

Idaho National Laboratory

National University Consortium Annual Report

FY 2017



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By the Numbers

114 students sponsored by NUC

Four
joint appointments

Eight INL employees with faculty engagement

Three
workshops

105 publications (including journal articles, presentations, dissertations, theses, and reports)

\$4.1M+
new contract funding

37 interns at INL

13 current LDRD projects

One Deslonde deBoiseblanc Distinguished Postdoctoral Appointee from Oregon State University

\$18M+ existing CINR funding with INL as a partner

Overview

The National University Consortium engages with INL through a variety of mechanisms, increasing the quality of our staff and the impact of our research. These add to INL's capabilities and reach throughout the United States. The focus of the INL NUC program office continues to be to increase its engagement and visibility, both internally and externally.

Overall, the number of students engaging in research and development activities through internships at INL or research and development projects at the universities increased substantially in 2017 to 113.

The NUC research teams, composed of both university and INL researchers, continue to win funding through the Department of Energy's Office of Nuclear Energy (DOE-NE) and other agencies to engage in direct funded work from INL. Ongoing research efforts are documented in the numerous publications detailed in the bibliography. Five of the seven NUC-funded Laboratory Directed Research and Development (LDRD) projects ended this year and many of the outcomes are listed below in the Scientific Highlights sections.

New to the report this year is a listing of the INL and externally-funded projects that engage INL and NUC members.

We've added two additional joint appointments: Carol Smidts as the NUC representative at the Ohio State University (TOSU) and collaborator on multiple INL-led projects and Dave Petti as an outgoing joint appointment to Massachusetts Institute of Technology (MIT). John Gilligan remained a joint appointment at North Carolina State University (NCSU) as the director of Nuclear Energy University Program (NEUP). Wade Marcum became a joint appointment at Oregon State University (OSU), succeeding Andy Klein in the role of NUC representative and engages in multiple INL-led projects. Anil Prinja from the University of New Mexico (UNM) remains the NUC representative on the INL Board of Managers.

Program Highlights

- An outgoing joint appointment was developed late in 2016 to allow David Petti to work half-time with MIT as the Executive Director of the MIT Study: Future of Nuclear Energy in a Carbon Constrained World. The two-year study will be completed in late 2018.
- Workshops sponsored with NUC funds expanded INL industry engagement. Workshops were held at MIT on coupled heat storage to light water reactors (LWRs); at NCSU on multiphysics model validation co-sponsored with Organisation for Economic Co-operation and Development's (OECD's) Nuclear Energy Agency (NEA) Expert Group on multiphysics experiments, benchmarking, and validation and the Nuclear Energy Knowledge and Validation Center (NEKVAC); and at TOSU on big data for nuclear power plants.
- International collaboration has developed between INL, OSU and Electricity de France (EdF) on INL's open source software, Risk Analysis and Virtual Environment (RAVEN).
- Student engagement increased from 61 students in FY 2016 to 113 in FY2017.
- Through the university-led projects under DOE-NE Nuclear Energy Enabling Technologies (NEET) and NEUP, NUC universities led 13 projects awarded from 2013–2016, all of which include INL engagement. Total funding for these projects is \$18.2 million with \$1.66 million to INL over the course of the projects. Three additional projects were awarded to NUC members in 2017 for a total of \$2.4 million with \$300,000 committed to INL. Many of these projects evolved from previous LDRD and NUC engagements.
- Publications increased from 73 in FY 2016 to 105 in FY 2017, 30 of which are in peer reviewed journals. The remaining are a combination of proceedings, transactions and presentations. An additional 24 are in press.
- Oregon State University partnered with INL to develop a nuclear materials course titled "Nuclear Fuel Qualification – Post-Irradiation Examination" that began fall semester 2017. Leading INL researchers, including Mitch Meyer, instructed the course on nuclear materials associated with post-irradiation examination, filling a gap in the curriculum for students who can then become INL employees.
- Thomas Holschuh, a Ph.D. graduate from OSU, was hired as the Deslonde de Boisblanc Distinguished Postdoctoral Appointment.
- Six of the 11 inaugural graduate fellows were from NUC universities.
- NUC was leveraged in support of the Versatile Fast Neutron Source (VFNS) program. Two professors from NUC schools are co-chairs on the Academic Advisory Committee and provide a voice for the value of this program at the congressional level.

Scientific Highlights

- Robert Youngblood performed LDRD with NCSU on simplifying conventional high-resolution computational fluid dynamics approaches. This demonstrated success in teaching low-resolution models to emulate high-resolution models. This represents meaningful progress towards the goal of significantly decreasing the computational resources and time needed to perform complex calculations related to reactor containment thermal-hydraulics.
- A joint proposal on a new approach to seismic risk modeling will be taken to both Electric Power Research Institute (EPRI) and the Nuclear Regulatory Commission (NRC). This work evolved from current LDRD and NEUP projects.
- NCSU developed several models that are now being incorporated into INL-developed tools for economic analysis of hybrid energy systems.
- TOSU researchers have designed and tested an online monitoring (OLM) system to track the impact of duty cycles on aging, control, and reliability of the steam bypass and delivery system. The OLM design incorporates measurement and control components, and alarm strategy. The final OLM design will include a database of the most effective signals (sensors) for detecting possible component faults.
- TOSU developed and demonstrated an advanced digital alarm system that allows real-time data processing from installed sensors in future hardware applications to minimize the potential of component failure. This provides a basis for future multi-laboratory, integrated testing of simulation models and hardware to further advance nuclear hybrid energy system concepts.
- NCSU also developed a model of the OSU Multi-Application Light Water Reactor (MASLWR) scaled thermal hydraulic test facility for benchmarking studies.
- OSU researchers mined data from the 2010 International Atomic Energy Agency (IAEA) testing in MASLWR to provide data for hybrid energy system model validation and provided a RELAP5-3D model for running simulations that can be used on valid current models.
- OSU designed a stress corrosion cracking under $s\text{-CO}_2$ test system including experimental test apparatus. The project tested initial proof of principle. Researchers are seeking Office of Energy Efficiency and Renewable Energy (EERE) follow-on funding. Extended collaboration is also sought through collateral project with DOE NE-6 and the University of Cincinnati.
- A TOSU research team simulated and measured the diffusion coefficient of cesium in water, and the team developed a BISON model for cesium release from a defected fuel. This uncovered new thermodynamic data for fission products and extended the capabilities of the MOOSE/BISON software.
- A TOSU research team developed the five-equation drift-flux model (DFM) to address thermal non-equilibrium conditions and phenomena in LWRs. Compared to other two-phase flow models, this five-equation DFM features relatively simple governing equations with necessary physics included. This work offers a practical and yet accurate tool to model transient two-phase flow phenomena in LWRs. This work extends the

application of the MOOSE framework in solving the thermal non-equilibrium, two-phase flow model.

- A TOSU research team added an external model to RAVEN to facilitate its connection to a hardware-in-the-loop test setup through a Distributed Test Facility (DTF). The DTF provides the capability to test the reliability and performance of digital instrumentation and control systems, hence has high importance to the cybersecurity of nuclear power plants.
- A TOSU research team completed ex-core characterization of new ultrasonic and fiber optic temperature sensors, allowing for phase two characterization during in-core testing to qualify the sensors for regular use in irradiation tests.
- A NCSU research team improved modeling and validation for the Transient Reactor Test Facility (TREAT) by establishing a neutronic model using Serpent Monte Carlo code of the TREAT M2calibration experiment and a model of phonon dispersion validated using Vienna Ab initio Simulation Package (VASP).
- OSU researchers improved understanding of the uncertainties in TREAT graphite, which can be extended to any graphite reactor—e.g., high temperature gas-cooled reactors (HTGRs)—allowing a better prediction of the material behavior and understanding of the complex physics of these reactors.
- OSU researchers coupled Serpent Monte Carlo code with MOOSE-based tools. This improved the model of TREAT within OpenMC for generation of weighted cross sections for MAMMOTH. This is important in high performance computing and multiphysics by minimizing memory-intensive cross-section data storage, which will eventually allow modern methods to be extended to full core analysis and reduce uncertainty in the physics analysis for existing and proposed reactor designs. This, in turn, allows larger problems to be explored than ever before.
- University of New Mexico researchers supported the experiment design for early TREAT experiments with ATF samples and provided critical material and flow data needed for Reactor Excursion and Leak Analysis Program-7 (RELAP-7) simulation of the experiments. Measurements performed at the University of New Mexico helped simulate advanced cladding materials and assess for failure prior to being placed in a reactor, reducing the required testing time for fuels within a reactor and potentially the number of concepts that need to be studied.

Research

The NUC receives funding from INL through a variety of sources: INL direct-funded programs, LDRD projects, NUC funding (\$200,000 per university) and NSUF projects. INL accounting systems lump all this into New Contract Funding, which is shown in the graphic. Below the graphic is a listing of direct-funded projects.

INL Direct Funded Projects at the Universities

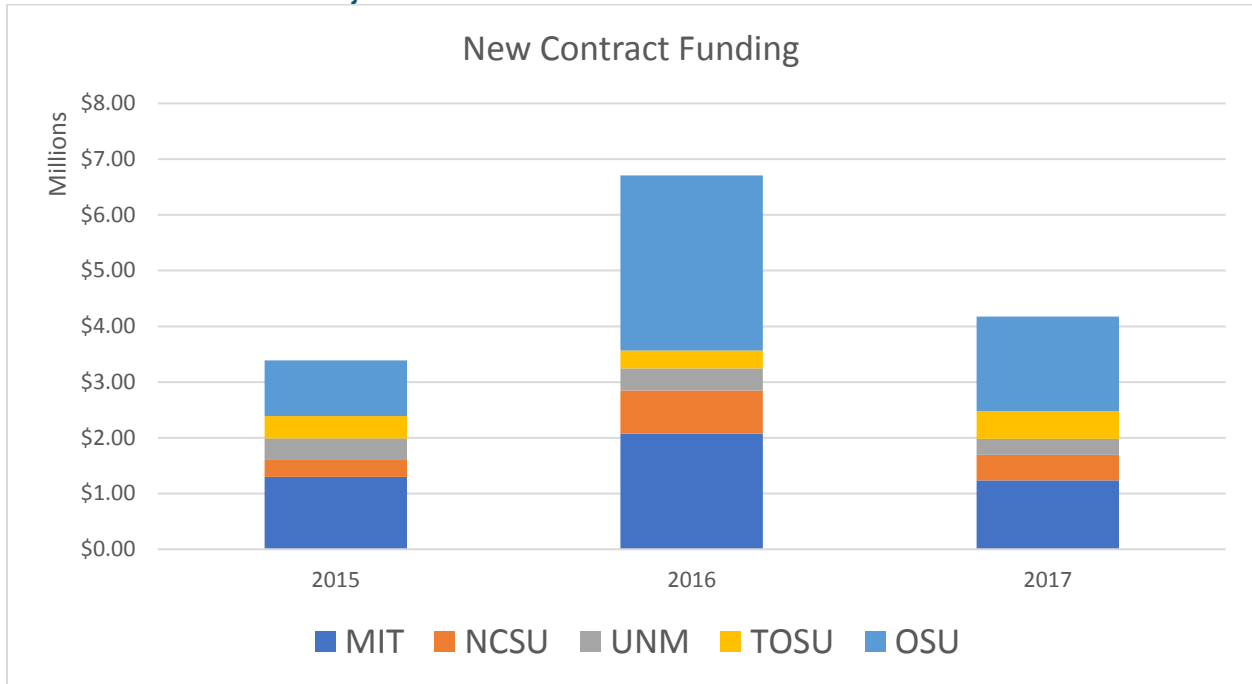


Figure 1. New contract funding. Note: This includes direct and indirect funding such as NSUF, LDRD and NUC project funding.

The Ohio State University

Independent Assessment of the RAVEN Code (EdF funded student)

C. Smith (INL); T. Aldemir (TOSU)

Massachusetts Institute of Technology

Exascale Computing Project (BES)

L. Kirby (Idaho State University); B. Forget and K. Smith (MIT); M. DeHart (INL)

Inpile Instrumentation Initiative (NE-NEET)

H. Hu (Formerly T. He) (INL); J. Li (MIT)

U.S. High-Performance Research Reactors LEU Fuel Conversion – Fuel Development and Qualification (NNSA-HPRR)

B. Robbins (INL); L. Hu (MIT)

Conceptual Design of a Compact X-ray Light Source (CXLS) for enhanced PIE at INL Development of Light Source for install at INL (MFC Program Development)

M. Meyer (INL); D. Moncton and B. Khaykovich (MIT)

High Fidelity Modeling for the TREAT Reactor (NE-NEAMS)

B. Forget and K. Smith (MIT); M. DeHart and R. Martineau (INL)

The U.S.-India collaborative for smart distribution System with Storage (UI-ASSIST) as the new consortia for Smart Grid and Energy Storage under the U.S.-India Joint Clean Energy Research and Development Center (JCERDC)

Led by Washington State University in collaboration with INL, MIT, LBNL, TAMU, U Hawaii, Snohomish County (WA) Public Utility District, Avista, Burns and McDonnell, ETAP Operation Technology, ALSTOM Grid/GE Grid Solutions, Clean Energy Storage, ABB, Philadelphia Industrial Development Corporation and the National Rural Electric Cooperative Association (NREXA). The India team is led by the Indian Institute of Technology (IIT) Kanpur and includes the partners IIT Delhi, IIT Madras, IIT Roorkee, IIT Bhubaneswar, and The Energy and Resources Institute (TERI) New Delhi

North Carolina State University

Numerical Simulation of High Wing Impact on Nuclear Energy Facilities (DOE-NE LWRS)

S. Prescott (INL); N. Dinh and A. Gupta (NCSU)

Participation in IAEA Coordinated Research Program on HTGR Uncertainty Analysis in Modeling (CEA Coordinated Program: NE-ART)

K. Ivanov (NCSU); G. Strydom (INL)

DOE LEAF Project

University of Tennessee in collaboration with INL, NCSU, Auburn, Genera and PerkinElmer

Oregon State University

INL HTTF Testing (DOE-NE ART)

H. Gougar (INL); S. Cadell (OSU)

Hydro-Mechanical Fuel Test Program (NNSA-HPRR)

A. M. Phillips (INL); W. Marcum (OSU)

Flow Testing of In-Pile Reactor (NNSA-HPRR)

A. M. Phillips (INL); W. Marcum (OSU)

Flow Testing of Plate Experiments (NNSA-HPRR)

A. M. Phillips (INL); W. Marcum (OSU)

Pump Commissioning Flow Tests (NRF/ATR)

R. Jones (INL); W. Marcum (OSU)

Characterization of Irradiated Fuels (NE-6)

S. Tesseyre (INL); J. Tucker (OSU)

Xe-100 Pebble Bed Advanced Reactor Project (DOE)

X-Energy partnering with INL, BWX Technology, Oregon State University, Teledyne-Brown Engineering, SGL Group, INL and ORNL

Microstructural Characterization of Irradiated Fuels and Materials for the United States High Performance Research Reactor Fuel Development Program and the Fuel Cycle Research and Development Program

J. Tucker (OSU); B. Miller (INL)

NEUP/NEET CINR Projects

Ongoing

Three-Dimensional Fuel Pin Model Validation by Prediction of Hydrogen Distribution in Cladding and Comparison with Experiment

PI: M. Avramova (NCSU); Collaborator: R. Williamson (INL)

\$800,000 total funding, \$80,000 to INL

R&D project awarded in 2013

Tritium Mitigation/Control for Advanced Reactor Systems

PI: R. Christensen (TOSU); co-PI: X. Sun (TOSU); Collaborators: P. Sabharwal (INL)

\$400,000 total funding, \$80,000 to INL

R&D project awarded in 2013

Risk-Informed Safety Margin Characterization (RISMC) for Nuclear Facility Seismic

PI: H. Sezen (TOSU); Collaborators: T. Aldemir, R. Denning, J. Hur (TOSU); N. Vaidya (Paul C. Rizzo Associates Inc.); Curtis Smith (INL)

\$800,000 total funding

R&D project awarded in 2013

Experimental Investigation and CFD Analysis of Steam Ingress Accidents in HTGRs

PI: R. Christensen; co-PIs: X. Sun (TOSU), P. Bardet (George Washington University); Collaborator: P. Sabharwal (INL)

\$800,000 total funding with \$90,000 to INL

R&D project awarded in 2014

Studies of lanthanide transport in metallic nuclear fuel

PI: J. Zhang (TOSU); Collaborators: R. Mariani, R. Martineau (INL)

\$800,000 total funding with \$22,400 to INL

R&D awarded in 2014

Alloying Agents to Stabilize Lanthanides Against Fuel Cladding Chemical Interaction: Tellurium and Antimony Studies

PI: J. Zhang (TOSU); Collaborators: M. Benson, R. Mariani, Y. Zhang (INL); M. Short (MIT)

\$800,000 total funding with \$160,000 to INL
R&D project awarded in 2014

Monitoring of actinide concentrations in molten LiCl-KCl salt using alpha spectroscopy

PI: L. Cao (TOSU); Collaborators: T. Blue (TOSU); M. Simpson (University of Utah); G. Fredrickson (INL)

\$799,969 total funding with \$80,000 to INL
R&D project awarded in 2015

Development of Accident Tolerant Fuel Options for Near Term Applications

PI: K. Shirvan (was M. Kazimi) (MIT); Collaborators: J. Hales, D Gaston (INL)

\$3 million total funding with \$160,000 to INL
Integrated Research Project (IRP) awarded in 2015

Computational and Experimental Benchmarking for Transient Fuel Testing

PI: W. Marcum (OSU); Collaborators: L. Hu (MIT); D. Wachs (INL)

\$4 million total funding with \$180,000 to INL
IRP awarded in 2015

Benchmark Evaluation of TREAT Reactor M2 and M3 Transient Experiments

PI: A. Hawari (NCSU); Collaborator: M. DeHart (INL)

\$400,000 total funding with \$80,000 to INL
R&D project awarded in 2015

Support for Reactor Operators in Case of Cyber-Security Threats

T. McJunkin (INL); C. Smidts (TOSU); I. Ray (Colorado State University); Q. Zhu (New York University); J. Hollern (AREVA)

\$800,000 total funding with \$80,000 to INL
R&D project awarded in 2016

Multi-group Transport Cross Section and Diffusion Coefficient Generation for Deterministic Reactor Models Using Monte Carlo Calculations

PI: K. Smith (MIT); Collaborators: B. Forget (MIT); J. Ortensi (INL)

\$800,000 total funding with \$180,000 to INL
R&D project awarded in 2016

Development and Application of a Data-Driven Methodology for Validation of Risk-Informed Safety Margin Characterization Models

PI: N. Dinh (NCSU); Collaborators: I. Bolotnov, J. Baugh, A. Gupta, M. Avramova (NCSU); C. Rabiti, R. Youngblood, S. Prescott (INL)

\$4 million total funding with \$480,000 to INL
IRP awarded in 2016

Microstructure Experiments-Enabled MARMOT Simulations of SiC/SiC-based Accident Tolerant Nuclear Fuel System

PI: J. Eapen (NCSU); Collaborator: D. Schwen (INL)

\$800,000 total funding with \$75,000 to INL
R&D project awarded in 2016

Newly Funded

These projects began October 2017.

Integrating Static PRA Information with RISMC Simulation Methods

PI: T. Aldemir (TOSU); Collaborators: D. Mandelli, A. Alfonsi (INL); A. Yilmaz (OSU)

\$800,000 total funding with \$120,000 to INL
NEUP R&D project

An Experimental and Analytical Investigation into Critical Heat Flux (CHF) Implications for Accident Tolerant Fuel (ATF) Concepts

PI: Y. Lee (UNM); Collaborators: W. Marcum (OSU), N. Brown (Pennsylvania State University); J. Strumpell (Areva); C. Jensen (INL); S. Walker, R. Issa, G. Hewitt (Imperial College, London); R. Rebak (GE Global)

\$800,000 total funding with \$50,000 to INL
NEUP R&D project

Combined modeling and experiments to predict corrosion and embrittlement in dual-phase stainless steels within the MARMOT framework

PI: J. Tucker (OSU); Collaborators: L. Arnadottir, B. Isgor (OSU); Y. Zhang (INL)

\$800,000 total funding with \$130,000 to INL
NEET project

NSUF Projects

Advanced High-Temperature Sensors

J. Daw (INL); D. Carpenter (MIT)

Radiation-Hardened Ultrasonic Sensors: Explore six different ultrasonic transducers' real-time response as a function of flux, temperature and other conditions. Follow-up collaboration with INL, Alternative Energies and Atomic Energy Commission (CEA), University of Pittsburgh, and AFO Research to include optical glasses and radiation-hardened fiber optics.

LWR In-Core Electrochemical Potential Probes

J. Daw (INL); D. Carpenter, G. Kohse (MIT)

TREAT Core Instrumentation Tests. A collaboration with MIT, OSU, University of Michigan and INL on instrumentation and benchmarking in support of the TREAT restart.

Rapid Turnaround Experiment: Microstructural Characterization of Post-Irradiation Alloys for Integrated FHR Technology Development

G. Zheng (MIT)

In support of the development of fluoride salt-cooled high-temperature reactor (FHR), Hastelloy N and 316L stainless steel as the most likely candidate alloys have been tested in molten FLiBe salt in MIT reactor for 1000 hours. To understand the corrosion behavior of the alloys in high-temperature molten salt under neutron irradiation, this project focuses on the microstructural analyses of the in-core tested alloys by using the facilities in the Center for Advanced Energy Studies (CAES) at INL.

NUC LDRD Projects

15-039: Transient Modeling of Integrated Nuclear Energy Systems with Thermal Energy Storage and Component Aging and Preliminary Model Validation via Experiment

PI: S. Bragg-Sitton (INL); Co-PIs: J.M. Doster, S. Terry (NCSU); C. Smidts (TOSU); Q. Wu (OSU)

Develop the high fidelity, experimentally validated simulation tools necessary to adequately characterize the coupled system response and to optimize the operational strategies for

accomplishing transient maneuvers. This is done by leveraging expertise and previous research, including existing models and experimental data while working with NUC partners.

15-060: Development of Efficient TREAT Modeling Capabilities with Graphite Data Improvement

PI: M. DeHart (INL); Co-PIs: T. Palmer (OSU); A. Hawari (NCSU); B. Forget, K. Smith (MIT); M. Liu, A. Ali (UNM)

Multipronged approach utilizing NUC capabilities to support modeling and experimentation related to the TREAT reactor.

15-094: Evaluation and Demonstration of the Integration of Safeguards, Safety and Security by Design

PI: J. Disser, J. Sanders (INL); Co-PIs: J. Lambert (INL); E. Blandford, E. Arthur, B. Merryman, N. Osterhaus (UNM)

15-141: Interfacing MOOSE Components to Enhance Capability

PI: H. Zhang (INL); Co-PIs: C. Smidts, X. Sun, J. Zhang (TOSU)

This LDRD uses a three-pronged approach to enhance MOOSE:

1. Develop a non-equilibrium chemical model for the assessment of chemical and corrosion reactions among coolant, cladding and fuel resulted from fission products release.
2. Support the two-phase flow modeling and validation activities by investigating the thermal non-equilibrium, five-equation drift-flux model (DFM) using the computational framework, MOOSE.
3. Investigate the connection between RAVEN/RELAP-7 and the distributed test facility (DTF) for instrumentation and control systems. A reduced-scale, hardware-in-a-loop (HIL) steam generator water level control system and a full-scale Nuclear Power Plant Simulator will be used to interact with RAVEN. This allows capabilities to be extended in the area of digital I&C reliability and reliability testing.

15-142: Neutron Dosimetry Through Novel Interrogation of Optical Materials, Towards In-Core Neutron Diagnostics

PI: S. Teyseyre (INL); Co PIs: J. C. Diels, A. Hecht (UNM)

Correlate neutron irradiation dose to refractive index of materials to develop a gamma blind mode of neutron dosimetry.

16-050: Stress Corrosion Cracking Testing in Supercritical Carbon Dioxide

PI: S. Teyseyre (INL); Co PIs: J. Tucker (OSU)

Two-pronged project to generate sCO₂ corrosion data and extend the capability of OSU's existing sCO₂ loop from a simple corrosion loop to a loop with stress corrosion cracking testing

capability with in-situ crack growth rate measurement. Proof of principle of the approach expected to yield eventual placement of like instrument at INL.

16-026: Computationally Efficient Prediction of Containment Thermal Hydraulics Using Multi-Scale Simulation: Feasibility Study

PI: R. Youngblood (INL); Co PIs: N. Dinh, I. Bolotonov (NCSU)

Develop a technical basis for the coarse-grained computational fluid dynamics (CFD) capability that is needed for high-fidelity analysis of containment thermal hydraulics.

16-149: In-Core Qualification of Developmental Instrumentation

PI: J. Daw (INL); Co PIs: J. Palmer (INL); J-F. Villard (CEA); G. Khose (MIT); J. Pearce (National Physical Laboratory); R. Pedrazzani (Luna Innovations)

Perform ex-core characterization of ultrasonic and fiber optic temperature sensors for measuring parameters such as temperature, strain, pressure, displacement, etc. Successful testing would lead to testing in-core in phase two.

16-036: Neutron Microscope to Enable High-Resolution Neutron Tomography at INL

PI: M. Abir (INL); Co PIs: W. Williams (INL); B. Khaydovich (MIT)

Development of a new type of neutron microscope utilizing focusing mirrors and modern solid-state detectors to form an automatic tomographic facility at NRAD to perform neutron diffraction studies of irradiated fuel.

16-058: Predicting Radiation-Induced Microstructural Change via Implementation and Validation of Multi-Scale Cluster Dynamics in MOOSE

PI: C. Permann (INL); Co-PIs: M. Short, Miaomiao Jin (MIT)

Develop a new MOOSE application to provide higher fidelity scale bridging between traditional molecular dynamics simulations and mesoscale simulations using MOOSE.

17A1-227FP: Multi-Physics, Multi-Scale Coupled Simulation of Power Impulse Experiments

PI: W. Jones (INL); Co PIs: H. Chen, S. Novascone, B. Spencer (INL); W. Marcum (OSU)

Computationally model loss of coolant accident (LOCA), reactivity-initiated accidents (RIA), and post-accident fuel migration of a Special Power Excursion Reactor Test (SPERT) or Power Burst Facility (PBF) type fuel/capsule/coolant experiment geometry. The modeling will be performed with verified codes, and validation will be performed against documented experimental results and new experiments performed at OSU that will explore post-accident fuel migration and dispersion. Ultimately, the combination of these methods and simulations will provide information to feed full-core simulations such as MELCOR.

17A1-105FP: Safety Margin Evaluation for Experiment Irradiation in ATR

PI: J. Nielsen (INL); Co PIs: R. Marlow, P. Murray (INL); L. Sun, L.-W. Hu (MIT)

Evaluates the departure from nuclear boiling ratio (DNBR) limit using various subcooled critical heat flux correlations and considers the impacts of changing the limit to the onset of nucleate boiling.

17P11-001FP: Enabling Material Discovery for Hybrid Energy Systems Using a Multimodal Optical Sensor

PI: D. Hurley (INL); R. Schley, L. He (INL); M. Khafizov (TOSU)

Development of laser-based characterization toolbox for characterization of materials for photovoltaic, solid-oxide fuel cell, and nuclear fuel applications.

Faculty and Staff Engagement

Benefits to the Universities

Massachusetts Institute of Technology

License Agreements:

- RELAP5-3D, Version 4.x.x
- BISON

\$1.23 million via subcontracts from INL

The Ohio State University

License Agreements

- BISON
- RAVEN

\$503,000 via subcontracts from INL

Oregon State University

License Agreements:

- BISON
- RAVEN
- RELAP5-3D, Version 4.x.x

\$1.69 million via subcontracts from INL

North Carolina State University

License Agreements:

- BISON
- MarmotViz
- PHISICS University
- RAVEN
- RELAP5-3D, Version 4.x.
- MAGPIE

\$458,000 via subcontracts from INL

University of New Mexico

License Agreements

- RAVEN
- RELAP5-3D, Version 4.x.x.

\$279,000 via subcontracts from INL

Joint Appointments

Incoming

John Gilligan, NEUP director, NCSU

Carol Smidts, NUC lead/Hybrid Energy Studies, TOSU

Wade Marcum, NUC lead, OSU (OSU match funded this joint appointment.)

Outgoing

Dave Petti, MIT executive director of the MIT study on the Future of Nuclear Energy in a Carbon Constrained World, MIT

INL Staff University Positions

J. Wagner, member, Nuclear Engineering Department Advisory Council, NCSU

S. Bragg-Sitton, adjunct faculty, Department of Nuclear Engineering, NCSU

S. Bragg-Sitton, courtesy faculty assistant professor, Department of Nuclear Engineering, OSU

S. Aumeier, member, Nuclear Engineering Advisory Committee, OSU

S. Schunert, adjunct faculty, Department of Nuclear Engineering, NCSU

R. Youngblood, adjunct faculty, Department of Nuclear Engineering, NCSU

R. Boring, committee member, Nuclear Engineering Advisory Committee, TOSU

D. Chichester, assistant faculty member, OSU

Trips by INL Staff to NUC Universities

The Ohio State University

- *Ron Boring*, May: Thesis committee
- *Andrea Alfonsi*, January: Collaboration opportunities and seminar
- *Shannon Bragg-Sitton*, November: Seminar and review of NHES LDRD
- *Colby Jensen*: Seminar at OSU

North Carolina State University

- *Kelly Beierschmitt*, May: INL leadership visit
- *Shannon Bragg-Sitton*: Serve on Ph.D. committees, discuss LDRD project

Oregon State University

- *Mark Peters*: INL leadership visit

University of New Mexico

- *Cristian Rabiti*: Ph.D. dissertation defense
- *Jason Hansen*: Give seminar and collaboration

Massachusetts Institute of Technology

- *Amy Lientz*: INL leadership visit
- *Richard Boardman*: Attend MIT Workshop

Trips to INL (or INL-related activities)

In total 74 trips were made to INL.

University of New Mexico

- *Osman Anderoglu*: Visit included seminars at EROB and MFC
- *Youho Lee*: Visit with seminars at EROB and MFC
- *Anil Prinja*: BEA Board of Managers meetings
- *Pat McDaniel*: NUC-MIT workshop

The Ohio State University

- *Marat Khafizov*: LDRD review meeting
- *Raymond Cao*: NSUF Partner Facility Working Group meeting
- *Carol Smitds*: Collaboration and Versatile Fast Neutron Source meetings
- *Halil Sezen, Tunc Aldemir and Rich Denning*: Collaboration and NEUP project meetings

Massachusetts Institute of Technology

- *Michael Short*: Explore joint MIT/INL radiation damage center concept/LDRD review with seminars at EROB and MFC
- *Ju Li*: Explore collaborations
- *Charles Forsberg*: Collaboration and engagement; VFNS Meeting
- *Guiqiu Zheng*: Conducting tests and preparing samples
- *Boris Khaykovich*: Discuss enhanced PIE needs at INL
- *David Moncton*: Discuss enhanced PIE needs at INL
- *Koroush Shrivani*: Knowledge Transfer Workshop
- *Neil Trodreas*: Speaker at Knowledge Transfer Workshop

Oregon State University

- *Cindy Sagers*: Explore collaboration potential
- *Wade Marcum*: Ongoing programs; VFNS meetings
- *Andy Klein*: BEA Board of Managers meetings

North Carolina State University

- *Yousry Azmy*: Engagement and collaboration
- *Nam Dihn*: Versatile Fast Neutron Source meetings in Washington, D.C.
- *Hong Luo*: R&D collaborations
- *Jason Hou*: R&D collaborations
- *Alan Rebar*: Explore NCSU level opportunities to collaborate
- *Mladen Vouk*: Explore NCSU level opportunities to collaborate
- *John Gilligan*: Explore NCSU level opportunities to collaborate

Workshops

Light Water Reactor Heat Storage for Peak Power and Increase Revenue

June 27–28, 2017

MIT

The goal of the workshop was to explore pathways to boost the long-term economic basis of nuclear energy by better matching nuclear power to market needs. Participants included utilities, Nuclear Energy Institute (NEI), EPRI, industry, national laboratories and universities. It was co-sponsored by MIT, INL and Exelon.

Multi-Physics Model Validation Workshop co-sponsored with OECD/NEA Expert Group on Multi-Physics Experiments, Benchmarking and Validation and the Nuclear Energy Knowledge and Validation Center (NEKVAC)

June 28–29, 2017

NCSU

The workshop was co-sponsored by NUC, INL, NEKVAC and NCSU. Participants represented national laboratories, industry, regulators, academia and international institutions. Discussion included emerging needs, technical challenges, opportunities for R&D, and collaboration on validation and uncertainty quantification of multiphysics models in nuclear reactor and nuclear energy applications.

Big Data for Nuclear Power Plants

Sept. 8, 2017.

TOSU

This workshop explored the state of the art and gaps in “big data” acquisition, storage and analysis within the nuclear industry to assess the potential for improving performance, safety and security of nuclear reactor operations. The workshop was sponsored by INL and TOSU. The 34 attendees came from academia, national laboratories, nuclear industry, utilities and related suppliers. A special issue of a peer-reviewed journal will be issued from the workshop-related papers in FY 2019.

Student Engagement

Students Funded by INL

During FY 2017, 113 NUC university students engaged in research related either at INL or as part of a collaborative research team with INL. These students were funded in multiple ways: LDRD project funds, NEUP project funds, as NEUP Fellows, internal university funding, BES funding, direct funding at INL through internships or at the university via project work and even one Department of Defense (DOD) SMART Scholarship. Appendix A includes more information on the INL's engagement with students.

Several students from NUC universities were also sponsored to attend INL-led workshops such as NEKVAC, the Advanced Test Reactor (ATR) Nuclear Science User Facilities (NSUF) workshop and the NSUF Thermal Hydraulics Workshop.

An example of the collaboration being done with students can be found in the NCSU Senior Design/Capstone Project. This project, led by Cristian Rabiti with INL, will connect five to seven seniors at NCSU to INL. The students will use the RELAP5-3D HTTR core model coupled to HTTR PHISICS core model including cross-sections to attempt to model load following using the blower and/or control rods. This collaboration will provide students with hands-on and meaningful work that not only enhances their learning experience, but benefits INL's research initiatives.

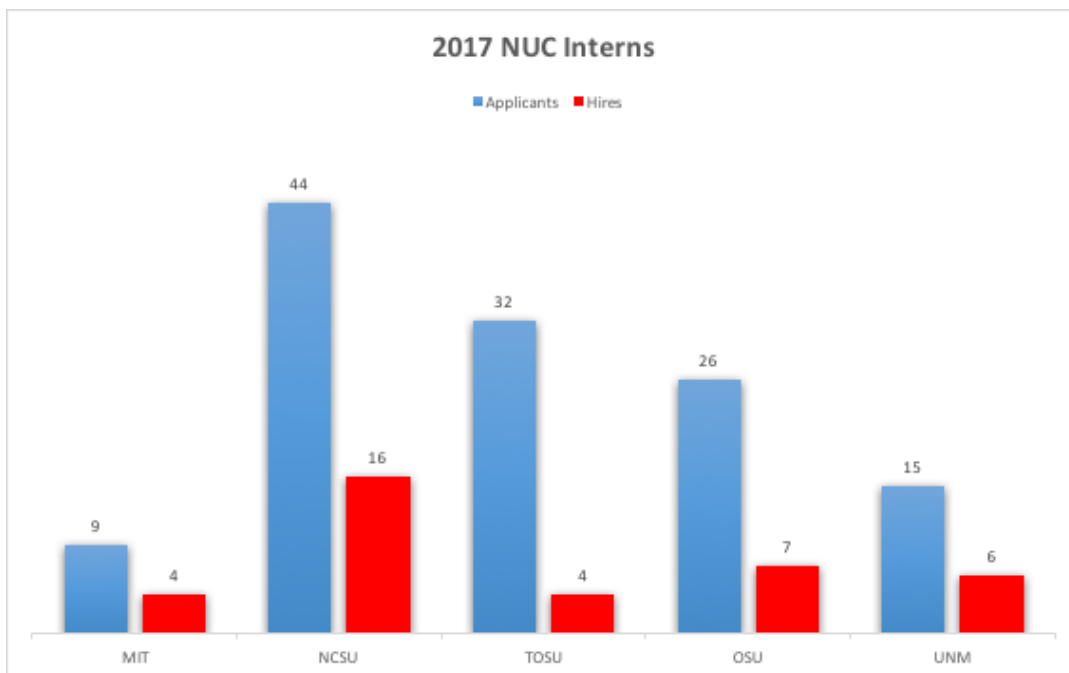


Figure 2. NUC interns at INL.

Incoming Graduate Fellows

The INL Graduate Fellowship Program, a collaboration between INL and universities, is designed to identify exceptional talent in research areas aligned with INL's strategic agenda to enable the current and future mission of the Department of Energy (DOE) and INL.

This arrangement is a triad between the student, the university thesis advisor, and INL technical advisor to provide meaningful research and mentorship throughout the entire program.

Konor Frick, NCSU

- NCSU advisor: Mike Doster, Department of Nuclear Engineering
- INL mentor: Shannon Bragg-Sitton
- Start date: December 2017
- Project: Development and simulation of a coupled thermal energy storage system for deployment in nuclear hybrid energy systems

Casey Icenhour, NCSU

- Advisor: Steve Shannon, Department of Nuclear Engineering
- INL mentor: Rich Martineau
- Start date: August 2017
- Project: Expansion of MOOSE capability to address a broader class of problems in nuclear science and engineering using vector finite elements

Ariana Foley, OSU

- OSU advisor: Haori Yang, School of Nuclear Science and Engineering
- INL mentor: Matt Kinlaw
- Start date: September 2020
- Project: Contribute to nonproliferation and security by focusing research on the determination of short-lived fission products yields through the precise measurement and analysis of delayed gamma-ray signatures immediately following photon-induced fission (photo-fission).

Musa Moussaoui, OSU

- OSU advisor: Wade Marcum
- INL mentor: Dan Wachs
- Start date: August 2019
- Project: Research will help develop experimental devices needed to conduct accident simulations at TREAT

Bill Chuirazzi, TOSU

- TOSU advisor: Raymond Cao
- INL mentor: Aaron Craft
- Start date: August 2018
- Project: Evaluate scintillators of different compositions to determine what materials are the most useful in creating fast and thermal neutron imagers.

Kelly McCary, TOSU

- TOSU advisor: Thomas Blue
- INL mentor: Joshua Daw
- Start Date: August 2018
- Project: High-temperature, radiation-resistant sapphire optical fiber distributed temperature and strain sensors for irradiation testing.

Postdocs

At INL

Thomas Holschuh, OSU, *Deslonde de-Boisblanc Distinguished Postdoctoral Appointment*

At Universities

Amir Ali, UNM

Maolong Liu, UNM

Shanbin Shi, TOSU

Publications and Intellectual Property

Journal Articles

1. Aydogan, E., S.a. Maloy, O. Anderoglu, C. Sun, J.g. Gigax, L. Shao, F.a. Garner, I.e. Anderson, and J.j. Lewandowski. "Effect of tube processing methods on microstructure, mechanical properties and irradiation response of 14YWT nanostructured ferritic alloys." *Acta Materialia* 134 (2017): 116-27. doi:10.1016/j.actamat.2017.05.053.
2. Brown, C.s., H. Zhang, V. Kucukboyaci, and Y. Sung. "Best estimate plus uncertainty analysis of departure from nucleate boiling limiting case with CASL core simulator VERA-CS in response to PWR main steam line break event." *Nuclear Engineering and Design* 309 (2016): 8-22. doi:10.1016/j.nucengdes.2016.09.006.
3. Buckner, M. Q., C. Y. Wu, R. A. Henderson, B. Bucher, N. Wimer, A. Chyzh, T. A. Bredeweg, B. Baramsai, A. Couture, M. Jandel, S. Mosby, and J. L. Ullmann. "Comprehensive 242 m Am neutron-induced reaction cross sections and resonance parameters." *Physical Review*, June 30, 2017. doi:https://doi.org/10.1103/PhysRevC.95.061602.
4. Cao, Lei, Josh Jarrell, Susan White, Kevin Herminghuysen, Andrew Kauffman, Douglas E. Hardtmayer, Jeff Sanders, and Shelly Li. "A radioactive tracer dilution method to determine the mass of molten salt." *Journal of Radioanalytical and Nuclear Chemistry* 314, no. 1 (2017): 387-93. doi:10.1007/s10967-017-5417-5.
5. Chaleff, Ethan S., Thomas Blue, and Piyush Sabharwall. "Radiation Heat Transfer in the Molten Salt FLiNaK." *Nuclear Technology* 196, no. 1 (2016): 53-60. doi:10.13182/nt16-52.
6. Chen, Minghui, Xiaodong Sun, Richard N. Christensen, Shanbin Shi, Isaac Skavdahl, Vivek Utgikar, and Piyush Sabharwall. "Experimental and numerical study of a printed circuit heat exchanger." *Annals of Nuclear Energy* 97 (2016): 221-31. doi:10.1016/j.anucene.2016.07.010.
7. Chen, Minghui, Xiaodong Sun, Richard N. Christensen, Isaac Skavdahl, Vivek Utgikar, and Piyush Sabharwall. "Pressure drop and heat transfer characteristics of a high-temperature printed circuit heat exchanger." *Applied Thermal Engineering* 108 (2016): 1409-417. doi:10.1016/j.applthermaleng.2016.07.149.
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9. Ellis, Matthew, Derek Gaston, Benoit Forget, and Kord Smith. "Preliminary Coupling of the Monte Carlo Code OpenMC and the Multiphysics Object-Oriented Simulation Environment for Analyzing Doppler Feedback in Monte Carlo Simulations." *Nuclear Science and Engineering* 185, no. 1 (2017): 184-93. doi:10.13182/nse16-26.
10. Fathi, Nima, Patrick Mcdaniel, Charles Forsberg, and Cassiano De Oliveira. "Power Cycle Assessment of Nuclear Systems, Providing Energy Storage for Low Carbon Grids." *Journal of Nuclear Engineering and Radiation Science*, 2017. doi:10.1115/1.4037806.
11. Forsberg, Charles W., Stephen Lam, David M. Carpenter, Dennis G. Whyte, Raluca Scarlat, Cristian Contescu, Liu Wei, John Stempien, and Edward Blandford. "Tritium

- Control and Capture in Salt-Cooled Fission and Fusion Reactors: Status, Challenges, and Path Forward." *Nuclear Technology* 197, no. 2 (2017): 119-39. doi:10.13182/nt16-101.
12. Forsberg, Charles W., Daniel C. Stack, Daniel Curtis, Geoffrey Haratyk, and Nestor Andres Sepulveda. "Converting excess low-price electricity into high-temperature stored heat for industry and high-value electricity production." *The Electricity Journal* 30, no. 6 (2017): 42-52. doi:10.1016/j.tej.2017.06.009.
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 15. Khafizov, M., V. Chauhan, Y. Wang, F. Riyad, N. Hang, and D.h. Hurley. "Investigation of thermal transport in composites and ion beam irradiated materials for nuclear energy applications." *Journal of Materials Research* 32, no. 01 (2016): 204-16. doi:10.1557/jmr.2016.421.
 16. Lam, Stephen T., John Stempien, Ronald Ballinger, and Charles Forsberg. "Tritium Management and Control Using Carbon in a Fluoride-Salt-Cooled High-Temperature Reactor." *Fusion Science and Technology* 71, no. 4 (2017): 644-48. doi:10.1080/15361055.2017.1290945.
 17. Li, Xiang, Adib Samin, Jinsuo Zhang, C. Unal, and R.d. Mariani. "Ab-initio molecular dynamics study of lanthanides in liquid sodium." *Journal of Nuclear Materials* 484 (2017): 98-102. doi:10.1016/j.jnucmat.2016.11.028.
 18. Liu, Maolong, Nicholas R. Brown, Kurt A. Terrani, Amir F. Ali, Edward D. Blandford, and Daniel M. Wachs. "Potential impact of accident tolerant fuel cladding critical heat flux characteristics on the high temperature phase of reactivity initiated accidents." *Annals of Nuclear Energy* 110 (2017): 48-62. doi:10.1016/j.anucene.2017.06.016.
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 21. Misenheimer, Corey T., and Stephen D. Terry. "Modeling Hybrid Nuclear Systems With Chilled-Water Storage." *Journal of Energy Resources Technology* 139, no. 1 (2016): 012002. doi:10.1115/1.4033858.
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24. Terrani, Kurt, Mehdi Balooch, David Carpenter, Gordon Kohse, Dennis Keiser, Mitchell Meyer, and Donald Olander. "Irradiation effects on thermal properties of LWR hydride fuel." *Journal of Nuclear Materials* 486 (2017): 381-90. doi:10.1016/j.jnucmat.2017.01.030.
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Presentations/Proceedings/Transactions:

1. Aggarwal, R., and C. Smidts. "International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technologies." Task Allocation in Geo-Distributed Cyber-Physical Systems.
2. Alberti, A., and T. Palmer. "Workshop on Parameter Space Dimension Reductions." PGD in Nuclear Reactor Physics: An Investigation of A Priori Model Reduction in Nuclear Reactor Physics Calculations.
3. Ali, A. F., et al. "International Topical Meeting on Nuclear Reactor Thermal Hydraulics." Surface Wettability Measurements of FeCrAl Alloys under LWR Environments.
4. Brown, E., et al. "American Nuclear Society Annual Meeting." Modeling the Transient Reactor Test Loop in TRACE for PWR Critical Heat Flux Benchmarking, vol. 116, pp. 1455–1457.
5. Chen, H., et al. "ASME 2016 International Mechanical Engineering Congress and Exposition." A MOOSE-Based Implicit Peridynamic Thermomechanical Model.
6. Doster, J. M., and Konor Frick. "Light Water Reactor Heat Storage for Peak Power and Increased Revenue: Focused Workshop on Near-Term Options." Heat Storage in Secondary Media.
7. Doster, J. M., and K. L. Frick. "American Nuclear Society Winter Meeting." Coupling of Thermal Energy Storage with Small Modular Reactors.
8. Doster, J. M., and K. L. Frick. "American Nuclear Society Annual Meeting." Coupling of Thermal Energy Storage with Small Modular Reactors.

9. Ellis, M., et al. "American Nuclear Society Winter Meeting." Spatially Continuous Depletion Algorithm for Monte Carlo Simulations.
10. Frick, K., et al. "International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technologies." Control Strategies for Coupling Thermal Energy Storage Systems with Small Modular Reactors.
11. Goodrich, S., and W. R. Marcum. "American Society of Mechanical Engineers 2017 Summer Heat Transfer Conference." Natural Convection Heat Transfer and Boundary Layer Transition for Vertical Heated Cylinders.
12. Harter, J., et al. "American Nuclear Society Winter Meeting." Quantifying the Uncertainty in Deterministic Phonon Transport Calculations of Thermal Conductivity using Polynomial Chaos Expansions.
13. Haugen, C. C., et al. "International Conference on Mathematics & Computational Methods Applied to Nuclear Science & Engineering." A Rejection Sampling Based Method for Determining Thermal Scattering Angle and Energy.
14. Hawari, A. I., et al. "American Nuclear Society Winter Meeting." Testing of Graphite Thermal Neutron Scattering Law Data in Support of TREAT Neutronic Analysis.
15. Hawkes, G., et al. "American Society of Mechanical Engineers Power and Energy Conference and Exhibition." Flow Testing and Analysis of the FSP-1 Experiment.
16. Hoover, K., et al. "American Nuclear Society Winter Meeting." SMR Re-Scaling and Modeling for Load Following Studies.
17. Howard, T. K., and W. R. Marcum. "American Nuclear Society Winter Meeting." An Approach to Assessment of Added Mass for a Plate in a Channel, vol. 115, pp. 1546–1549.
18. Jarell, Joshua T., et al. "American Nuclear Society Winter Meeting." Charge Carrier Diffusion Length Determination in 4H-SiC Schottky Alpha Detectors, vol. 115.
19. Jarrell, J., et al. "American Nuclear Society Annual Meeting." Elevated Temperature Alpha Spectroscopy with Nickel-Platinum 4H-SiC Schottky Diodes, vol. 116, pp. 123–125.
20. Jones, W. F., et al. "International Meeting on Reduced Enrichment for Research and Test Reactors." USHPRR Fuel Development Flow Testing Overview, pp. 1–10.
21. LaBrier, D. P., and W. R. Marcum. "American Nuclear Society Annual Meeting." Methodology of Experiment Design for Transient Critical Heat Flux Model Development, vol. 116, pp. 1397–1400.
22. Latimer, G. D., et al. "American Nuclear Society Winter Meeting." Vibration Analysis of Advanced Test Reactor Mini-Plate Hydraulic Tests in the OSU HMFTF.
23. Lee, Y., et al. "American Nuclear Society Winter Meeting." A NEUP Example of US-UK Collaboration: An Experimental and Analytical Investigation into Critical Heat Flux Implications for Accident Tolerant Fuel Concepts.
24. Li, H., et al. "International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technologies." Fault Propagation and Effects Analysis for Designing an Online Monitoring System for the Secondary Loop of a Nuclear Power Plant Part of a Hybrid Energy System.
25. Li, H., et al. "American Nuclear Society Winter Meeting." Failure Diagnosis of the Holdup Tank System via ISFA Technique.

26. Liu, M., et al. "Test, Research, and Training Reactor Conference." Development of Electrical Capacitance Sensors for Accident Tolerant Fuel (ATF) Testing at the Transient Reactor Test (TREAT) Facility.
27. Misenheimer, C. T., et al. "International Embedded Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies." Analysis of a Hybrid Nuclear Energy System Using Absorption Chillers and Stratified Chilled Water Storage with an mPower Reactor.
28. Nixon, C. A., et al. "American Nuclear Society Winter Meeting." The Dynamic Response of a Wire-Wrapped Pin – A New Experimental Method, vol. 115, pp. 1692–1695.
29. Odeniyi, A., and S. D. Terry. "Illinois Education and Technology Conference." Hybridization and Optimization of Gas Turbines for Compressed Air Energy Storage Systems.
30. Rai, D. K., et al. "NEUWAVE-9 Workshop." Neutron Focusing Mirrors for Enhanced Neutron Radiography with Thermal Neutrons and Application for Irradiated Nuclear Fuel (Poster).
31. Rai, D. K., et al. "American Physical Society Winter Meeting." Neutron Focusing Mirrors for Neutron Radiography of Irradiated Nuclear Fuel at Idaho National Laboratory, vol. 62.
32. Rechar, Rob P., et al. "International High-Level Radioactive Waste Management." Feasibility of Direct Disposal of Salt Waste from Electrochemical Processing of Spent Nuclear Fuel.
33. Shi, S., et al. "25th International Conference on Nuclear Engineering." Development of Five-Equation Drift Flux Model for Thermal Non-Equilibrium Phenomena in LWRs, vol. 8.
34. Smidts, C. "U.S. Women in Nuclear National Conference." Nuclear Hybrid Energy Systems (NHES).
35. Teeter, L. "1st International Network Meeting of the European School of Materials." Corrosion Research and Current Activities at Oregon State University.
36. Teeter, L., et al. "2017 Symposium of the Pacific Northwest Chapter of the AVS." Environmentally Induced Cracking of Energy System Materials in sCO₂.
37. Teeter, L., et al. "The Minerals, Metals, and Materials Society Conference." Corrosion of Fe-Ni-Cr Alloy 800H in Supercritical CO₂ and its Effects.
38. Teeter, L., et al. "Oregon State University Graduate Research Expo." SCC in sCO₂ for Energy Systems Materials (Poster).
39. Wang, C., et al. "11th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Operation and Safety." Scaling Analysis and Test Facility Design for Steam Ingress Accident in MHTGR.
40. Wang, Y., et al. "The Minerals, Metals, and Materials Society Conference." Anisotropic thermal conductivity and interface resistance in PyC coated ZrO₂ particles.
41. Wu, X., et al. "American Nuclear Society Winter Meeting." Tritium Release Limit for Fluoride Salt-Cooled High-Temperature Reactors, vol. 115, pp. 1059–1062.
42. Yessayan, Raffi, et al. "International Conference on Mathematics & Computational Methods Applied to Nuclear Science & Engineering." Development of a Parallel Performance Model for the THOR Neutral Particle Transport Code.

43. Zheng, G., et al. "American Nuclear Society Annual Meeting." Microstructure of In-Core Molten Salt Corrosion Hastelloy N and 316 Stainless Steel.
44. Zheng, G., et al. "Materials Research Society Fall Meeting." Post-Irradiation Examination of Structural Alloys Exposed to Molten FLiBe Salt in MIT Reactor.
45. Zhu, M., et al. "American Nuclear Society Winter Meeting." Effect of Aging and Demand for Reliability Analysis of Degrading Components.

In-Press

1. Adam, B., L. Teeter, J. Mahaffey, M. Anderson, and J. Tucker. "Effects of Corrosion in Supercritical CO₂ on the Microstructural Evolution in an Fe-Ni Superalloy." Effects of Corrosion in Supercritical CO₂ on the Microstructural Evolution in an Fe-Ni Superalloy.
2. Dave, A., J. Morrell, and K. Sun. "Safety Margin Characterization for ATR Experiments."
3. Dave, A., J. Morrell, K. Sun, L. Hu, J. Nielsen, P. Murray, and R. Marlow. "Safety Margin Evaluation for ATR In-core Experiments supporting LEU U-Mo Fuel Development." Proceedings of Test, Research & Training Reactors (TRTR) National Organization conference, San Diego.
4. Frick, K., J. M. Doster, and S. M. Bragg-Sitton. "Design of a Sensible Heat Peaking Unit for Small Modular Reactors." In Transactions of the American Nuclear Society, November 2017.
5. Frinck, K., J. M. Doster, and S. Bragg-Sitton. "Design of a Sensible Heat Peaking Unit for Small Modular Reactors." In Transactions of the American Nuclear Society. Proceedings of American Nuclear Society Winter Meeting, Washington, D.C.
6. Goodrich, S., and Wade R. Marcum. "Natural Convection Heat Transfer and Boundary Layer Transition from Vertical Heated Cylinders." Proceedings of 17th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Xi'an.
7. Guo, Q., M. Pietrykowski, R. Aggarwal, C. Liu, and C. Smidts. "A Distributed Test Facility for Cyber-Physical Systems: Part I. Fundamental Principles." , IEEE Transactions on Control of Network Systems.
8. Harter, J. R., P. A. Greaney, and T. S. Palmer. "Deterministic Phonon Transport Predictions of Thermal Conductivity in Uranium Dioxide with Xenon Impurities." Journal of Heat Transfer.
9. Hess, S., S. Prescott, C. Smith, L. Lin, N. Dinh, R. Sampath, and N. Montanari. "Integrated Use of Modeling and Simulation in High Winds PRA." Proceedings of International Topical Meeting on Probabilistic Safety Assessment and Analysis, Pittsburgh.
10. Howard, T. K., and Wade Marcum. "Particle Image Velocimetry Analysis of Vortex Shedding Between Tandem Plates." Proceedings of 17th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Xi'an.
11. Isler, Jeremy, Jinsuo Zhang, Robert Mariani, and Cetin Unal. "Experimental solubility measurements of lanthanides in liquid alkalis." Journal of Nuclear Materials 495 (2017): 438-41. doi:10.1016/j.jnucmat.2017.08.039.
12. Jensen, C., W. R. Marcum, W. F. Jones, A. Weiss, A. M. Phillips, N. Woolstenhulme, K. Holdaway, G. D. Latimer, M. Moussaoui, S. Liu, and J. Campbell. "Experimental and Numerical Hydraulic Characterization of a Drop-In MP-1 Large B Experiment." Nuclear Engineering and Design.

13. Jin, M., C. Permann, and M. Short. "Breaking the Power Law: Multiscale Simulations of Self-Ion Irradiated Tungsten." *Journal of Nuclear Materials*.
14. Li, H., X. Diao, S. Li, B. Li, and C. Smidts. "Fault Propagation and Effects Analysis for Designing an Online Monitoring System for the Secondary Loop of a Nuclear Power Plant Part of a Hybrid Energy System." *Nuclear Technology*, 2017.
15. Lin, L., N. Dinh, N. Montanari, R. Sampath, N. Akinici, and S. Prescott. "Assessment of Smoothed Particle Hydrodynamic in application of High-Wind risk analysis." *Proceedings of 17th International Topical Meeting on Nuclear Reactor Thermal Hydraulics*.
16. Marcum, Wade R., A. M. Phillips, W. F. Jones, A. W. Weiss, and T. K. Howard. "Early Observations on the Experimental Study of Fluid-Structure-Interactions While Testing Plate Type Fuel." *Proceedings of 17th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Xi'an*.
17. Misenheimer, Corey T., and Stephen D. Terry. "The development of a dynamic single effect, lithium bromide absorption chiller model with enhanced generator fidelity." *Energy Conversion and Management* 150 (2017): 574-87. doi:10.1016/j.enconman.2017.08.005.
18. Morris, J., J. Hendrie, S. Pelka, S. Teyseyre, J.-C. Diels, and A. A. Hecht. "High precision measurements of refractive index change in CaF₂ crystals as a function of reactor dose." High precision measurements of refractive index change in CaF₂ crystals as a function of reactor dose.
19. Morris, J., J. Hendrie, S. Pelka, J.-C. Diels, and A. A. Hecht. "Fabry Perot crystal rotation effects on nested cavity modes within a mode locked laser cavity."
20. Morris, J., J. Hendrie, S. Teyseyre, J.-C. Diels, and A. A. Hecht. "LAMMPS simulations and displacement energies on the CaF₂ crystal lattice."
21. Pelka, S., J. Morris, J. Hendrie, S. Teyseyre, J.-C. Diels, and A. A. Hecht. "Color center formation vs. dose in CaF₂ crystals from reactor irradiation."
22. Rai, Durgesh K., Muhammad Abir, Huarui Wu, Boris Khaykovich, and David E. Moncton. "Focusing mirrors for enhanced neutron radiography with thermal neutrons and application for irradiated nuclear fuel." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 879 (2018): 141-46. doi:10.1016/j.nima.2017.10.013.
23. Smidts, C., Y. Zhao, X. Diao, I. Ray, J. Hollern, Q. Zhu, and T. McJunkin. "Support for Reactor Operators in Case of Cyber-Security Threats." In *Transactions of the American Nuclear Society . Proceedings of American Nuclear Society Winter Meeting, Washington, D.C. .*
24. Wu, X., S. Shi, S. Zhang, D. Arcilesi, R. N. Christensen, P. Sabharwall, and X. Sun. "Overall Mass Transport Analysis for Tritium Removal in FHRs."

Dissertations & Theses

1. Daniels, Mahlon Tucker. *Integration of Large-Scale Steam Accumulators for Energy Storage in Nuclear Hybrid Energy Systems*. Master's thesis, 2017.
2. Fathi, Nima. *Evaluation and Enhancement of Clean Energy Systems: Analytical, Computational and Experimental Study of Solar and Nuclear Cycles*. Ph.D thesis, University of New Mexico, 2017.

3. Hoover, Kyle. SMR Full-Power Scaling Analysis and Numerical Simulations for Nuclear Hybrid Energy System Testing. Master's thesis, Oregon State University, 2016.
4. Misenheimer, Corey Thomas. Modeling Chilled-Water Storage System Components for Coupling to a Small Modular Reactor in a Nuclear Hybrid Energy System. Ph.D thesis.
5. Morris, Joseph P. High Precision Refractive Index Measurement Techniques Applied to the Analysis of Neutron Damage and Effects in CaF₂ Crystals. Ph.D thesis, University of New Mexico, 2017.
6. Pelka, Sara. Examination of Color Center Formation in CaF₂ Crystals When Exposed to Gamma and Mixed Neutron/Gamma Fields. Master's thesis, University of New Mexico, 2017.
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Reports:

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Invention Disclosure Records and Patents

Invention Disclosure Records

Apparatus for determining a thermal conductivity and a thermal diffusivity of a material and related methods

D. Hurley (INL), R. Schley (INL) and M. Khafizov (TOSU).

A novel indirect heated high-heat-flux heater rod

W.R. Marcum (OSU), D.M. Wachs (INL), C. Jensen (INL), D. LaBrier (OSU), J. Nylander (OSU)

Patents

Patent Application BA-859: Apparatus for Determining a Thermal Conductivity and a Thermal Diffusivity of a Material, and Related Methods

D. Hurley (INL), R. Schley (INL) and M. Khafizov (TOSU).