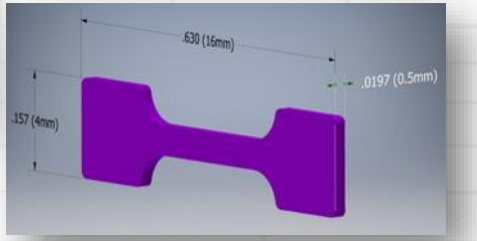
Miscellaneous Material
Oxide-Coated F/M Steels 3µm Al2O3 coated
Oxide-Coated F/M Steels 1.5 µm FeCrAl 1.5 µm Al2O3 coated
Adv Mfg Grade 91
HEAs
Hetero Nano-composites

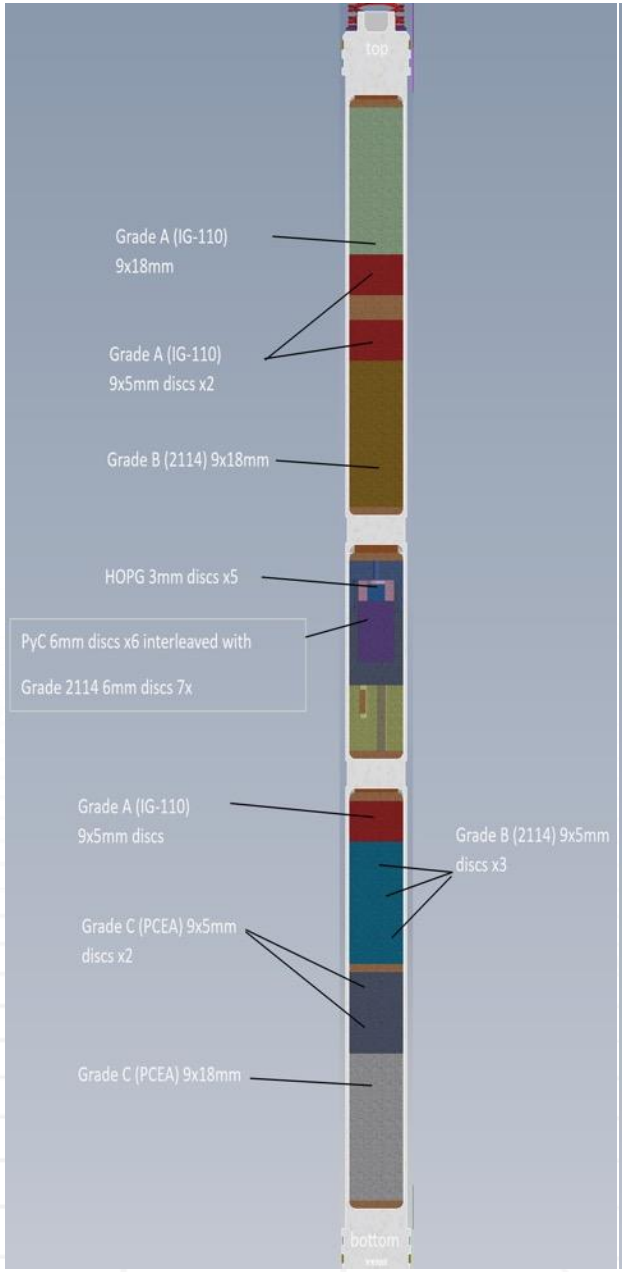
Graphite
IG110
HOPG
PyC
NBG18

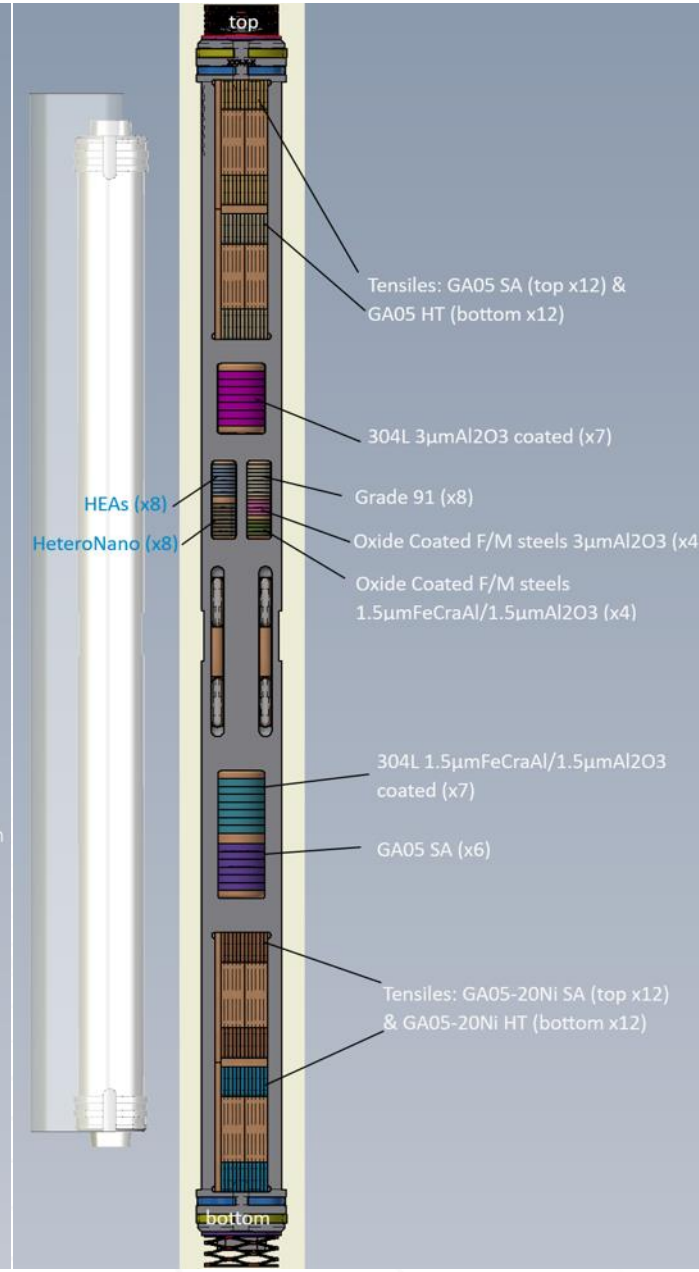












US-UK Project Timeline & Strategy

Activity	Finish Date
Final Design Complete	September 2023
Assembly Complete	late 2024
Commence Irradiation	September 2025

Capsule	DPA Target	Temperature
C1	1.0 dpa minimum	750 ± 50°C
C2	2.0 dpa minimum	750 ± 50°C
C3	3.0 dpa minimum	750 ± 50°C
AFA1	1.0 ± 0.3 dpa	400 ± 50°C
AFA2	1.0 ± 0.3 dpa	650 ± 50°C
AFA3	8.0 dpa nominal	400 ± 50°C
AFA4	4.0 dpa nominal	400 ± 50°C
AFA5	4.0 dpa nominal	650 ± 50°C



ATR Position B-7		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12	Cycle 13
CAPSULE POSITION	A	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE
	B	AFA1	AFA4	AFA4	AFA4	AFA4	AFA4	AFA4	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE
	C	C1	C1	C1	C2	C2	C2	C2	C2	C2	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE
	D	AFA5	AFA5	AFA5	AFA5	C3	C3	C3	C3	C3	C3	C3	C3	C3
	E	AFA2	AFA3	AFA3	AFA3	AFA3	AFA3	AFA3	AFA3	AFA3	AFA3	AFA3	AFA3	AVAILABLE
	F	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE	AVAILABLE

NFML SAM-2 – NSUF Directed Project

SiC Interest and Applications

- Monolithic SiC – high temperature, low activation structural material
- Wide bandgap semiconductor – 3.26 eV
- Fuel applications (TRISO, accident tolerant cladding)
- Passive metrology – well characterized volumetric swelling (both fluence and temperature)

ATR Irradiation

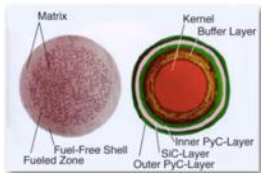
- Small B position (NW) 0.875” diameter
  - Thermal Flux: 2.5E+14 Fast Flux: 8.1E+13
- Insertion Cycle: 169A (DEC 2020) 12 Cycles (4-5 years)

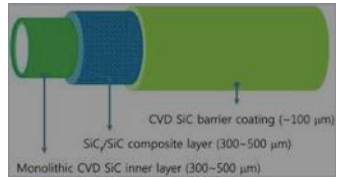
PIE and Data Results

- Mechanical, thermal, and electrical properties
- Measurements repeated after annealing above irradiation temperature (158°C) to remove fast neutron damage.

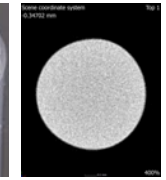
Schedule

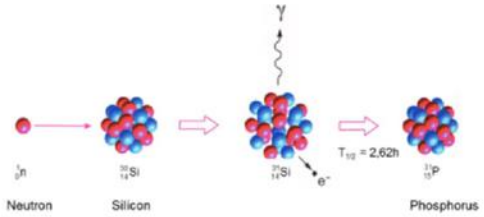
- First 3 capsules removed and disassembled
- Started tensile testing on baseline unirradiated and irradiated specimens from first 3 capsules-complete in summer 2023
- Every year another 1-3 capsules removed, and PIE performed.
- Re-utilizing the irradiation space with other drop in capsules experiments (GENIE-AH)

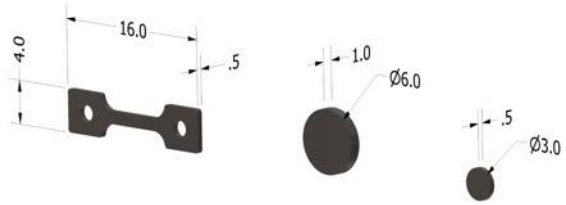


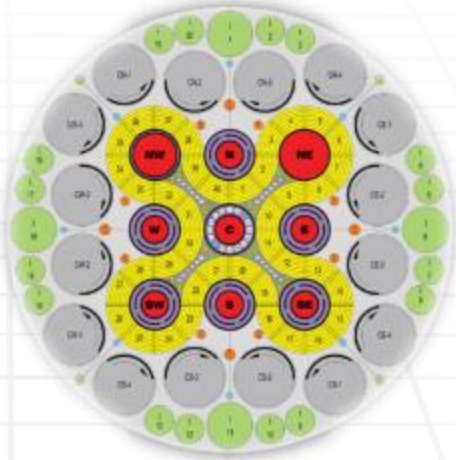


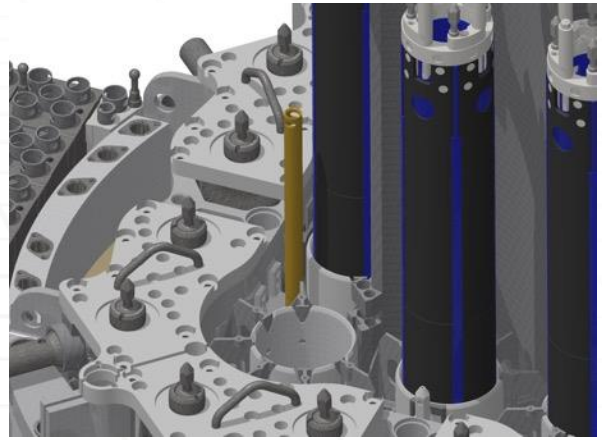












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Keith Jewell – Idaho National Laboratory

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