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Nuclear Science User Facilities Program



The Nuclear Science User Facilities (NSUF)

Vision

U.S. leads the world in nuclear energy research with cutting edge resources.

Mission

Coordinate a consortium of institutions to provide access, at no cost to the user, to unique and highly specialized nuclear research facilities and technical expertise.

Goal

Produce the highest quality research results that will impact and increase understanding of advanced nuclear energy technologies important to DOE-NE and support national priorities by adapting to the needs of DOE-NE programs, industry, and new innovative concepts.

Strategic R&D Support

Provide mechanisms for research organizations to collaborate, conduct irradiations and post irradiation analyses, and utilize high performance computing at facilities not normally accessible to these organizations.

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

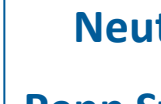
Unique aspects of NSUF

- **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
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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



New NSUF Partner Capabilities

Activated Materials Laboratory at the APS-U

- NSUF leadership continued collaboration meetings with the Argonne National Laboratory (ANL) Advanced Photon Source Upgrade (APS-U) Activated Material Laboratory (AML).
- NSUF funded construction of the AML in FY2022 as part of the APS-U project.
- The collaboration is planned to provide access to NSUF users at the High-Energy X-ray Microscope (HEXM) beam station for **irradiated fuels and materials** research.
- This capability is planned to be ready for users at the start of FY2025.



Pictures courtesy of ANL APS-U

New Partner – Penn State University Reactor Facility

Radiation Science & Engineering Center

Neutron Beam Laboratory

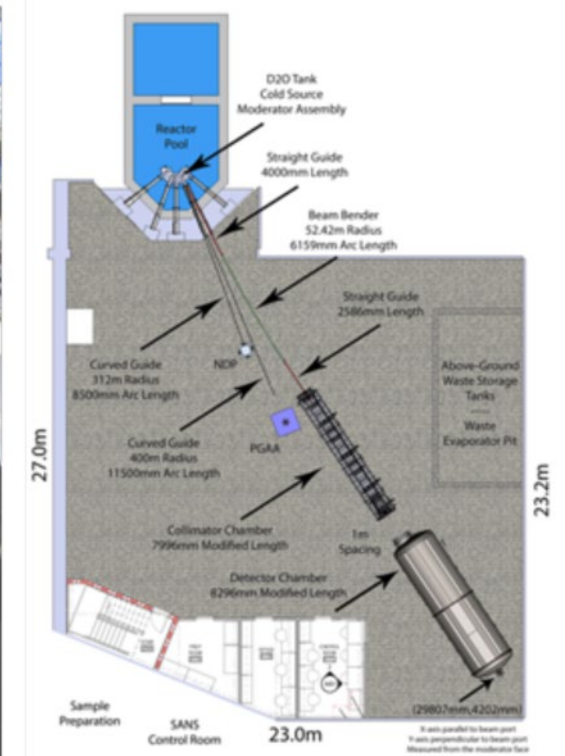
Five new core neutron beam ports provide seven new neutron beam lines for the beam experimental facilities.

- 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 PSU SANS facility will have 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)

“The addition of new neutron beam port facilities including a Small Angle Neutron Scattering (SANS) instrument that is donated by The Helmholtz-Zentrum Berlin (HZB), time-of-flight 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 – University of Texas at Austin Reactor

Nuclear Engineering Teaching Laboratory

Prompt Gamma Neutron Activation Analysis Capability

The UT PGNAA facility is currently being used to:

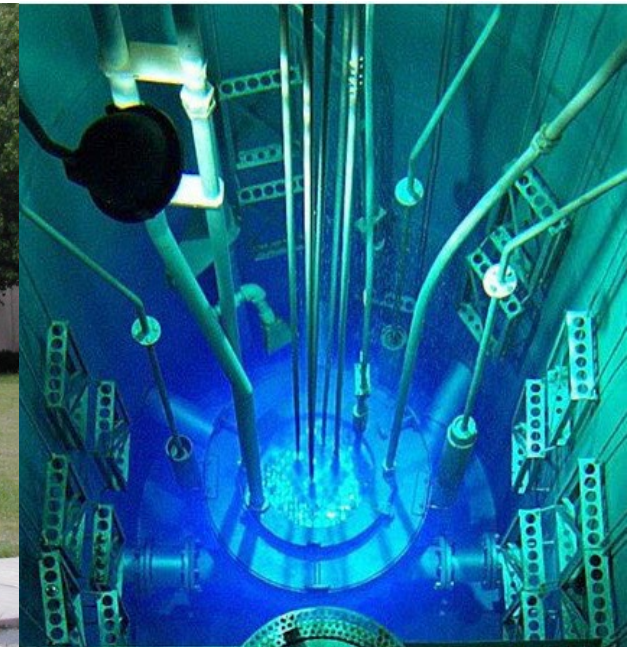
- assay boron concentration for an ONR research project,
- measure hydrogen content in steel for correlation to stress cracking phenomena, and
- determine mercury content in scale and corrosion layers inside steel pipe. Hydrogen concentrations less than 20 ppm in steel have been measured to date.

Plans for PGNAA Upgrades:

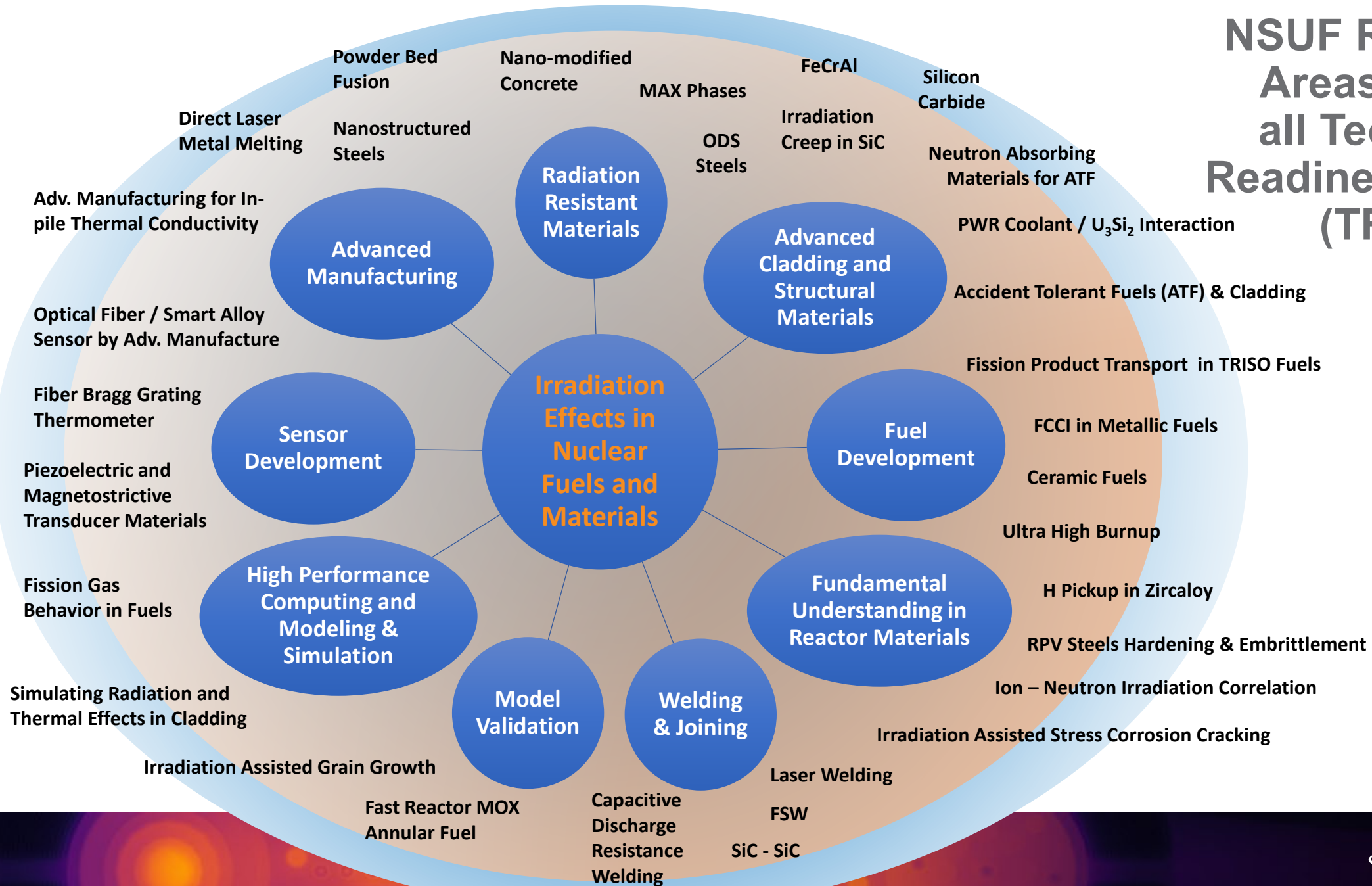
- automated (sample) motion controls
- shielding optimization
- environmental chamber for reduction of humidity (in progress)
- development of fluorine-based neutron (detector) shielding (in progress)

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

“Researchers, scientists and engineers from universities, national laboratories and private industry performing research on failures related to corrosion and process-contamination of materials applicable to advanced reactor fuel and/or advanced reactor materials.”



NSUF Research Areas Cover all Technical Readiness Levels (TRLs)

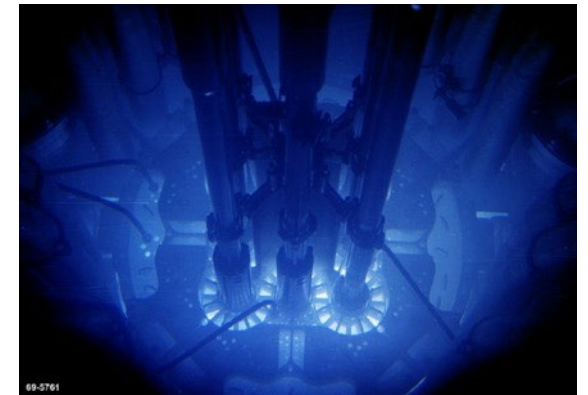


The Nuclear Science User Facilities

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



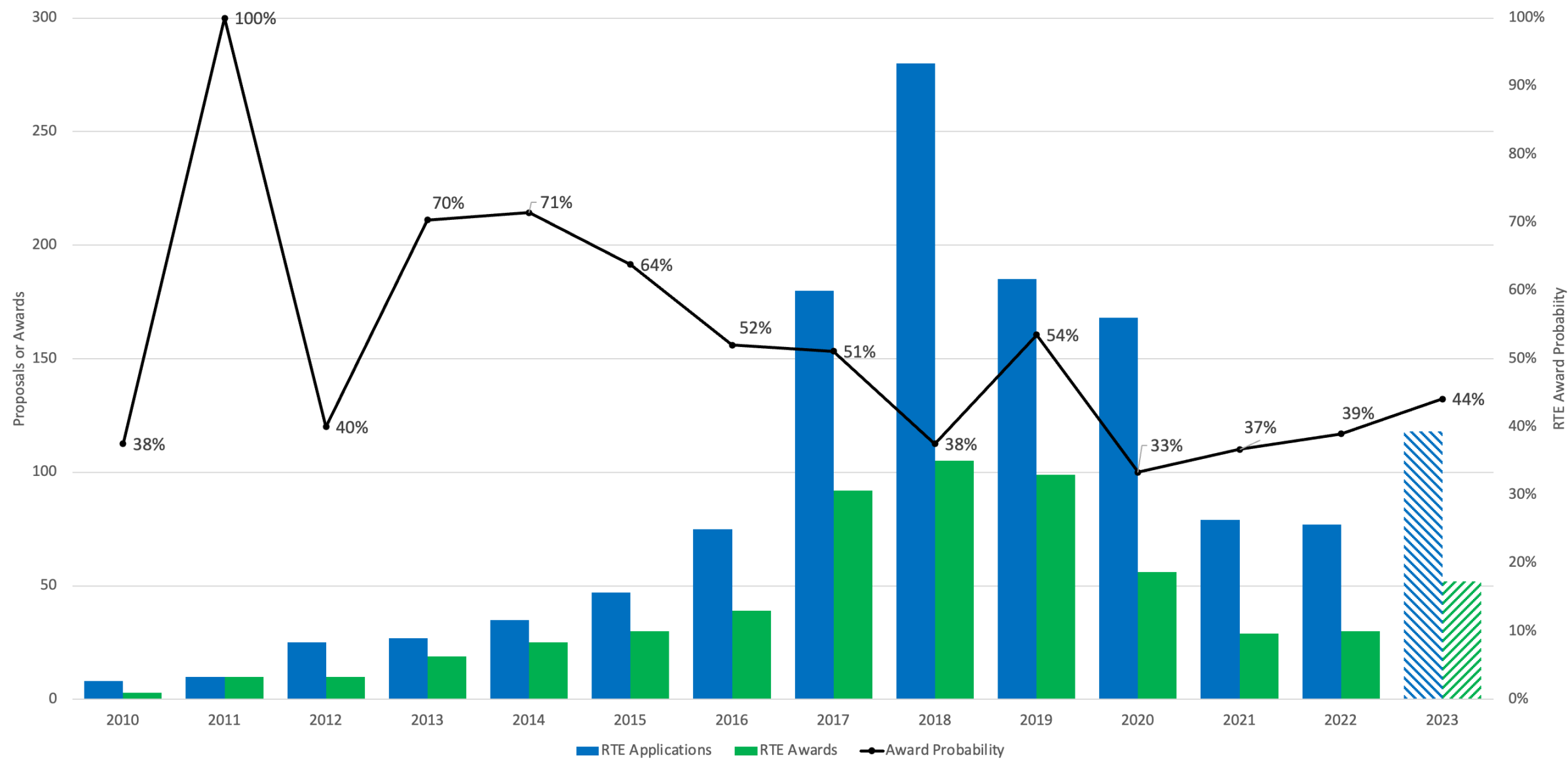
FY 2007 – FY2023

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

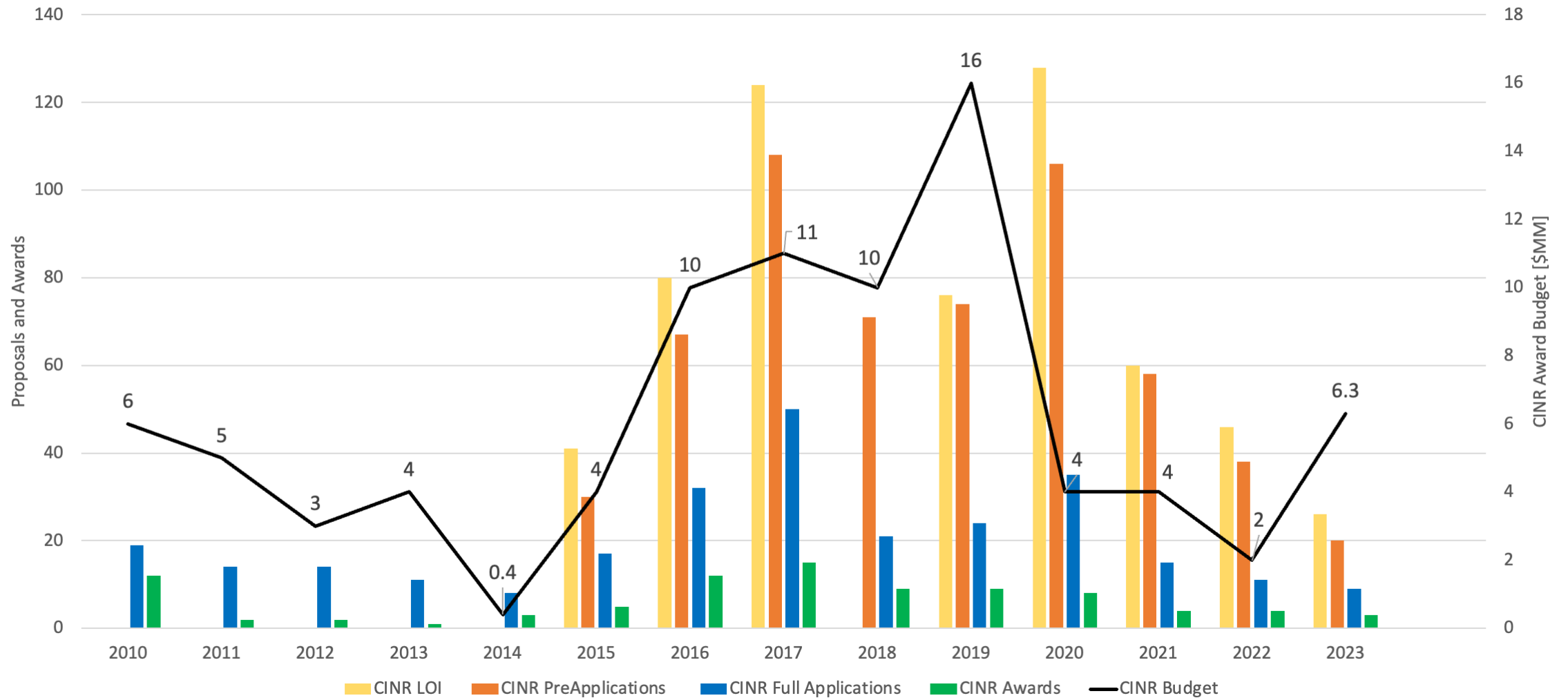
702 total projects awarded

- 427 projects to 55 US universities
- 210 projects to 8 national laboratories
- 29 projects to 12 industry
- 36 projects to 13 international
- Total NSUF Access Award Funding: \$123MM

NSUF Rapid Turnaround Experiments (small projects)

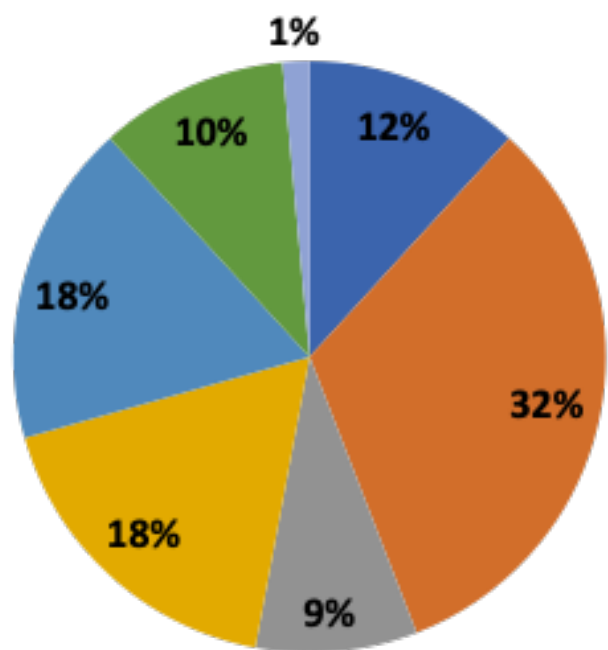


NSUF Consolidated Innovative Nuclear Research (large) Projects



CINR Awarded Projects FY 2015 – FY 2022

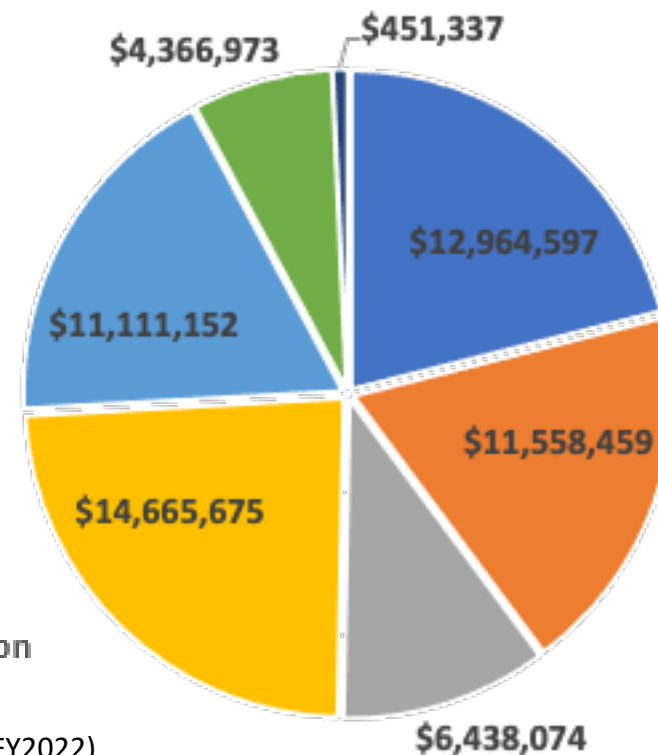
Number of Awards by Field



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

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

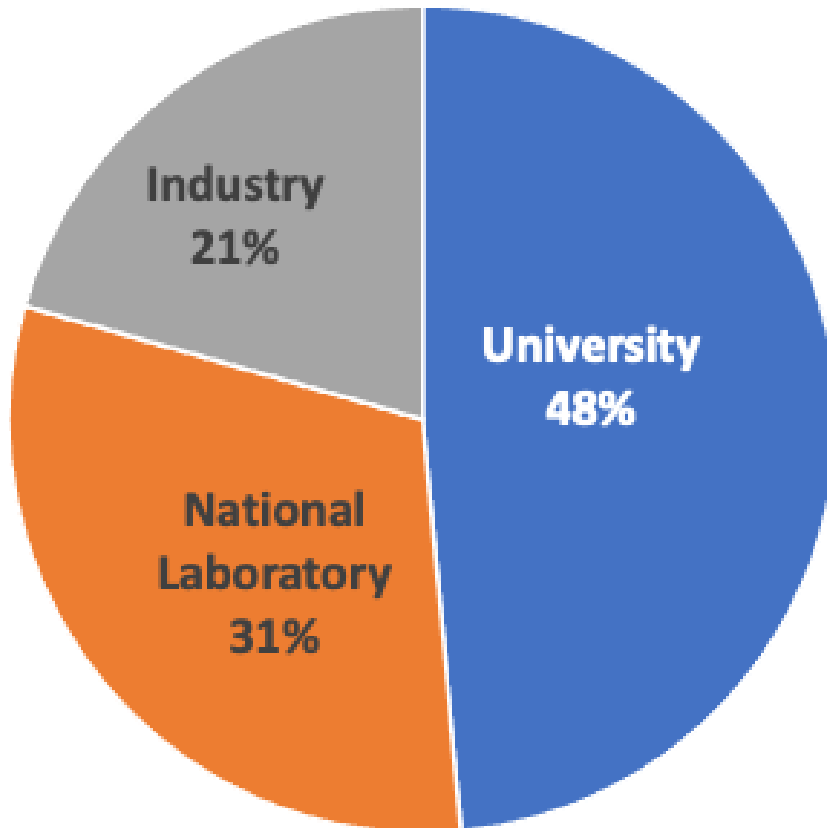
Value of Awards by Field



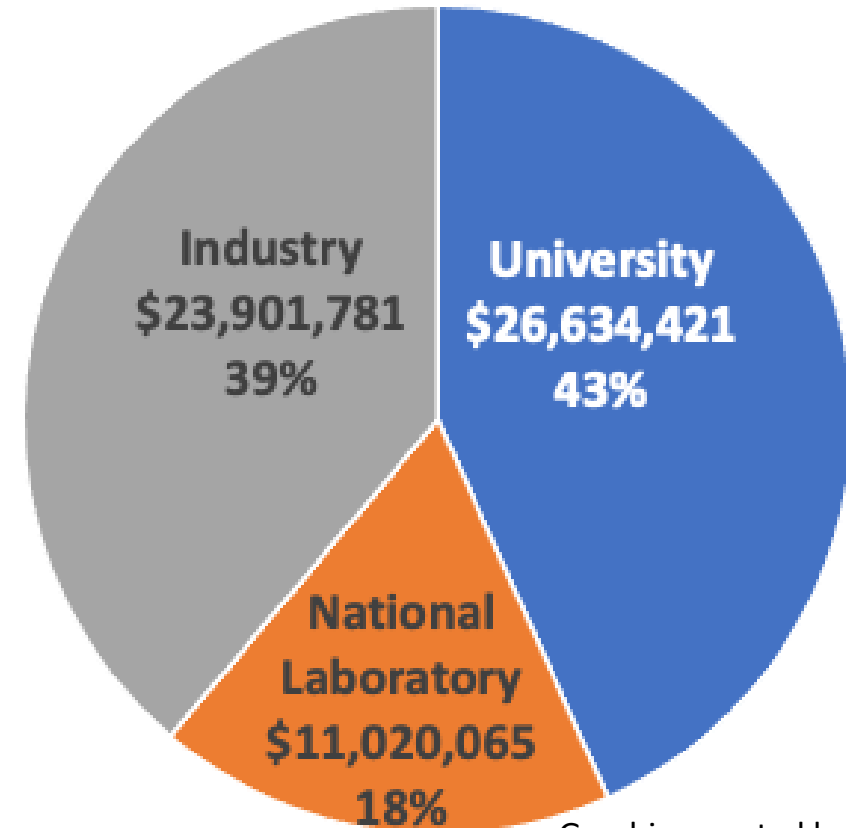
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CINR Awarded Projects FY 2015 – FY 2022

Number of Awards by Institution Type
2015 - 2022



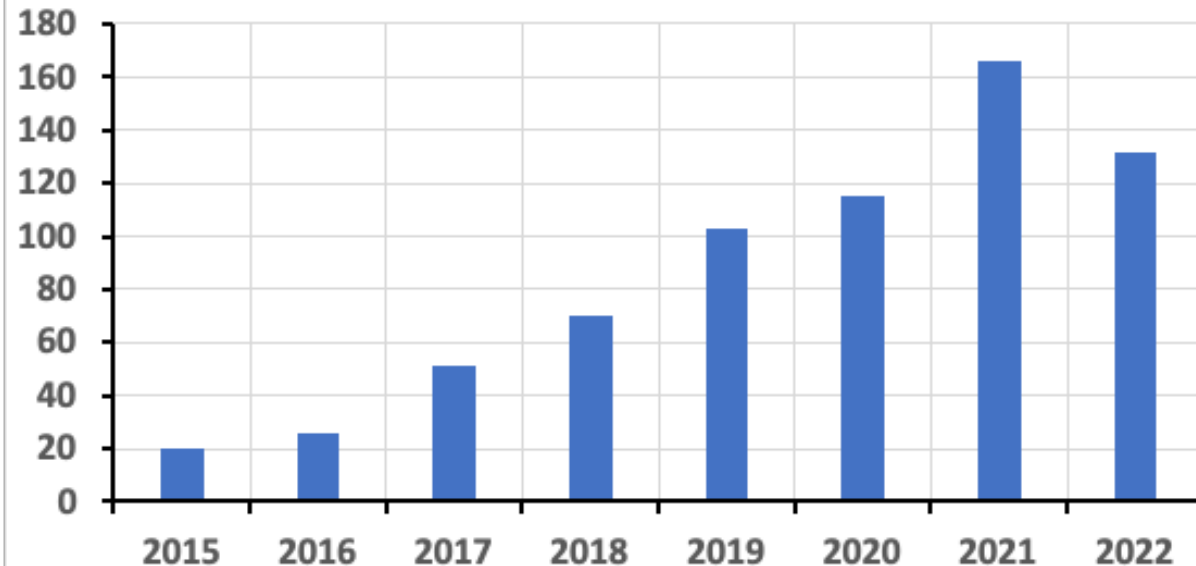
Value of Awards by Institution Type
2015 - 2022



Graphics created by Simon Pimblott

NSUF Productivity and Impact

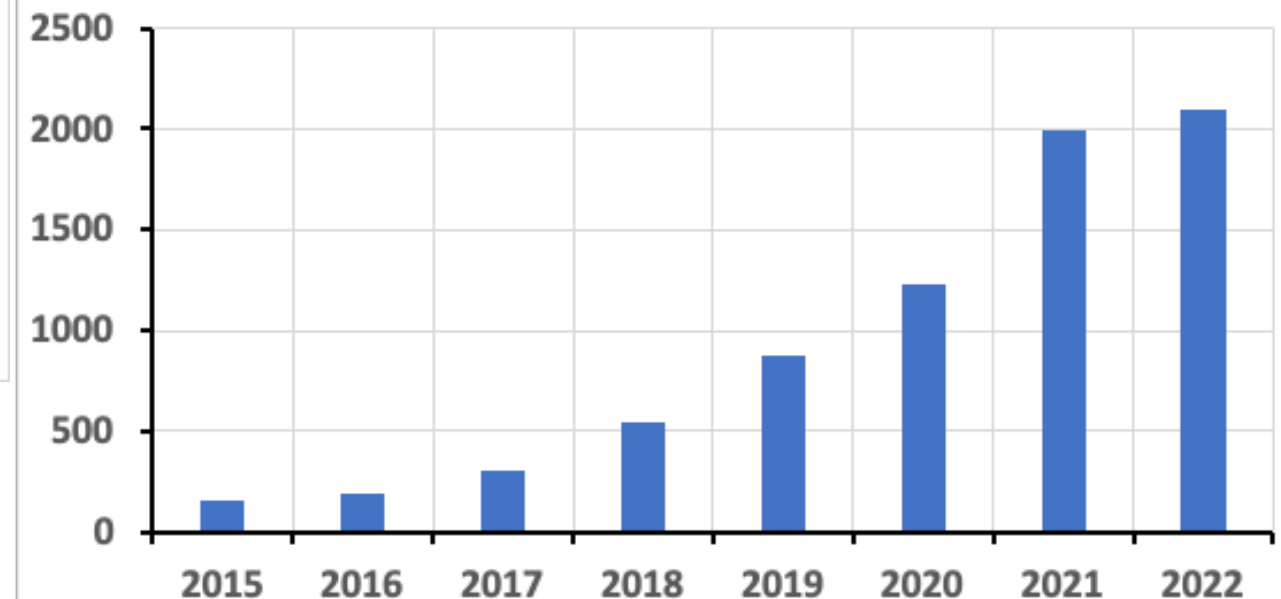
Number of NSUF Supported Peer Reviewed Publications



- Total NSUF citations: 7680 in 5407 citing articles
- H-index score of 40 (score of 32 to 9/2021)
- Journal of Nuclear Materials is the top journal for NSUF.

- Calculated by calendar year, not FY
- Total NSUF publications through CY2022: 725
- Increase in RTE awards through FY 2019.

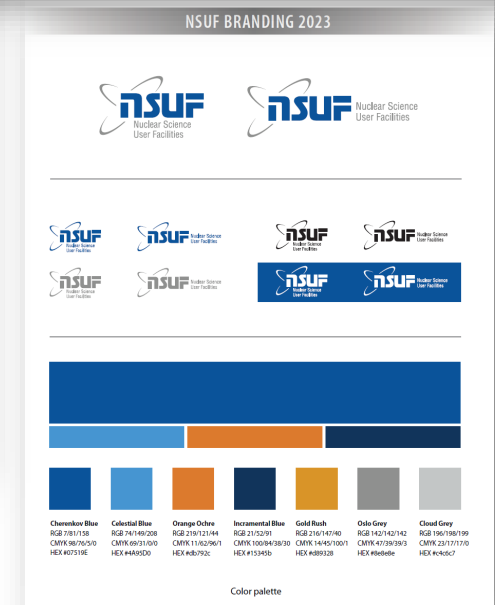
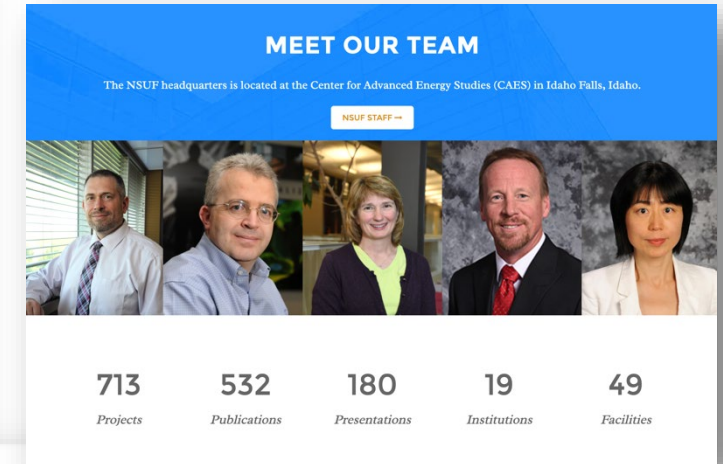
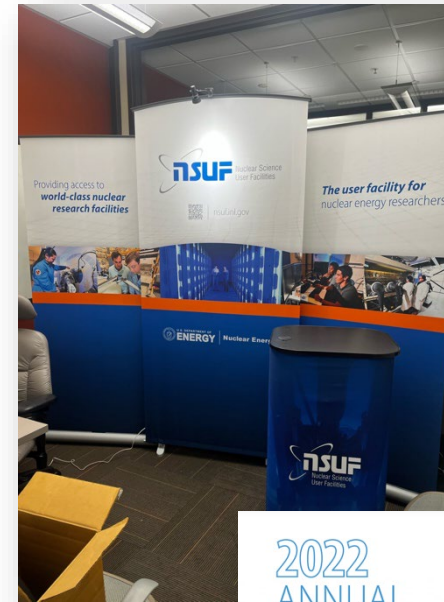
Number of Citations of NSUF Supported Peer Reviewed Publications



Data generated and graphics created by Simon M. Pimblott

Communications and Community Outreach

- Annual Report and Fact Sheets
- Messaging
 - Newsletter, Articles, Emails
- Meetings, Presentations, and Conferences
 - Creating metrics, engagement plans
- Branding Refresh



New Website: NSUF Research



The new Research site replaces the old Proposal and Infrastructure sites with a unified portal experience



Integrates multiple sources of data into a single master record improving accuracy and reliability



Links between Proposals, NEID, NFML, and Publications have been simplified and improved dramatically

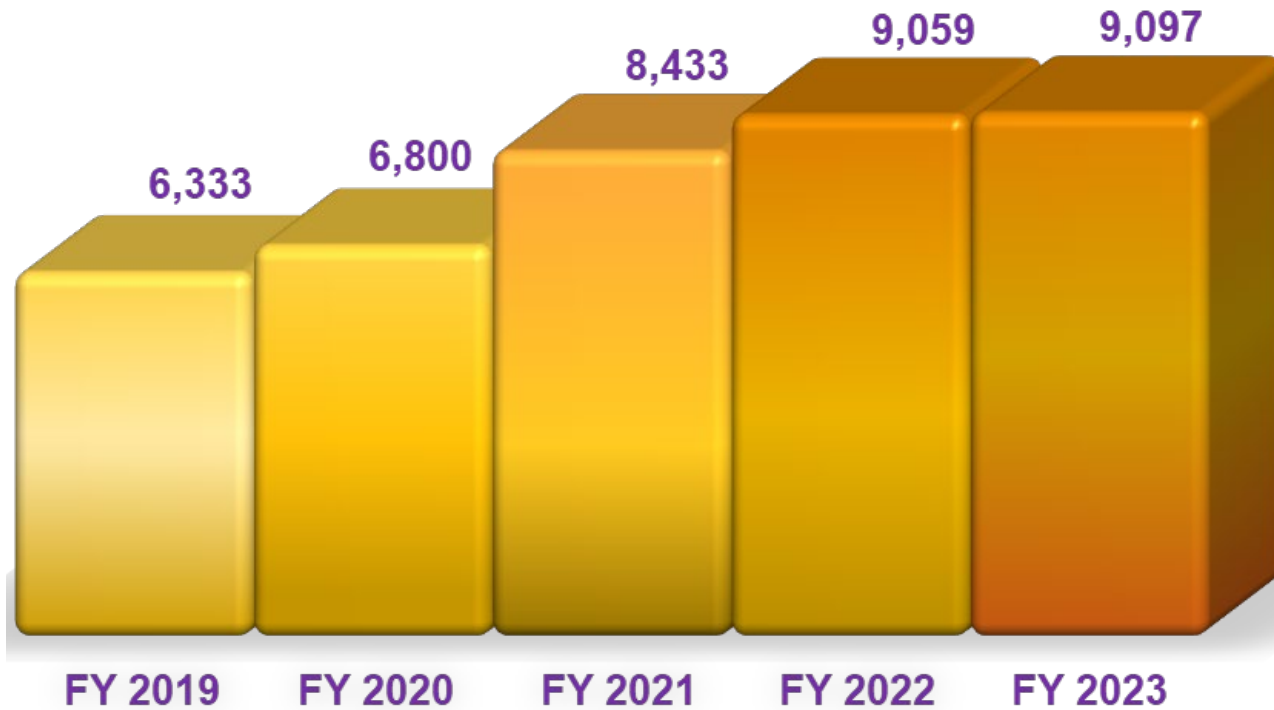


User experience improvements enhance the convenience and utility of existing systems while providing new capabilities for scalability and feature development



Research supported by the NSUF is easier to propose, manage, and communicate to site users

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 have been neutron irradiated:
EBR-II (INL), **ATR** (INL), **HFIR** (ORNL), **FFTF** (Hanford/PNNL),
José Cabrera Nuclear Power Station, commercial NPP (TBD)

A smaller number were proton irradiated:

- LANSCE (Los Alamos National Laboratory)

In past years, 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 ATR Project



NIFT-E “Neutron Irradiation as a Function of Temperature – Experiment

Strategic Objectives

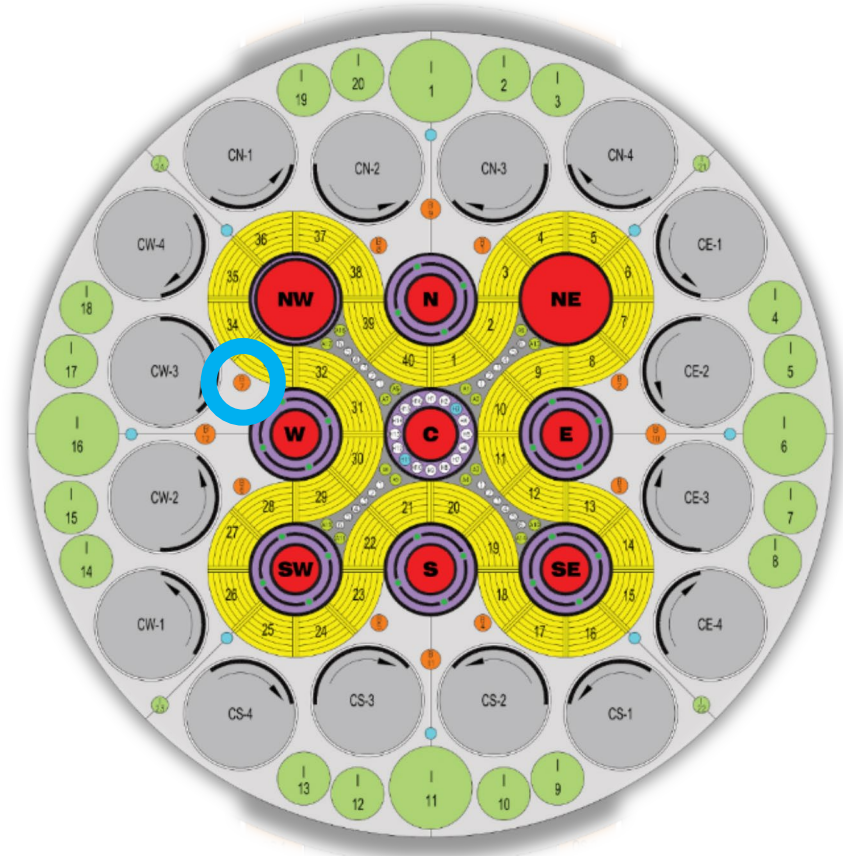
- Explore sharing of nuclear facilities between US and UK
- Further nuclear energy research collaboration

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

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

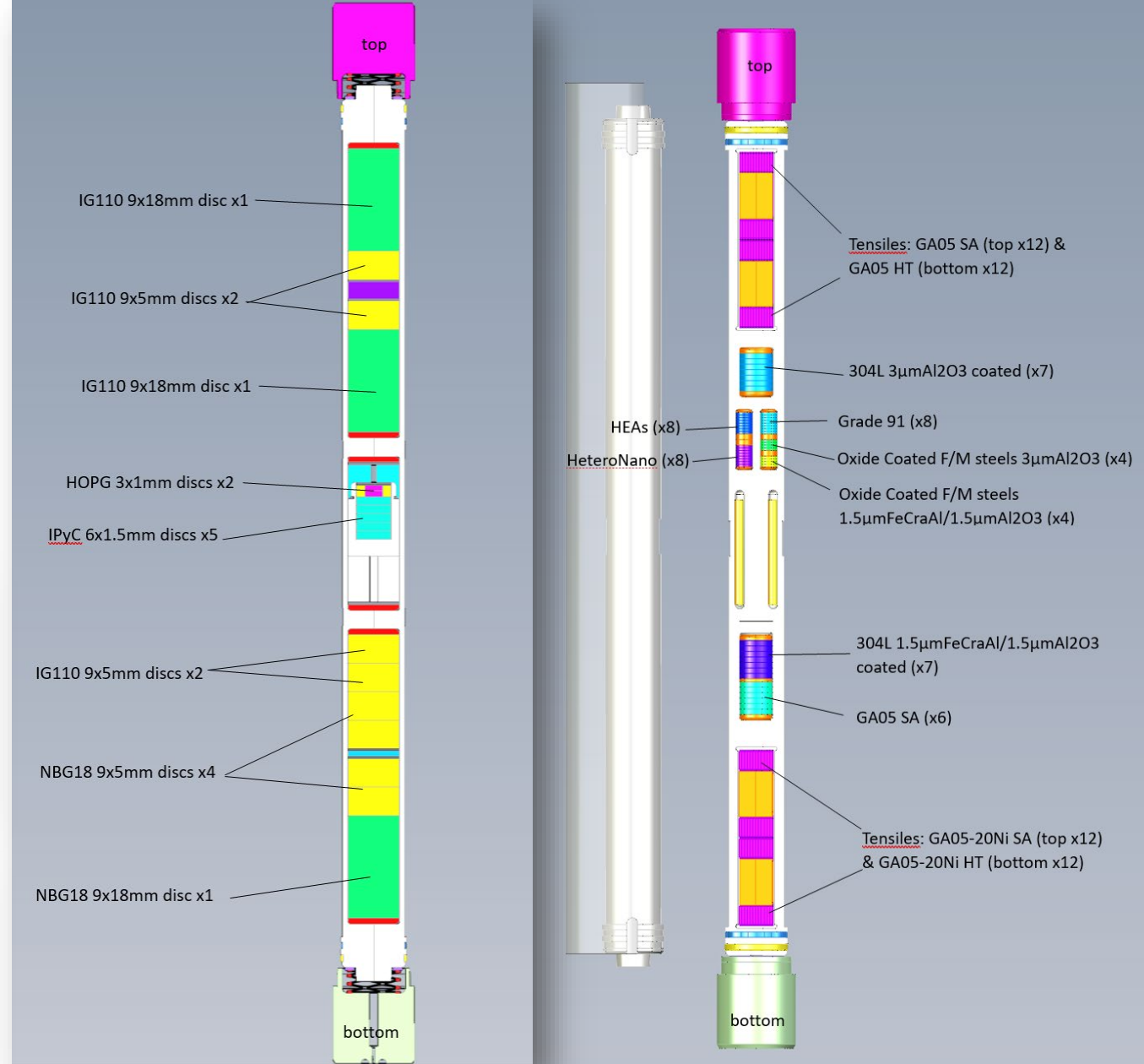
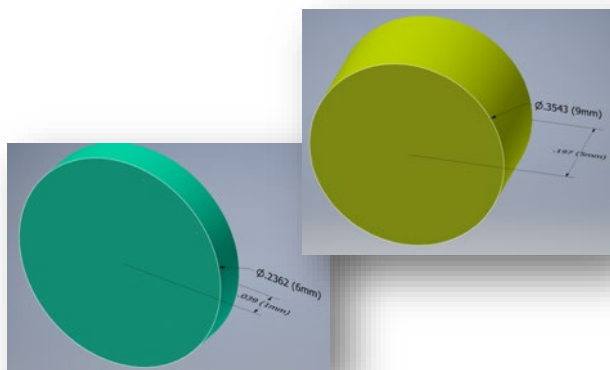
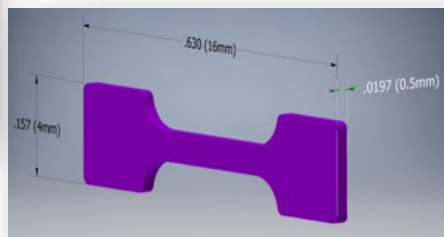
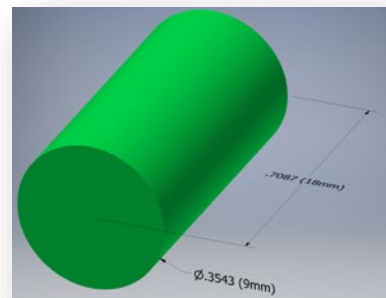


Specimens & Capsules

Alumina-Forming Alloys
GA05 SA
GA05 HT
GA05 20Ni SA
GA05 20Ni HT
AISI Type 304L SS 3 μ m Al ₂ O ₃ coated
AISI Type 304L SS 1.5 μ m FeCrAl 1.5 μ m Al ₂ O ₃ coated

Miscellaneous Material
Oxide-Coated F/M Steels 3 μ m Al ₂ O ₃ coated
Oxide-Coated F/M Steels 1.5 μ m FeCrAl 1.5 μ m Al ₂ O ₃ coated
Adv Mfg Grade 91
HEAs
Hetero Nano-composites

Graphite
IG110
HOPG
IPyC
NBG18



International Collaborations – NSUF NFML



Harvesting Activities

Decommissioned Halden Reactor Project (Norway)



- Continued effort to transfer title to and ship stainless steel samples from Norway to the INL
- Part of a funded HRR irradiation that did not undergo post-irradiation examination
- Title Transfer between the Institutt for Energiteknikk and the USDOE is under review
- Shipping and Transportation arrangements are underway
- Samples will be brought to the INL, added to the NFML, and made available for NSUF users and/or DOE-NE programs.

International Collaborations – NSUF NFML



DOE Program-to-Program Transfer
CRADA - Ki-Jang Research Reactor (KJRR)
Fuel Assembly Irradiation



- U-7Mo dispersed in Al-Si matrix, Al-clad fuel plates (2017 CRADA included title transfer to DOE-ID)
- Primary purpose of the campaign was to provide data about the irradiation performance of the KJRR fuel assembly.
- Korea Atomic Energy Research Institute (KAERI) fabricated the KJRR fuel experiment and shipped to the INL to be irradiated in the ATR, PIE in the HFEF, and as-Run irradiation conditions analysis performed.



Lead Test Assembly



Fuel Plates



CINR Awarded Projects

Focus on Key Technologies and Understanding

Additive / Advanced Manufacturing

Completed in:	FY17
	FY18
	FY19
	FY20
	FY21
	FY22

FY	Title	Institution	Funding
2015	Irradiation Influence on Alloys Fabricated by Powder Metallurgy and Hot Isostatic Pressing for Nuclear Applications	BSU	\$1,598
2016	Enhancing irradiation tolerance of steels via nanostructuring by innovative manufacturing techniques	ISU	\$2,459
	Irradiation performance testing of specimens produced by commercially available additive manufacturing techniques	CSM	\$2,030
	Irradiation Testing of LWR Additively Manufactured Materials	GEH	\$1,982
2017	Radiation Effects on Zirconium Alloys Produced by Powder Bed Fusion Additive Manufacturing Processes	WCLS	\$830
2018	High-dose ion irradiation testing and relevant post-irradiation examination of friction-stir-welded ODS MA956 alloy	PNNL	\$182
	Irradiation Testing of Materials Produced by Additive Friction Stir Manufacturing	Aeroprobe	\$1,837
	Nanodispersion Strengthened Metallic Composites with Enhanced Neutron Irradiation Tolerance	MIT	\$2,046
2019	Irradiation studies on electron beam welded PM-HIP pressure vessel steel	Purdue	\$2,072
2021	Effect of neutron irradiation on friction stir welded Ni-based ODS MA754 alloy	PNNL	\$227
			\$15,264

CINR Awarded Projects

Focus on Key Technologies and Understanding

Advanced Fuel Development

Completed in:	FY17
	FY18
	FY19
	FY20
	FY21
	FY22

FY	Title	Institution	Funding
2015	Microstructural Evolution in Low Fluence Irradiated Metallic Fuels	INL	\$663
2016	Fission Product Transport in TRISO	UMich	\$22
	Radiation-Enhanced Diffusion of Ag, Ag-Pd, Eu, and Sr in Neutron Irradiated PyC/SiC Diffusion Couples	ORNL	\$518
2017	Irradiation of Advanced Neutron Absorbing Material to Support Accident Tolerant Fuel	AREVA	\$630
	Irradiation, Transient Testing and Post Irradiation Examination of Ultra High Burnup Fuel	EPRI	\$3,588
	Disc Irradiation for Separate Effects Testing with Control of Temperature (DISECT)	SCK-CEN/INL	
	Accident Tolerant fuel Test for the Interaction of Coolant with Uranium Silicide (ATTICUS)	SCK-CEN/INL	
2019	High power irradiation testing of TRISO fuel particles with UCO and UO ₂ kernels in miniature fuel specimen capsules in HFIR	Kairos	\$2,997
	Thermal Conductivity Measurement of Irradiated Metallic Fuel Using TREAT	UPitt	\$1,895
2020	Investigation of Degradation Mechanisms of Cr coated Zirconium alloy cladding in Reactive Initiate Accidents (RIA)	UWisc	\$1,683
2023	UN multi-design irradiation campaign: a critical assessment of accelerated burnup and main correlations for mechanistic fuel performance modeling	UTSA	\$2,498
			\$14,495

CINR Awarded Projects

Focus on Key Technologies and Understanding

Fundamentals for Reactor Materials

Completed in:	FY17
	FY18
	FY19
	FY20
	FY21
	FY22

FY	Title	Institution	Funding
2015	Advanced Characterizations of Low-dose Neutron Irradiated T91 and HT9 Alloys	UIII-Urbana	\$219
	In-situ Synchrotron Wide-Angle X-ray Scattering (WAXS) Tensile Investigation of Neutron Irradiated Ferritic Alloys	UIII-Urbana	\$765
2016	Beamline Examination of a Hf-Al Metal-Matrix Composite Material	INL	\$342
	Correlative Atom Probe and Electron Microscopy Study of Radiation Induced Segregation at Low and High Angle Grain Boundaries in Steels	ORNL	\$150
	Effect of Gamma Irradiation on the Microstructure and Mechanical Properties of Nano-modified Concrete	Vanderbilt	\$185
	Feasibility of Combined Ion-Neutron Irradiation for Accessing High Dose Levels	UMich	\$187
	Radial Heat Flux – Irradiation Synergism in SiC ATF Cladding	ORNL	\$843
	Role of minor alloying elements on long range ordering in Ni-Cr alloys	OrStU	\$90
	Understand the phase transformation of thermal aged and neutron irradiated duplex stainless steels used in LWRs	UFla	\$579
	Correlation between Microstructure and Mechanical Properties of Neutron-Irradiated Ferritic-Martensitic and Austenitic Steels	ORNL	\$652
2017	Improved Understanding of Zircaloy-2 Hydrogen Pickup Mechanism in BWRs	EPRI	\$817
	Positron Annihilation Studies of Neutron Irradiated Ferritic Alloys	UIII-Urbana	\$203
	X-ray Characterization of Atomistic Defects Causing Irradiation Creep of SiC	ORNL	\$150

CINR Awarded Projects

Focus on Key Technologies and Understanding

Fundamentals for Reactor Materials

Completed in:	FY17
	FY18
	FY19
	FY20
	FY21
	FY22

FY	Title	Institution	Funding
2018	Rapid Simulation of Irradiation Damage in PWR Internals	ORNL	\$323
	Understanding Swelling-Related Embrittlement of AISI316 Stainless Steel Irradiated in EBR-II	INL	\$1,077
2019	Integral Fuel Rod Real-Time Wireless Sensor & Transmitter Irradiation Test and Post Irradiation Examination	WCLS	\$3,097
	Irradiation-assisted Stress Corrosion Cracking of PWR-irradiated Type 347 Stainless Steel	WCLS	\$927
	NuScale SMR Materials Irradiation and Testing	NuScale	\$2,482
2020	Improving Lifetime Prediction of Electrical Cables in Containment	PNNL	\$22
	Effect of neutron irradiation on microstructure and mechanical properties of nanocrystalline	NSCU	\$204
	X-ray diffraction tomography analysis of SiC composite tubes neutron-irradiated with a rad	ORNL	\$50
	Synergy of radiation damage with corrosion processes through a separate effect investigation	NSCU	\$175
	Demonstration of Self Powered Neutron Detectors Performance and Reliability	INL	\$705
2021	Assessment of Irradiated Microstructure and Mechanical Properties of FeCrAl Alloy Fabrication Routes	GE Research	\$2,149

CINR Awarded Projects

Focus on Key Technologies and Understanding

Fundamentals for Reactor Materials

Completed in:	FY17
	FY18
	FY19
	FY20
	FY21
	FY22

FY	Title	Institution	Funding
2022	Mechanical response and chemical effects at the fuel-cladding interface of HT-9 and metallic fuel	Purdue	\$652
	Accelerated Irradiation and Evaluation of Ultrastrong and Elastic Glassy Carbon	INL	\$256
	Integrated Effects of Irradiation and Flibe Salt on Fuel Pebble and Structural Graphites for Molten Salt Reactors	Kairos	\$833
	Gamma irradiation effects on the mechanical behavior of seismic protective devices	SUNY-Buffalo	\$451
2023	Investigation of intergranular cracking of highly irradiated austenitic stainless steels – materials of pressurized water reactors – in ambient conditions	ORNL	\$1,575
	Irradiation-Corrosion of Alumina-Forming Austenitic Stainless Steels in Static Lead	Purdue	\$2,289
			\$22,451

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

Focus on Key Technologies and Understanding

Computational Model Development and Validation

Completed in:	FY17
	FY18
	FY19
	FY20
	FY21
	FY22

FY	Title	Institution	Funding
2017	HPC Access to Advance Understanding of Fission Gas Behavior in Nuclear Fuel	UTenn	\$890
	In-Situ Ion Irradiation to Add Irradiation Assisted Grain Growth to the MARMOT Tool	PennSt	\$125
	Simulation of Radiation and Thermal Effects in Advanced Cladding Materials	PNNL	\$45
	Study of the Irradiation Behavior of Fast Reactor Mixed Oxide Annular Fuel with Modern Microstructural Characterization to Support Science Based Model Validation	INL	\$773
2018	Demonstration of a Methodology for Direct Validation of MARMOT Irradiation-Induced Microstructural Evolution and Physical Property Models Using U-10Zr	TAMU	\$2,080
	Facilitating MARMOT Modeling of Radiation Phenomena in U-Pu-Zr fuels through experiments (MORPH experiment)	UFla	\$801
			\$4,714

CINR Awarded Projects

Focus on Key Technologies and Understanding

Welding & Joining Advanced Cladding

Completed in:	FY17
	FY18
	FY19
	FY20
	FY21
	FY22

FY	Title	Institution	Funding
2016	Effects of High Dose on Laser Welded, Irradiated AISI 304SS	BSU	\$613
2017	Capacitive Discharge Resistance Welding of 14YWT for Cladding Applications	LANL	\$59
	Performance of SiC-SiC Cladding and Endplug Joints under Neutron Irradiation with a Thermal Gradient	GA	\$985
			\$1,657

Nuclear Materials Discovery & Qualification Initiative

FY	Title	Institution	Funding
2020	Machine Learning on High-Throughput Databases of Irradiation Response and Corrosion Properties of Selected Compositionally Complex Alloys for Structural Nuclear Materials	UWisc	\$502
2021	Computer vision and machine learning for microstructural qualification	Carnegie Mellon	\$494
			\$996