2019 ANNUAL REPORT

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

LETTER FROM INL'S CHIEF RESEARCH OFFICER

Dr. Marianne Walck

DEPUTY LABORATORY DIRECTOR,
SCIENCE AND TECHNOLOGY
AND CHIEF RESEARCH OFFICER
IDAHO NATIONAL LABORATORY

The Laboratory Directed Research and Development (LDRD) program is a vital resource for Idaho National Laboratory (INL) to achieve our mission to discover, demonstrate, and secure innovative nuclear energy solutions, clean-energy options, and critical infrastructure. Our LDRD investments stimulate high-impact research, sustain and amplify INL's core capabilities, and recruit and retain world-class science and technology (S&T) talent for INL and the nation.

To attain our mission and that of the U.S. Department of Energy (DOE), our LDRD program aligns with our S&T strategy. This strategy revolves around INL's five S&T strategic initiatives: (1) Nuclear Reactor Sustainment and Expanded Deployment, (2) Integrated Fuel Cycle Solutions, (3) Advanced Materials and Manufacturing for Extreme Environments, (4) Integrated Energy Systems, and (5) Secure and Resilient Cyber-Physical Systems. The integration and application of our core capabilities in basic and applied research, development, and demonstration (RD&D) are essential to meet our strategic objectives and fulfill our vision to change the world's energy future. In collaboration with our university, industry, and other national laboratory partners, LDRD investments foster our core capabilities, accelerate scientific discovery, and develop solutions to the world's energy and national security challenges.

INL's LDRD program strives to invest in exploratory, transformative, revolutionary, high-risk, and potentially high-impact S&T concepts. It also provides a means to enhance university and industry partnerships and feed the S&T talent pipeline through undergraduate and graduate internships, postdoctoral assignments, and INL staff education. LDRD projects are selected on a competitive basis through rigorous peer- and management-review processes, ensuring the selected projects have significant technical merit and bolster INL's mission. Scientific discoveries, new programs, intellectual property, national and international awards, and publications exemplify the benefits of the program.

I invite you to discover the novel and influential RD&D and the phenomenal researchers empowered by INL's LDRD program.

INL and the nation harvest lasting impact from our LDRD program long after a project is complete. In the following pages, you will read about cutting-edge RD&D supported through INL's LDRD program—the RD&D that has and continues to build our core capabilities and serve DOE and an expansive sponsor base consistent with DOE and INL missions. This report includes projects that concluded in fiscal year (FY) 2019 and is by no means all-inclusive, but it illustrates the breadth of RD&D that cultivates INL's scientific and technical vitality, attracts promising young scientist and engineers, and helps to educate the next generation of researchers.

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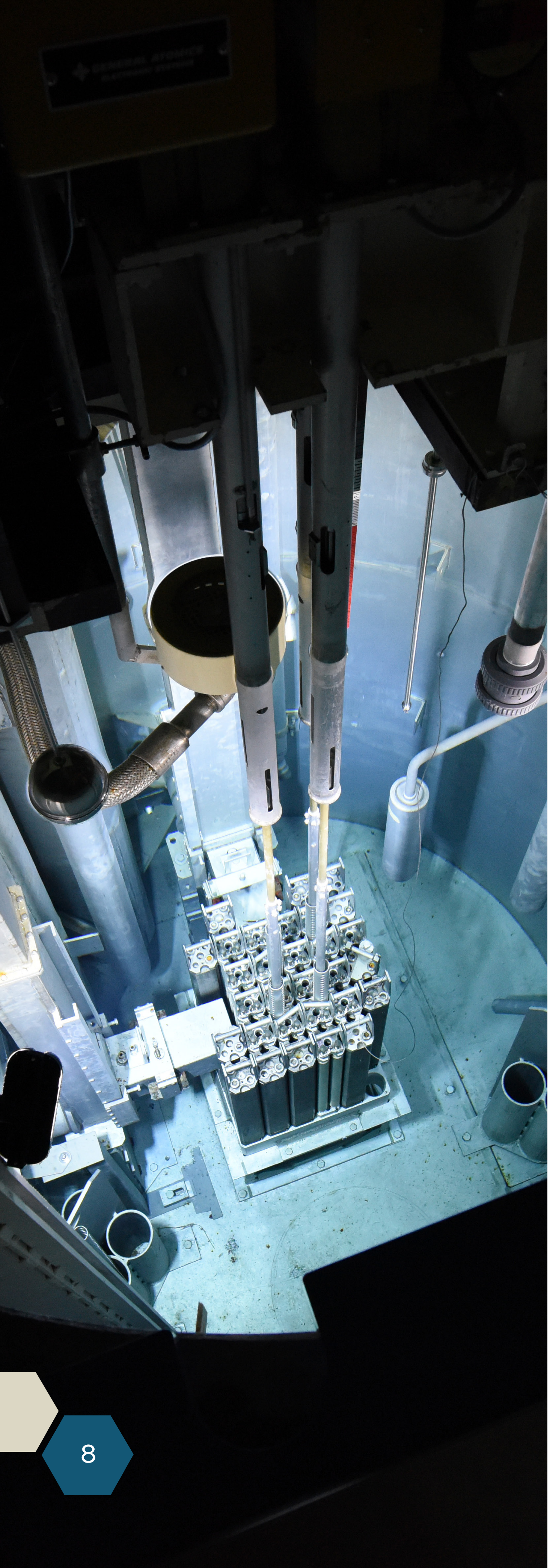
ACRONYM LIST

2D	two-dimensional
3D	three-dimensional
AAG	American Association of Geographers
AD	automatic differentiation
AM	advanced manufacturing
ANDES	Advanced Test Reactor Nondestructive Examination System
AR	as received
ATF	Accident Tolerant Fuels
ATR	Advanced Test Reactor
CDI	capacitive deionization
CNT	carbon nanotubes
CyberPARC	Cyber Partnership for the Advancement of Resilient Control Systems
DFN	discrete fracture network
DFT	density-function theory
DHS	Department of Homeland Security
DoD	Department of Defense
DOE	Department of Energy
ECAP	equal channel angular pressing
EMI	Engineering Mechanics Institute
FAST	Fission Accelerated Steady-State Testing (experiment)
FCD	field control devices
FE-CDI	flowing electrode-capacitive deionization
FORGE	Frontier Observatory for Research in Geothermal Energy
FTM	facilitated transport membranes
FY	fiscal year
GPS	global-positioning system
GTO	Geothermal Technology Office
HEA	high-entropy alloy
HMI	human/machine interfaces
HRA	human-reliability analysis
HTM3D	Hydro-Thermal-Mechanical Solver for three dimensional Problems
IC	intelligence community
ICS	industrial-control system
ICSD	industrial-control-system diagnostics
IDR	Invention Disclosure Record
INL	Idaho National Laboratory
LDRD	Laboratory Directed Research and Development
LIB	lithium ion batteries
LOCA	loss-of-coolant accident
LWR	light-water reactor
MARCH	Minimal Activation Retrievable Capsule Holder
MCNP	Monte Carlo N-Particle
MEITNER	Modular Examination Instrument for Transportable Nuclear Energy Research
MFC	Materials and Fuels Complex
MMRTG	Multi-Mission Radioisotope Thermoelectric Generators
MOOSE	Multiphysics Object-Oriented Simulation Environment
MORS	Military Operations Research Society
NCP	nonlinear complementarity problem
NDE	nondestructive examination
NE	Office of Nuclear Energy
NNSA	National Nuclear Security Administration
ODH	oxidative dehydrogenation
PAN	peroxyacetyl nitrate
PARROT	Play Appliance for Resilient Response of Operational Technologies
PC	personal computer
PCMI	pellet/cladding mechanical interaction
PETSc	Portable, Extensible Toolkit for Scientific Computation (code)
PI	principal investigator
PIE	post-irradiation examination
PPB	parts per billion
PPM	parts per million
PRA	probabilistic risk assessment
QS-DEM	quasi-static discrete element model
R&D	research and development
RAMS	Reliability and Maintainability Symposium
RD&D	research, development, and demonstration
RE	reverse engineering
REE	rare-earth element
RFF	reactive force field
RIA	reactivity insertion accidents
RTG	radioisotope thermoelectric generator
S&T	Science and Technology
SCADA	supervisory control and data acquisition
SDR	Software Disclosure Record
SEM	scanning electron microscopy
TEM	transmission electron microscopy
TLT	temperature-limited transients
TODGA	tetraoctyl diglycolamide
TREAT	Transient Reactor Test Facility
UC	University of California
U.S.	United States
V2X	vehicle to vehicle
XAFS	X-ray absorption fine structure
XFC	extreme fast charging



LDRD PORTFOLIO

Aligned to DOE's and INL's strategic plans, INL's diverse LDRD portfolio explores scientific and engineering concepts, including advanced-reactor modeling, nuclear waste reduction, and fuel recycling. INL's LDRD research stimulates exploration at the forefront of cybersecurity, electric-grid reliability, and wireless technology. The forward-looking nature of the lab's RD&D strengthens the DOE mission by advancing integrated energy systems and evolving energy security needs.

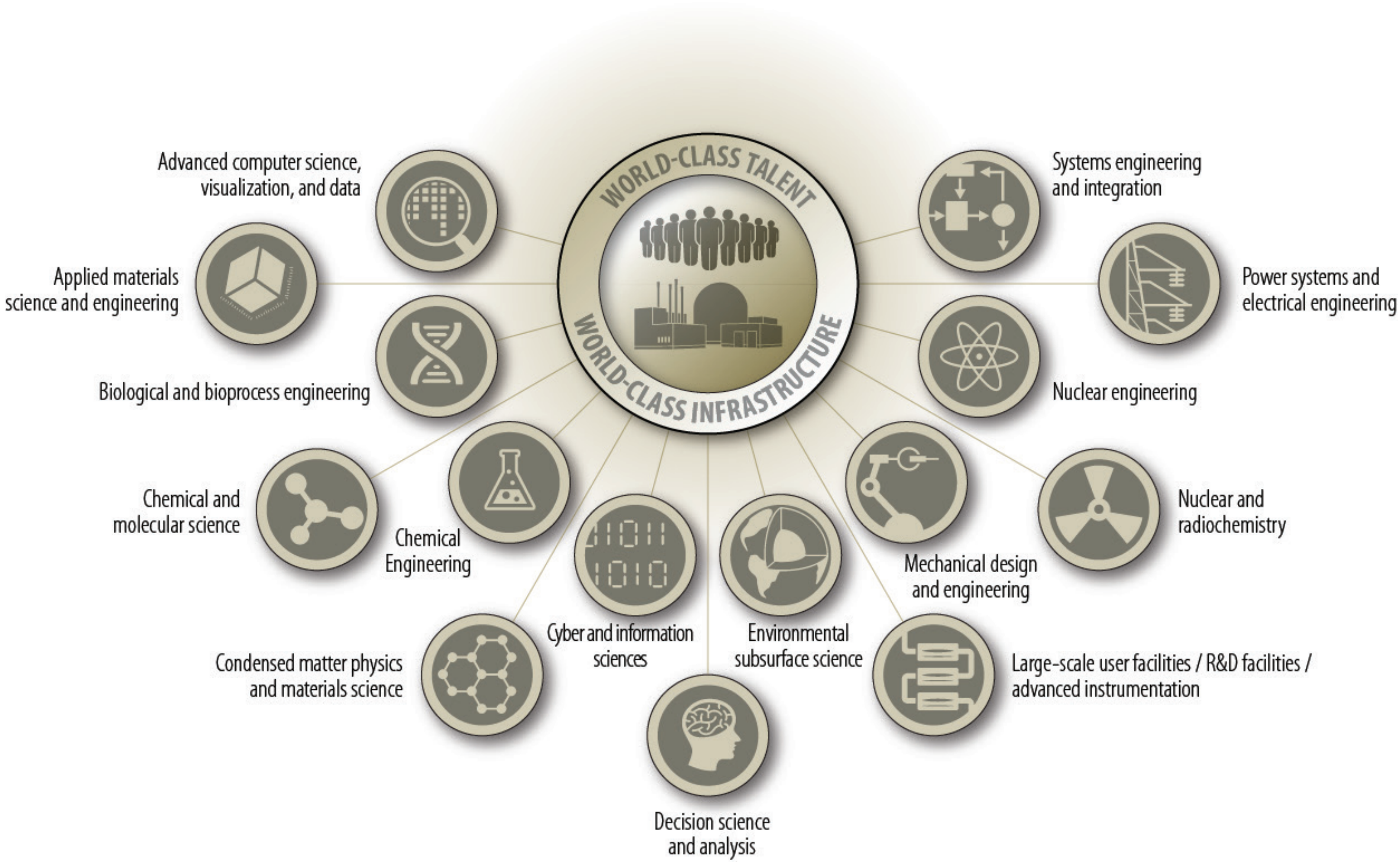
INL's diverse LDRD portfolio comprises three investment components:

- The Strategic R&D Fund addresses research priorities to fill S&T gaps to advance INL S&T initiatives.
- The Seed Fund supports smaller-scale, investigator-initiated and exploratory projects that have no programmatic funding. The research projects must align to INL's mission, but not necessarily with a specific INL S&T initiative, as is required for the Strategic R&D Fund.
- The Named Postdoctoral Fellowship Fund supports three name-distinguished postdoctoral fellowships: (1) Russell Heath Distinguished Postdoctoral Fellowship; (2) Deslonde de Boisblanc Distinguished Postdoctoral Fellowship; and (3) Glenn T. Seaborg Distinguished Postdoctoral Fellowship.

Out-of-cycle LDRD funding opportunities may be held, as determined by the deputy laboratory director for S&T, based on laboratory need and availability of funds. Out-of-cycle proposals undergo the same rigorous review as other LDRD proposals.

Project Selection & Oversight

The laboratory ensures that LDRD program goals and objectives are aligned with DOE Order 413.2C, Chg. 1, and that the LDRD portfolio is managed with integrity and transparency. All LDRD projects go through a rigorous proposal review and selection process, and ongoing projects applying for renewal are contingent on a progress report review. These steps ensure that LDRD investments are continually aligned with INL's vision, mission, and S&T initiatives, and are technically sound, innovative, cutting-edge RD&D projects that comply with the LDRD Order. New project



proposals and ongoing project progress reports are subject to multiple levels of review (by management, technical reviewers, and a strategic review committee).

Lab leadership establishes review committees for each focus area and for seed proposals. These committees review new project proposals and ongoing project progress reports and make funding recommendations. Committees are staffed by senior and midcareer researchers and technical managers who are subject-matter experts without any conflict of interest with the proposed projects. The deputy lab director for S&T reviews the committees' recommendations with the associate laboratory directors and makes final funding decisions on the LDRD portfolio. DOE's Idaho Operations Office concurs on each proposed and continuing project prior to project authorization. Researchers are notified of the LDRD schedule and review processes through the RD&D annual request for proposals (i.e., annual call), the INL intranet LDRD site (hosted on SharePoint), in-person meetings, and lab-wide email notifications.

Throughout this report, icons will indicate the core capabilities supported by LDRD projects.

Core Capabilities

Of the 24 core capabilities distributed across DOE's science and applied-energy laboratories, INL has 13 DOE-acknowledged core and two emerging capabilities. The acknowledgement of these capabilities highlights the exceptional breadth of INL's scientific and technological foundation. The core capabilities represent a science and engineering skill set extending across a continuum, connecting basic and applied research to testing, demonstration, and deployment. These core capabilities are sustained and enhanced through INL's LDRD projects.

Please note that, due to space constraints, only select project products are included in this report. Publications that have been submitted for publication or which are under review are not included, nor are conference presentations.

FY 2019 PROGRAM STATISTICS

25
POSTDOCS

43
INTERNS

$27M
PROGRAM COST

4
PATENTS GRANTED

43
NEW PROJECTS

46
PUBLICATIONS

117
ACTIVE PROJECTS

45
PROJECTS ENDING

19
NONPROVISIONAL U.S. PATENT APPLICATIONS

2
COPYRIGHTS ASSERTED

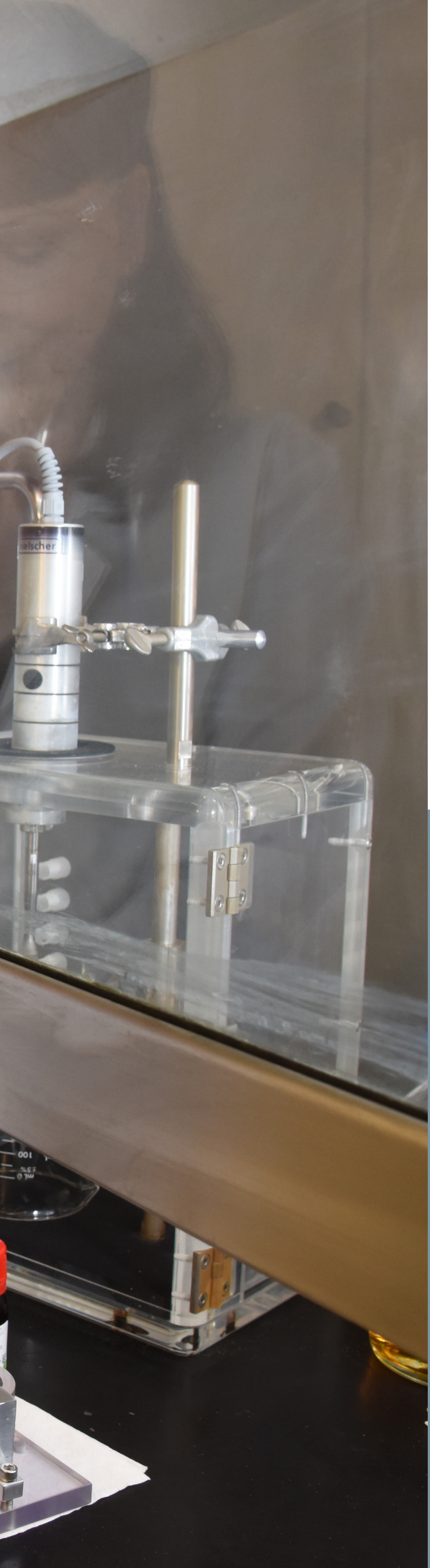
21
INVENTION DISCLOSURE RECORDS (IDRS)

47
UNIVERSITIES
External collaborators on LDRD projects

3
SOFTWARE DISCLOSURE RECORDS (SDRS)

18
LICENSES ISSUED

3
INDUSTRIES
External collaborators on LDRD projects



NUCLEAR REACTOR SUSTAINMENT AND EXPANDED DEPLOYMENT & INTEGRATED FUEL CYCLE SOLUTIONS

A mission of INL is to advance nuclear energy as a resource capable of meeting the nation's energy, environmental, and national security needs by resolving technical, cost, safety, proliferation risk, and security barriers through RD&D. In support of this mission and DOE-Office of Nuclear Energy (NE) priorities—specifically existing fleet, advanced-reactor pipeline, and fuel-cycle infrastructure—INL established this strategic initiative to accelerate deployment of advanced nuclear energy technologies and to advance technologies that address nuclear-waste management and disposition.

SUCCESS STORY

The research conducted under INL's LDRD advances the scientific state of the art for nuclear energy on Earth, but also powers and enables U.S. missions to Mars and far outer space through projects like "Opportunities for Center for Space Nuclear Research" (19P45-017) and "Rapid Field Chemical Detection and Determination of Actinide" (18A40-001).

Design of Low-activation Retrievable Sample Holder for TREAT Irradiation of Science-based Specimens

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-111

PRINCIPAL INVESTIGATOR:
Nick Woolstenhulme, INL

CO-INVESTIGATORS:
Clint Baker, INL
Connie Hill, INL
Dan Chapman, INL
Cynthia Adkins, INL

COLLABORATOR:
Boise State University

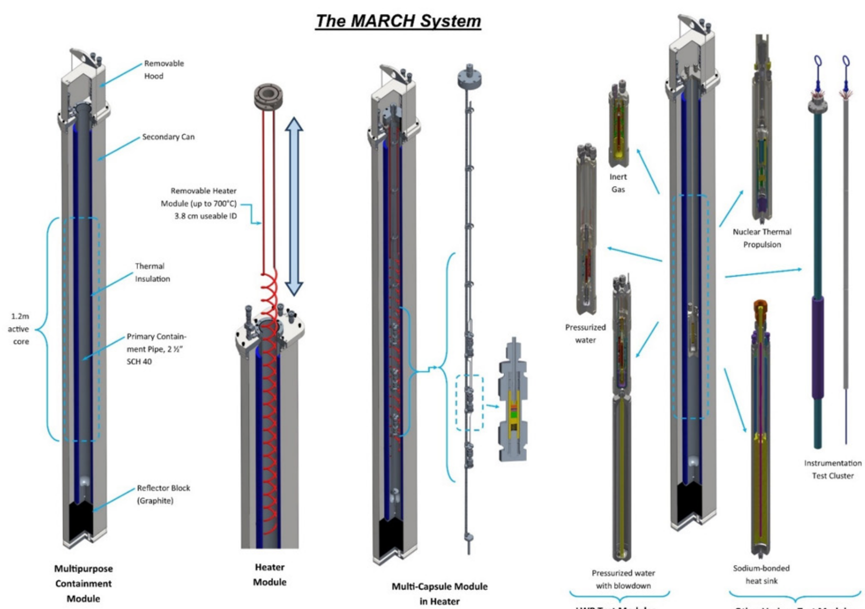
AWARD WINNER

INL Poster Competition top poster for Nuclear Reactor Sustainment and Expanded Deployment & Integrated Fuel Cycle Solutions

An irradiation vehicle system to provide pioneering data sets for modern model validation, identify fundamental behavior to sharpen fuel research focus, and advance the state of nuclear safety advancements by cultivating broad interest in transient science

The Transient Reactor Test Facility (TREAT) was constructed in the late 1950s, provided thousands of transient irradiations before being placed in standby in 1994, and was restarted in 2017 in order to resume its crucial role in nuclear-heated safety research. Advances in modern computational capabilities and a resurgence of interest in novel reactor technology have created an opportunity for emphasizing modernized science-based and separate effects test capabilities at TREAT. An innovative approach to this type of testing leveraged the relatively low radioisotope accumulation during brief TREAT irradiations by arranging small fresh-fuel specimens in low-activation hardware "modules" so that they can be easily extracted and shipped for examination within weeks. The Minimal Activation Retrievable Capsule Holder (MARCH) irradiation-vehicle system was developed and underwent successful design and predictive modeling. It was subsequently transitioned for continued development and use in DOE fuel-development programs. Other innovative modules were conceptualized and demonstrated, many of which were adopted for continued development by direct sources.

At present, all irradiations that have been or will be performed in TREAT during its first four years of operation will utilize the MARCH system initially developed under this project.



Overview of the MARCH system and various irradiation modules for testing current fleet reactor fuel fuels, advanced reactor nuclear fuels, and transient science.

TALENT PIPELINE:

Four interns

- Laura Rill,
  Boise State University
- Kiegen Schauer,
  Boise State University
- Kristine Diedrich,
  Boise State University
- David Coy,
  University of Pittsburgh

PUBLICATIONS/PRESENTATIONS:

Woolstenhulme, N., A. Fleming, T. Holschuh, C. Jensen, D. Kamerman, and D. Wachs. 2019. "Core-to-specimen Energy Coupling Results of the First Modern Fueled Experiments in TREAT." Annals of Nuclear Energy (in press).

Woolstenhulme, N., C. Baker, C. Jensen, D. Chapman, D. Imholte, N. Oldham, C. Hill, and S. Snow, "Development of Irradiation Test Devices for Transient Testing." Nuclear Technology 205.10: 1251–1265. DOI: 10.1080/00295450.2019.1590072.

Woolstenhulme, N., C. Baker, J. Bess, D. Chapman, D. Dempsey, C. Hill, C. Jensen, and S. Snow. 2018. "New Capabilities for In-Pile Separate Effects Tests in TREAT." Transactions of the American Nuclear Society Summer Meeting, held 17–21 2018 in Philadelphia, PA.

Bess, J., N. Woolstenhulme, C. Jensen, J. Parry, and C. Hill. 2018. "Nuclear Characterization of a General-Purpose Instrumentation and Materials Testing Location in TREAT," Annals of Nuclear Energy 124: 270–294. https://doi.org/10.1016/j.anucene.2018.10.011

Woolstenhulme, N., C. Baker, J. Bess, D. Chapman, D. Dempsey, C. Hill, C. Jensen, S. Snow, and D. Wachs. 2018. "A Modular Irradiation Vehicle System for High-Throughput Science-Based Testing in TREAT." INL Nuclear Fuels and Materials Spotlight 6:41. (INL/EXT-18-51258)

Design to Enable Narrow Pulse Width in Transient Tests

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-024

PRINCIPAL INVESTIGATOR:
Nick Woolstenhulme, INL

CO-INVESTIGATORS:
Thomas Holschuh, INL
John Bess, INL
Jim Parry, INL
Cody Race, INL
Todd Palmer, Oregon State University

COLLABORATOR:
Oregon State University

Methods, strategies, and designs to enable TREAT to perform reactivity insertion accidents (RIAs) testing on light-water reactor (LWR) specimens in a way that more accurately simulates and captures the relevant pellet/cladding mechanical interaction (PCMI) phenomena for safety research on advanced LWR fuels including Accident Tolerant Fuels (ATF)

TREAT's flexible design and multimission nature saw historic experiments for different reactor fuels and transient types. However, TREAT was never specifically adapted to address very brief pulse transients akin to postulated LWR RIAs. The behaviors of fuel under these conditions depend strongly on energy-input duration and resulting cladding time and temperature response, under PCMI. INL researchers developed pulse-narrowing capabilities for the future of TREAT following its return to operational status. Multiple strategies for narrowing TREAT's pulse width were developed and underwent modeling and experimentation. Two concepts were selected and pursued in detail: (1) passive neutron-absorbing assemblies, which enhance TREAT's feedback physics for moderately reduced pulse width, and (2) an active system which terminates pulses by rapidly injecting a gaseous neutron absorber into chambers located in the core. The combination of passive neutron-absorbing assemblies enhances TREAT's feedback physics for moderately reduced pulse width, and the active system that rapidly injects gaseous neutron absorber and terminates pulses is accurately predicted to dramatically reduce TREAT's current pulse width (by approximately a factor of two).

This project developed the information needed to deploy a set of capabilities which are crucial in enabling TREAT to adequately address a major component of accident testing and will be crucial for industrial partners to resolve data gaps in performance of state-of-the-art and advanced LWR fuels.

TALENT PIPELINE:

Three interns:

- Charlie Folsom, Utah State University (transitioned to INL technical staff during project)
- Tony Alberti, Oregon State University (graduated Ph.D.)
- Austin Warren, Oregon State University

One postdoc:

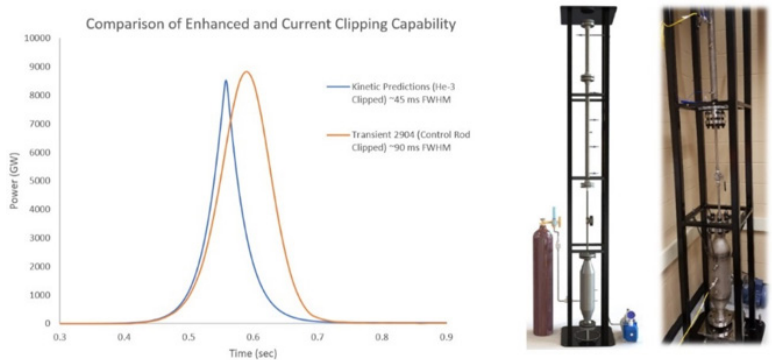
- Tommy Holschuh, (transitioned to INL technical staff during project)

PUBLICATIONS/PRESENTATIONS:

Bess, J., N. Woolstenhulme, C. Davis, L. Dusanter, C. Folsom, J. Parry, T. Shorthill, and H. Zhao. 2018. "Narrowing Transient Testing Pulse Widths to Enhance LWR RIA Experiment Design in the TREAT Facility." Annals of Nuclear Energy 124: 548–571. DOI: 10.1016/j.anucene.2018.10.011.

Holschuh, T., N. Woolstenhulme, B. Baker, J. Bess, C. Davis, and J. Parry. 2019. "Transient Reactor Test Facility Advanced Transient Shapes." Nuclear Technology 205.10: 1346–1352. DOI: 10.1080/00295450.2018.1559712.

Mignot, G., A. Warren, S. Balderrama, and N. Woolstenhulme. 2019. "Experiments on Helium-3 Negative Reactivity Insertion—HENRI—Prototype." NURETH 2019: Proceedings of the 18th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, held 18–22 August 2019 in Portland OR. ISBN: 978-0-89448-767-5



(Left): Comparison of pulse width for enhanced ^{3}He Clipping and current TREAT control clipping and (right): rendering and photo of lab test helium injection system, which demonstrated that adequate helium injection rates can be achieved.

Digital Neutron Imaging of Irradiated Nuclear Fuel Using a Gamma-discriminating Scintillation System

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-093

PRINCIPAL INVESTIGATOR:
Aaron Craft, INL

CO-INVESTIGATOR:
Glen Papaioannou, INL

COLLABORATORS:
Paul Scherrer
Institute Technical University Munich

Digital neutron radiographs of highly radioactive objects in a matter of minutes

The most common type of digital neutron imaging system used today consists of a neutron-sensitive scintillator screen that produces visible light, which is then captured by a digital camera. Digital neutron imaging systems were not thought to be useful for imaging irradiated nuclear fuel because the large gamma-radiation field emitted would damage digital components and degrade the image produced by the gamma-sensitive imaging detector. INL researchers designed, developed, and demonstrated a novel digital neutron-imaging system for examination of irradiated nuclear fuel. The system uses first-of-a-kind scintillator screens. Radiographs of irradiated nuclear fuel pins were successfully acquired, representing the first neutron radiographs of irradiated nuclear fuel ever acquired with a digital-camera-based neutron-imaging system.

This project also developed a prototype digital-camera-based neutron-radiography system for testing various scintillator screens. This digital-imaging system was employed with standard promptly decaying screens to produce INL's first digital neutron tomography and the world's first digital neutron tomography of irradiated nuclear fuel. The move from two-dimensional (2D) radiography to 3D tomography represents a new realm of nondestructive examination capability for post-irradiation examination of nuclear fuels and a significant advance in the quality of data over current capabilities.

A digital neutron tomography system successfully produced the world's first digital neutron tomography of irradiated of nuclear fuel. Use and further development of this system is being included in program test plans for Advanced Fuel Cycle research and development.

TALENT PIPELINE:

One graduate fellow:

- William Chuirazzi, Ohio State University

PUBLICATIONS/PRESENTATIONS:

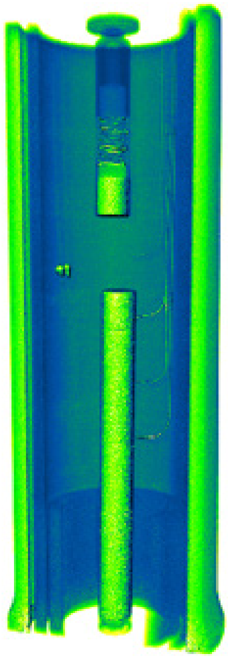
Schillinger, B. and A. Craft. 2017. "A freeware path to neutron computed tomography. Physics Procedia 88: 348–353. (INL/JOU-18-51144)

Craft, A., C. Grunzweig, M. Morgano, W. Chuirazzi, and E. Lehmann. 2019. "Gamma discriminating scintillation screens for digital transfer method neutron imaging with camera-based systems." WCNR-11 in Materials Research Proceedings (accepted for publication INL/CON-18-50213 and INL/JOU-19-55508)

Craft, A., B. Schillinger, W. Chuirazzi, G. Papaioannou, and A. Smolinski. 2019. "First neutron computed tomography with digital neutron imaging systems in a high-radiation environment at the 250 kW Neutron Radiography Reactor at Idaho National Laboratory." WCNR-11: 11th World Conference on Neutron Radiography held 2–7 September 2018 in Sydney, Australia. (INL/CON-18-50206 and INL/JOU-19-55507)

Schillinger, B., A. Craft, and J. Kruger. 2019. "The ANTARES instrument control system for neutron imaging with NICOS/Taco at MLZ converted to a mobile system used at Idaho National Laboratory." WCNR-11: 11th World Conference on Neutron Radiography held 2–7 September 2018 in Sydney, Australia. (INL/CON--18-50216 and INL/JOU-19-55506)

Schillinger, B., and A. Craft. 2019. "Epithermal neutron radiography and tomography on large and strongly scattering samples." WCNR-11: 11th World Conference on Neutron Radiography held 2–7 September 2018 in Sydney, Australia. (INL/CON--18-50212 and INL/JOU-19-55505)



The world's first digital neutron tomography of irradiated nuclear fuel. This image is a cutaway view of the 3D rendering showing the internal configuration of a fuel rodlet that underwent transient testing in the TREAT reactor prior to the performance of neutron tomography. The effects of the transient test ultimately caused the rodlet to break, as shown in the neutron tomogram.

Early Demonstration of Combinatorial Alloy Fabrication and Fission Accelerated Steady-state Testing Irradiation Testing

PORTFOLIO COMPONENT:
FY 2019 Out of Cycle

PROJECT NUMBER:
19P45-027

PRINCIPAL INVESTIGATOR:
Jeffery Aguiar, INL

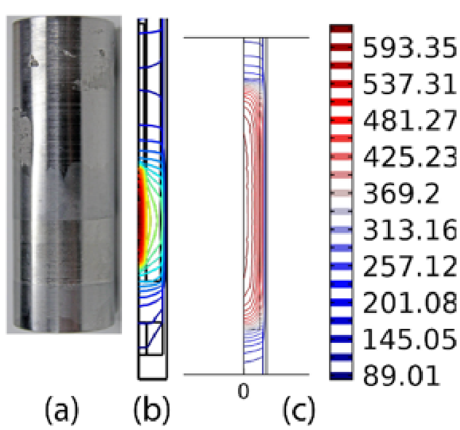
CO-INVESTIGATORS:
Geoffrey Beausoleil, INL
Seongtae Kwon, INL
Taylor Sparks, University of Utah
Eric Eyerman, California Nanotechnologies
Khalid Hattar, Sandia National Laboratories

COLLABORATORS:
California Nanotechnologies
Sandia National Laboratories
University of Utah

Rapidly prepared novel high entropy alloys for irradiation experiments

Rapid development of improved cladding materials for nuclear reactors would extend the lifetime of the fuel under normal operation conditions. Withstanding the extreme environments of accident scenarios and meeting the needs of advanced reactor designs requires introducing cladding-candidate materials to reactor environments early in the development cycle. Research into novel structural materials, such as high-entropy alloys (HEAs), can easily examine basic material properties out of reactor; however, this method is of limited value if the integrated response to the in-reactor environment and fuel-cladding interaction is not examined. INL researchers fabricated 18 HEAs into compositionally graded cladding materials using advanced manufacturing techniques within three months and validated an approach to adding material data to the metallurgical and nuclear materials community. Characterization of a wide range of compositional space within an extensive experimental test matrix brought improved understanding of advanced-alloy chemistries, potential advantageous solid-state transitions, and mechanisms of defect formation as a result of neutron irradiation. Ultimately, this project successfully demonstrated INL's ability to utilize existing experiment programs to fabricate complex geometries and tailor compositions over a wide range of technical interest in mechanical and irradiation properties, accelerate the ability to advance the technical readiness level of advanced structural-materials characterization to span potential structural materials for nuclear materials under a shortened timeline measured in months rather than years or decades, and improve the viability of advanced-reactor designs for future energy production and security using nonprototypical irradiation testing.

Subsequent neutron irradiations of these developed HEAs will be performed in the Advanced Fuels Campaign Fission Accelerated Steady-State Testing (AFC-FAST) project in the Advanced Test Reactor (ATR).



A comparison between the fabricated ingot from CalNano and the thermal contour map from thermal analysis shows (a) the as cast ingot from CalNano with the graded HEA layers, (b) the full contour map of the rodlet (fuel, cladding, and plenum), and (c) the zoomed-in contour map of the fuel. In order to ensure comparable environments between each HEA, the HEA zones were positioned in the cladding so that they were likely to reside within the near-uniform thermal region of the fuel (assuming little to no axial migration of the fuel).

TALENT PIPELINE:

One grad fellow:

- Marcus Parry, University of Utah

Four interns:

- Danielle Beaty, University of Utah
- Hayden Johnson, University of Utah
- Krithika Iyer, University of Utah
- Michael Grant, Rochester Institute of Technology

PUBLICATIONS/PRESENTATIONS:

Parry, M., D. Beatty, K. Iyer, T. Tasdizen, T. Sparks, and J. Aguiar. 2019. "Combinatorial Alloy Fabrication and Synergies with Predictive Frameworks for High-entropy Alloy Design and Down-selection." ICME 2019: 5th World Congress on Integrated Computational Materials Engineering, held 21–25 July 2019 in Indianapolis, IN.

Dholabhai, P., M. Grant, K. Iyer, T. Tasdizen, Y. Zhang, and J. Aguiar. "Developing a Combinatorial Modeling Approach to Multi-scale Modeling and Predictions for High Entropy Alloy Design." ICME 2019: 5th World Congress on Integrated Computational Materials Engineering, held 21–25 July 2019 in Indianapolis, IN.

Beatty, D., M. Parry, S. Kwon, K. Iyer, T. Tasdizen, T. Sparks, J. Aguiar. 2019. "High-Entropy Alloy Design, Exploration, and Down-Selection Using Combinatorial Fabrication and Characterization for Nuclear Applications," HEA 2019: 1st World Congress on High Entropy Alloys, held 17–20 November in Seattle, WA.

Dholabhai, P., M. Grant, K. Iyer, T. Tasdizen, Y. Zhang, and J. Aguiar. 2019. "Multi-scale Framework for Predicting Mechanical Properties in High Entropy Alloys," HEA 2019: 1st World Congress on High Entropy Alloys, held 17–20 November in Seattle, WA.

Beausoleil, G., S. Kwon, E. Eyerman, and J. Aguiar. 2020. "Decoding Early Candidacy of High Entropy Alloys for Nuclear Application using the Advanced Test Reactor through Predictive Methods," 150th Annual Meeting of the Minerals, Metals, and Materials Society Annual Meeting, held 23–27 February 2020 in San Diego, CA.

Multipurpose Nondestructive Examination Station in the Advanced Test Reactor Canal

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-070

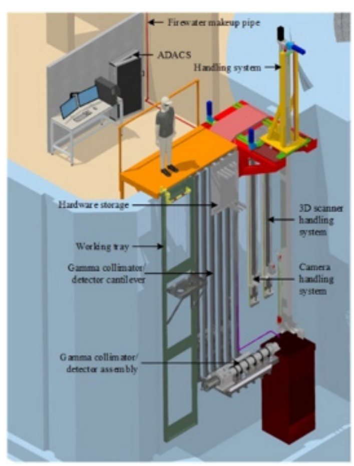
PRINCIPAL INVESTIGATOR:
Nick Woolstenhulme, INL

Nuclear fuel and material irradiation experimentation data quality improvements and reduction of the required number of experiment cycles

The ATR is the largest and most capable research reactor operating in the United States today. Examination of ATR-irradiated material specimens is often completed using in-core instrumentation or hot-cell-based post-irradiation examination (PIE). Specimen attributes that cannot be studied using in-core instrumentation are typically verified by PIE, but only long after the specimen has cooled and been shipped to a PIE facility. Poolside nondestructive examination (NDE) is a common technique that has been employed both in research and commercial nuclear-reactor settings to examine fissile material during cooling between cycles. The ATR canal is a natural location for NDE between cycles, but prior to this LDRD, ATR's application of this technique has been limited to specific experiment programs whose design was geared toward highly unique data. The ATR NDE System (ANDES) provided a multitude of NDE techniques to support several common ATR experiments, driver fuel, and reactor-dosimetry operations. ANDES provides poolside PIE that would augment current hot-cell-based PIE with unparalleled multifunctional NDE for multiple types of specimens. This creates an opportunity for gathering midirradiation data that can be used to develop continuous-performance correlations, rather than cumulative data, to enhance understanding and modeling of advanced nuclear fuels and materials.

ANDES could significantly enhance the performance data gathered from future nuclear-irradiation experiments, such as those from DOE-NE and the U.S. Navy.

Detailed design schematic of ANDES, mounted on the ATR cooling-canal wall.



TALENT PIPELINE:

One INL staff master's Thesis:

- D. Devin Imholte

PUBLICATIONS/PRESENTATIONS:

Imholte, D. 2019. "Conceptual Design of the Non-Destructive Examination System (ANDES)," Master's thesis, University of Idaho, Moscow, ID.

Neutron-spectrum Generator

CORE CAPABILITY
Nuclear Physics

PORTFOLIO COMPONENT:
FY 2018 Out of Cycle

PROJECT NUMBER:
18A40-023

PRINCIPAL INVESTIGATOR:
Wade Scates, INL

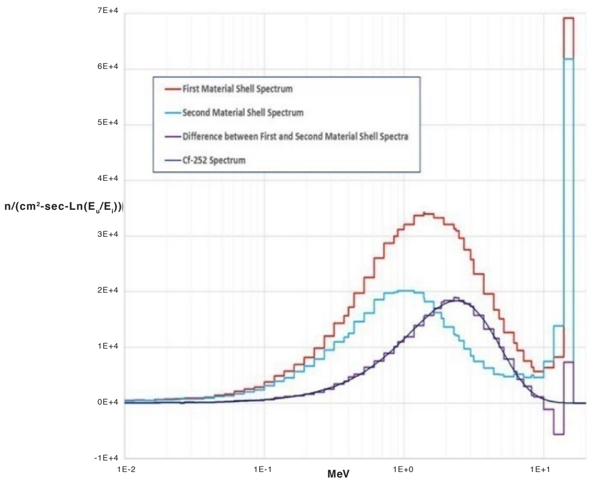
CO-INVESTIGATOR:
Bradley Schrader, INL

Technique to improve calibration process for neutron instruments and expand basic nuclear physics research

DOE facilities use ^{252}Cf to generate a neutron spectrum for calibration of neutron detectors and instrumentation. Because ^{252}Cf has a relatively short half-life, it must be replaced frequently to produce a usable neutron flux. DOE's radioactive-source loan-lease program was discontinued in 2013; thus, the price of ^{252}Cf has risen to approximately $1M/milligram. This project utilizes spectral subtraction, a technique that overcomes the limitations of prior methods to develop material similar to ^{252}Cf. This technique is like background subtraction, except the positive and negative spectra are engineered through material selection. The technique can generate a spectrum very similar to ^{252}Cf's while possessing a reasonable flux. More importantly, this technique can closely match any fission spectrum, meaning it may also have an important use in basic nuclear-physics research.

Initial indications are that this technique may allow INL to produce nearly any neutron-energy spectrum desired in a highly controlled, well characterized, and reproducible field. This ability could allow basic material research at reduced time and cost and within a more-reproducible neutron field than is possible using conventional methods, enabling the study of the effects that altering the neutron-energy spectra has on materials.

INTELLECTUAL PROPERTY:
One IDR



Example of engineered ^{252}Cf spectrum using subtraction technique.

Quantification of Reactor Kinetics Parameters in TREAT during Temperature-limited Transients

PORTFOLIO COMPONENT:
FY 2017 Named Postdoc

PROJECT NUMBER:
17P10-010

PRINCIPAL INVESTIGATOR:
Tommy Holschuh, INL

CO-INVESTIGATORS:
Dan Wachs, INL
David Chichester, INL

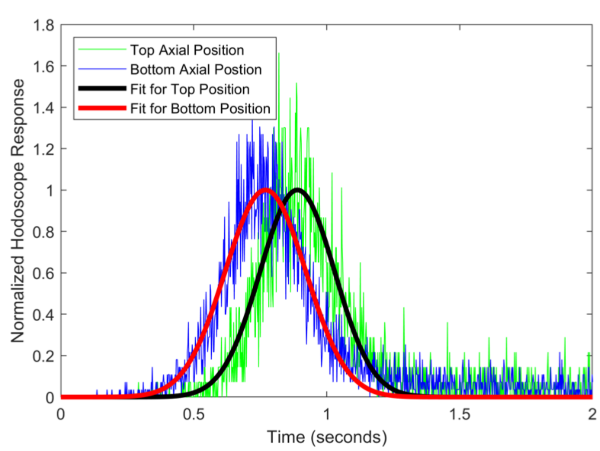
Increased accuracy in assessment of TREAT pulse width and energy deposition rates to fueled specimens in the reactor

TREAT performed temperature-limited transients (TLTs) beginning in early 2018 as part of the TREAT restart. TLTs are reactor operations in which transient control rods are ejected with a reactivity worth greater than the value necessary for prompt-critical operations. This project used the characteristics of TLTs to quantify two parameters of TREAT, (1) the prompt-neutron lifetime and (2) the value of reactivity feedback during a TLT. Measurement of prompt-neutron lifetime would also be more appropriately performed during a pulse because this is the desirable operation of TREAT for fuel testing. Analysis of data from all TLTs produced a lower value of neutron lifetime, as expected during a TLT, though the uncertainty from the previous work and this LDRD did not conclusively identify a new value to be used for future calculations. However, it did establish an opportunity for more-accurate determinations of prompt-neutron lifetime when coupled with transient models of the TREAT reactor. The TREAT hodoscope was used to determine the value of reactivity feedback and observe the first experimental criticality wave in TREAT, possibly the first criticality wave ever measured because other transient reactors produce much shorter pulses at a decreased neutron flux.

Support from this project for the Deslonde de Boisblanc Distinguished Postdoctoral researcher led to the transition of Dr. Tommy Holschuh to INL technical staff.

TALENT PIPELINE:
One distinguished postdoc:
- Tommy Holschuh (transitioned to INL staff)

PUBLICATIONS/PRESENTATIONS:
Holschuh, T., and D. Wachs, "Measurement of Reactor Kinetics Parameters in TREAT During Temperature Limited Transients." ANS 2019 Annual Meeting, held June 9–13, 2019 in Minneapolis, MN.



Normalized hodoscope response during TLT of reactivity insertion equivalent to 3.85 %Δk/k. The delay in the neutron population between the bottom and top axial position is approximately equivalent to the total movement duration of the transient control rods during the reactor pulse.

New Approach for PIE Using Modular Transportable Instrumentation

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-223

PRINCIPAL INVESTIGATOR:
Nicholas Boulton, INL

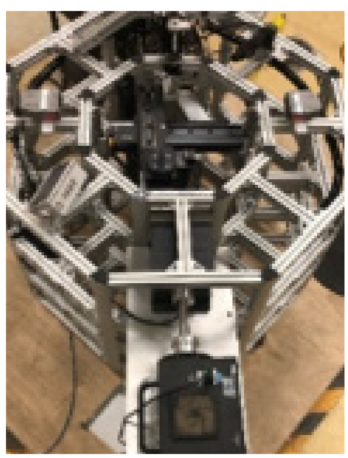
CO-INVESTIGATOR:
Aaron Craft, INL

COLLABORATOR:
Endigit

Quick, cost-effective method to perform multiple PIE tests synchronously for nuclear-fuel research and development cycles

Traditional PIE methodology requires the use of remote equipment in large hot-cell facilities, an expensive method that results in the long duration of the research cycle. Additionally, the remote nature of instrumentation, imposed geometrical requirements, and harsh environment within the hot cell limit applicable technologies and hardware, hinder maintenance, and complicate upgrades. A novel PIE apparatus, the Modular Examination Instrument for Transportable Nuclear Energy Research (MEITNER)—capable of delivering higher throughput, increased flexibility, improved data quality, and new data streams—was developed. The system is capable of simultaneously performing multiple and correlative NDE functions with increased efficiency, as well as enabling simplified maintenance and upgrades. Thus, it improves the nuclear-fuel R&D cycle. MEITNER's PIE capabilities include visual examination, dimensional inspection, surface profilometry, gamma-emission tomography, eddy-current testing, and radiographic examination. The modular approach of the platform also allows rapid and cost-effective development of novel PIE methods. The relatively transportable nature of this system allows it to be implemented at any location with a crane, cask, and in-floor pit or similar facility.

In addition to the successful PIE examinations performed on irradiated nuclear fuel, the MEITNER project expanded Materials and Fuels Complex's (MFC) PIE capabilities by providing its first out-of-cell gamma-emission tomography system dedicated to PIE activities on irradiated nuclear fuel.



The MEITNER mockup platform shows the 4-axis stage, visual-inspection camera, and optical profilometry and gamma spectrometer.

TALENT PIPELINE:
One intern:
- Robert Powers III, Oregon State University

Advanced Manufacturing of Uranium Dioxide Fuel Pellets with Radially and Axially Zoned Burnable Poisons and Hour-glassing Control Features

PORTFOLIO COMPONENT:
FY 2017 Out of Cycle

PROJECT NUMBER:
17P11-018

PRINCIPAL INVESTIGATOR:
Adrian Wagner, INL

CO-INVESTIGATORS:
Robert O'Brien, INL
Randall Scott, INL
Connie Hill, INL
Aaron Craft, INL
Andrew Smolinski, INL
Daniel Schwen, INL
Raul Rebak, General Electric
Charles Paone, General Electric
James Tulenko, University of Florida
Peter Hosemann, University of California (UC), Berkeley

COLLABORATORS:
General Electric
University of Florida,
UC Berkeley

Techniques to improve performance of gadolinia-doped nuclear fuels

Gadolinia-doped uranium dioxide pellets are used widely across the LWR industry to establish higher core fuel loadings and to help level the power of reactors as a function of burnup on each loading. The bulk addition of gadolinia results in overall lower softening and melting temperatures; it creates consequent challenges for mechanical stability at operating temperatures and under irradiation, and it has, in practice, been linked to PCMI that drives failures of fuel rods and assemblies through hour-glassing and hard-contact establishment with irradiated claddings. This project evaluated and demonstrated that advanced manufacturing (AM) techniques—employing 3D printing techniques of laser-AM, stereo laser lithography, and spark plasma sintering—can significantly improve performance of gadolinia-doped nuclear fuels by constraining the gadolinia to outer-rim regions of pellets as a functional gradient material. These techniques may provide equivalent power damping and increased melting point at the hot pellet center than is seen in bulk-doped pellets. Additionally, advanced modeling and simulation tools, specifically the BISON code coupled to benchmarked codes such as Monte Carlo N-Particle (MCNP) transport code, were used to develop geometrical features on or within the pellet structure that may mitigate undesirable hour-glassing behavior.

TALENT PIPELINE:

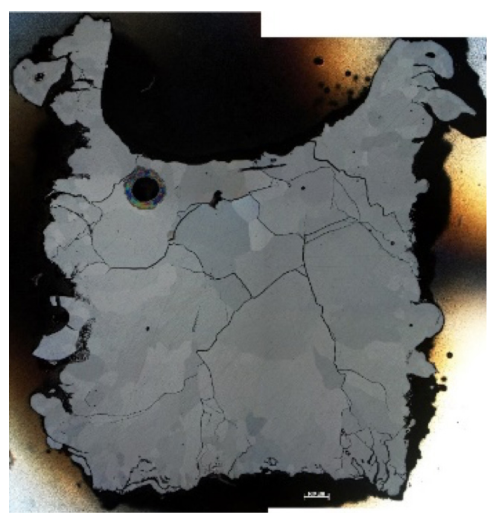
The ability to fabricate fuel by both advanced and additive manufacturing techniques has sparked interest in advanced fuel types with enhanced thermal conductivity and unique compositions.

One intern:

- Patrick Moo, University of Florida

INTELLECTUAL PROPERTY:

- One nonprovisional U.S. patent application filed: 16/372,730 Advanced manufacturing of uranium dioxide fuel pellets with radially and axially zoned burnable poisons and hour-glassing control features
- 1 IDR



Optical image on longitudinally sectioned fabricated depleted UO_2 fuel pellet via a directed energy-deposition technique. This image shows intergranular and transgranular cracking due to the presence of high residual stress.

Application of Traditional Risk-assessment Methods to Cybermanipulation Scenarios

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-164

PRINCIPAL INVESTIGATOR:
Katya Le Blanc, INL

CO-INVESTIGATOR:
Robert Youngblood, INL

COLLABORATORS:
Idaho State University
Sandia National Laboratories

Enhanced risk assessment method for cyber-risk characterization and failure modes that cybermanipulation could inject into nuclear facilities

Existing risk-assessment tools are adapted to generate and work with large scenario sets, but many of these tools make implicit assumptions about the probabilities of combinations of events that are inapplicable to cybermanipulation scenarios. Also, some existing methods are not well adapted to analyze the modes of failure that cybermanipulation could inject. This project characterized an effective risk-assessment methodology and adapted existing risk-analysis methods for application to the problem of identifying vulnerabilities to cybermanipulation in nuclear facilities. Efficacy of the adapted method was demonstrated on a simple test facility (the Idaho State University flow loop) and, after refinement, it was tested for system and plant response to cybermanipulation on a larger scale in a realistic facility (INL's Human Systems and Simulation Laboratory).

This project resulted in programmatic funding under the DOE NE Cyber Program to conduct research on risk management and extend and refine the developed risk assessment methods.

An effective cyber-risk-analysis method should consider the operator as part of the control system that is strongly driven by procedures and trust in their indicators. The developed risk-method insights were evaluated in an operator study in INL's Human Systems Simulation Laboratory.

TALENT PIPELINE:
One postdoc:
- Wei Zhang

PUBLICATIONS/PRESENTATIONS:

Yadav, V., R. Youngblood, K. Le Blanc, J. Perschon, and R. Pitcher. 2019. "Fault-Tree Based Prevention Analysis of Cyber-Attack Scenarios for PRA Applications," RAMS 2019 Reliability and Maintainability Symposium: pp. 1-7. (INL/CON-18-45151)

Youngblood, R. and K. Le Blanc, "Application of Traditional Risk Assessment Methods to Cyber Manipulation: Adapting Traditional Logic Modeling Techniques to Address Cyberattack," PSAM 2018 Probabilistic Safety Assessment and Management, held 16–21 September 2018 in Los Angeles, CA. (INL/CON-17-43801)

Exploration of Advanced Partitioning Methods

ADDITIONAL CORE CAPABILITIES
Computational Science
Applied Mathematics

PORTFOLIO COMPONENT:
FY 2018 Out of Cycle

PROJECT NUMBER:
18P37-028

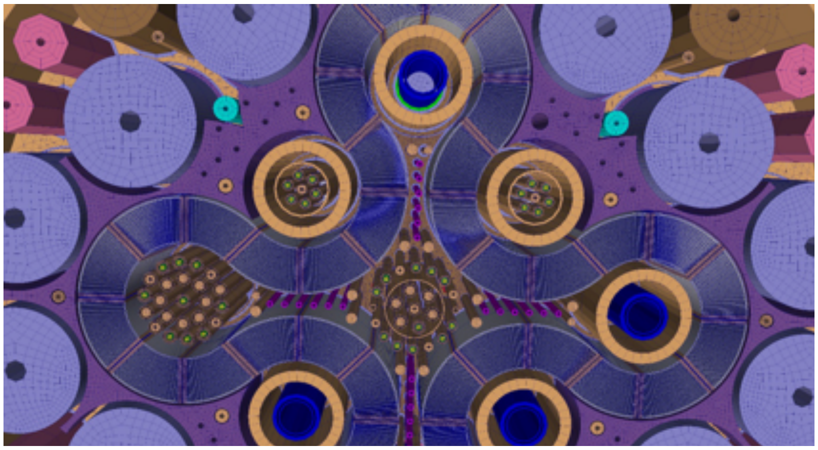
PRINCIPAL INVESTIGATOR:
Fande Kong, INL

CO-INVESTIGATORS:
Derek Gaston, INL
Cody Permann, INL
John Peterson, INL

Graph-partitioning techniques for next-generation supercomputers to enable highly efficient numerical simulations for a wide range of applications from nuclear energy and nuclear security to environmental science

Multiphysics Object-Oriented Simulation Environment (MOOSE) framework is a parallel, scalable scientific simulation package for solving challenging multiphysics problems by leveraging supercomputers and state-of-the-art solver techniques. When performing calculations on modern supercomputers, the framework must effectively spread work among many processor cores. The process of "spreading" a problem is termed partitioning, and this process plays a critical role in parallel efficiency, especially when the number of processor cores becomes large (typically in excess of one thousand cores). The existing partitioning capability in MOOSE works well for small-to-midsize problems but is suboptimal for large-scale simulations due to imbalanced workloads. This imbalance is exacerbated as scaling limits are approached, limiting overall scalability. To address these limits in partitioning, INL researchers (1) leveraged state-of-the-art partitioning techniques in existing high-performance DOE software, such as PETSc (the Portable, Extensible Toolkit for Scientific Computation), (2) explored a general-purpose hierarchical partitioner which takes into account the existence of multiple processor cores and shared memory in a compute node while partitioning a graph into an arbitrary number of subgraphs, (3) implemented an edge-weighted partitioning approach that takes the underlying physics process into consideration and assigns a high weight for each edge where heavy computation is involved, (4) added a new capability to support a partitioning strategy based on a vertex-weighted graph for workload-balance improvements, and (5) developed a novel partition-based workload-assigning approach for distributing work evenly within the "shared" regions of the partitioned data. Each of these complementary capabilities developed in this project significantly improves the existing partitioning capability of MOOSE for all application domains while extending the applicability of the framework on next-generation architectures.

The new partitioning capability has enabled MOOSE multiphysics simulations to scale to tens of thousands of processor cores on modern supercomputers.



A new graph-partitioning solution enables high-fidelity neutron-transport simulation for the ATR using tens of thousands of processors.

PUBLICATIONS/PRESENTATIONS:

Kong, F., R. Stogner, D. Gaston, J. Peterson, C. Permann, A. Slaughter, R. Martineau. 2018. "A general-purpose hierarchical mesh partitioning method with node balancing strategies for large-scale numerical simulations," ScalA 2018 9th IEEE/ACM Workshop on Latest Advances in Scalable Algorithms for Large-Scale Systems held November 12, 2018, in Dallas, TX: 62–72. ISBN: 9781728101774.

Kong, F., D. Gaston, J. Peterson, C. Permann, A. Slaughter, A. Lindsay, and R. Martineau. 2019. "An Efficient Parallel Algorithm for Multiphysics Simulations on 3D Unstructured Meshes," CSE 2019: SIAM Conference on Computational Science and Engineering, held 25 February–1 March 2019 in Spokane, WA.

Kong, F. 2019. "A general-purpose hierarchical mesh partitioning method with node balancing strategies for large-scale numerical simulations," SC18: The International Conference for High Performance Computing, Networking, Storage, and Analysis, held 11–16 November 2018 in Dallas, TX.

Human-reliability Analysis for Advanced Reactor Technologies and Systems

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-201

PRINCIPAL INVESTIGATOR:
Ronald Boring, INL

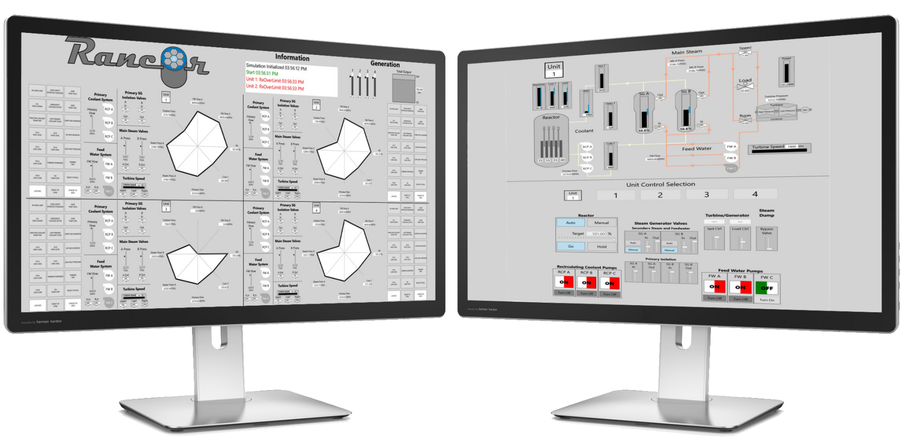
CO-INVESTIGATORS:
Shawn St. Germain, INL
Harold Blackman, Boise State University
Carol Smidts, The Ohio State University

COLLABORATORS:
The Ohio State University
Boise State University
University of Idaho

Human-reliability analysis methods for digital human-machine interfaces integrated into advanced, digital nuclear-operations control rooms

Human reliability analysis (HRA) is a framework to identify and quantify the human component of system risk. While originally developed primarily for nuclear energy applications, HRA has been adopted in other safety-critical areas, like the oil and gas, aerospace, and defense industries. Designed to model human operators in analog control rooms, HRA has not kept pace with advances in digital human-machine interfaces (HMIs). Digital technologies are being incorporated into control rooms in the form of control room modernization and new builds. These digital HMIs potentially change the types of tasks operators perform (e.g., more monitoring due to increased automation). As a result, human-error types and probabilities may be different than in analog control rooms. This project focused on bringing HRA methods up to date with contemporary and future digital-HMI technologies. INL researchers reviewed human-failure events that are specific to digital HMIs, crosswalked existing HRA methods to these human-failure events, adapted HRA methods, and developed new test beds for collecting HRA data on digital HMIs.

INL asserted copyright on the Rancor microworld simulator that represents a simplified nuclear-power-plant control interface on which students can quickly be trained to proficiency and that allows for collection of larger sample sizes from participants, not possible for an actual plant simulator. Rancor is licensed for research at University of Idaho, The Ohio State University, the Norwegian University of Science and Technology, and Chosun University.



The Rancor microworld simulator, shown with the control screens for four reactor units.

TALENT PIPELINE:

Two external postdocs supported at universities:

- Martin Rasmussen, Norwegian University of Science & Technology
- Yunfei Zhao, The Ohio State University

One INL postdoc:

- Thomas Ulrich

Three interns:

- Kateryna Savchenko, University of Idaho
- Thomas Ulrich, University of Idaho (transitioned to postdoc)
- Jooyoung Park, Chosun University

INTELLECTUAL PROPERTY:

- One copyright asserted: Rancor Microworld Simulator Environment for Nuclear Process Control
- One SDR

PUBLICATIONS/PRESENTATIONS:

Boring, R. 2019. "Human reliability analysis for verification and validation of new designs." Proceedings of the Human Factors and Ergonomics Society, 2019 Annual Meeting 63:1. (INL/CON-19-54937)

Boring, R., T. Ulrich, R. Lew, and M. Rasmussen Skogstad. 2019. "Human reliability studies with microworld simulators." Proceedings of the Human Factors and Ergonomics Society, 2019 Annual Meeting 63:1. (INL/CON-19-54935)

Medema, H., K. Savchenko, R. Boring, T. Ulrich, and J. Park. 2019. "Human reliability considerations for the transition from analog to digital control technology in nuclear power plants." NPIC&HMIT 2019: Proceedings of the 11th Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies, held 9–14 February in Orlando, FL: 132–141. (INL/CON-17-42177)

Ulrich, T., R. Boring, and R. Lew. "On the use of microworlds for an error seeding method to support human error analysis," Resilience Week 2019 Symposium, held 4–7 November 2019 in San Antonio TX. (INL/CON-19-55604)

Savchenko, K., H. Medema, R. Boring, and T. Ulrich. 2018. "Measuring mutual awareness for digital human-machine interfaces: A questionnaire for simulator studies," Advances in Intelligent Systems and Computing 778: 36-46. (INL/CON-17-43892)

Lew, R., T. Ulrich, R. Boring, and S. Werner. 2017. "Applications of the Rancor microworld nuclear power plant simulator," Proceedings of resilience Week 2017: 143–149. ISBN: 978-1-5090-6055-9. (INL/CON-17-42216)

Multiphysics, Multiscale Coupled Simulation of Power-impulse Experiments

ADDITIONAL CORE CAPABILITY
Computational Science

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-227

PRINCIPAL INVESTIGATOR:
Warren Jones, INL

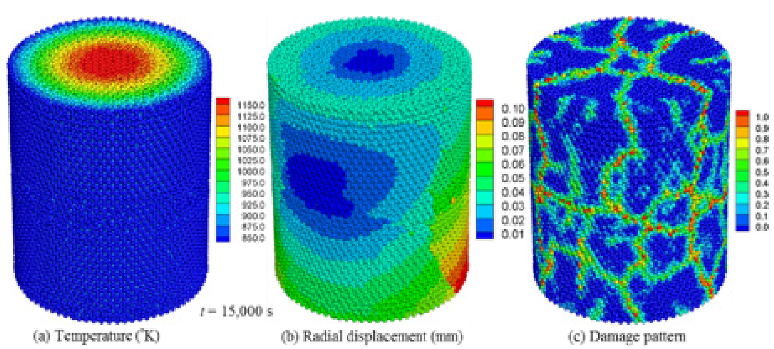
CO-INVESTIGATORS:
Benjamin Spencer, INL
Stephen Novascone, INL
Wade Marcum, Oregon State University
Hailong Chen, University of Kentucky

COLLABORATORS:
Oregon State University
University of Kentucky

Peridynamics capabilities for nuclear-fuels fracture and fragmentation modeling and simulation

The modeling of short-time-scale power excursions on nuclear fuel necessitates the bridging of computational methods and algorithms. Prior to this effort, only analytical approximations were available. To bridge this computational gap, an algorithm and computational methodology were developed to integrate peridynamics (a mathematical theory of mechanics that unifies continuous and discontinuous media into a single, consistent set of equations) into the MOOSE framework to generate a more realistic solution to a loss-of-coolant simulation of fuel rods and fuel bundles. To capture the behavior of the components and coolant in the presence of fracture, phase change, and material relocation, this project applied multiphysics modeling with existing multiphysics codes such as STARCCM+, CTH or ALEGRA to the solution of RIA transient simulations of fuel fracturing, relocation, and dispersion simulations. Experiments on the transient dispersion of particles in a rod-burst event in the presence of moving coolant were performed to both use as validation data for simulations and to provide new information to industry on the dispersion of fuel particles in a fuel-pin array as a function of their characteristic particulate-size distributions.

The capabilities being developed under this LDRD project support development of accident-tolerant fuels and techniques to analyze the behavior of fuel under accident conditions.



Peridynamic modeling of fuel fracture.

TALENT PIPELINE:

One intern:

- Griffen Latimer,
  Oregon State University

PUBLICATIONS/PRESENTATIONS:

Chen, H. 2019. "A comparison study on peridynamic models using irregular non-uniform spatial discretization." Computer Methods in Applied Mechanics and Engineering 345: 539–554. DOI: 10.1016/j.cma.2018.11.001.

Chen, H. and B. Spencer. 2018. "Peridynamic Bond-Associated Correspondence Model: Stability and Convergence Properties." International Journal for Numerical Methods in Engineering 117(6): 713–727. DOI: 10.1002/nme.5973.

Hu, Y., H. Chen, B. Spencer, and E. Madenci. 2018. "Thermomechanical Peridynamic Analysis with Non-uniform Domain Discretization." Engineering Fracture Mechanics 197: 92–113.

Chen, H. 2019. "A Comparison Study on Deformation Gradients in Peridynamics." 15th US National Congress on Computational Mechanics, held July 28–August 1, 2019 in Austin, TX.

Latimer, G., W. Marcum, and W. Jones. 2019. "Dispersion of Surrogate LWR Fuel Experiments under LOCA Conditions." NURETH 2019: Proceedings of the 18th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, held 18–22 August 2019 in Portland OR.

Latimer, G., W. Marcum, and W. Jones. "Single Rod and 5x5 Rod Bundle Blowdown Experiments on the Dispersion of Surrogate Fuel.", International Topical Meeting on Advances in Thermal Hydraulics – 2018 in Orlando, FL, November 11-15, 2018. pp. 777-788.

Opportunities for Center for Space Nuclear Research

ADDITIONAL CORE CAPABILITY
Nuclear Physics

PORTFOLIO COMPONENT:
FY 2019, Out of Cycle

PROJECT NUMBER:
19P45-017

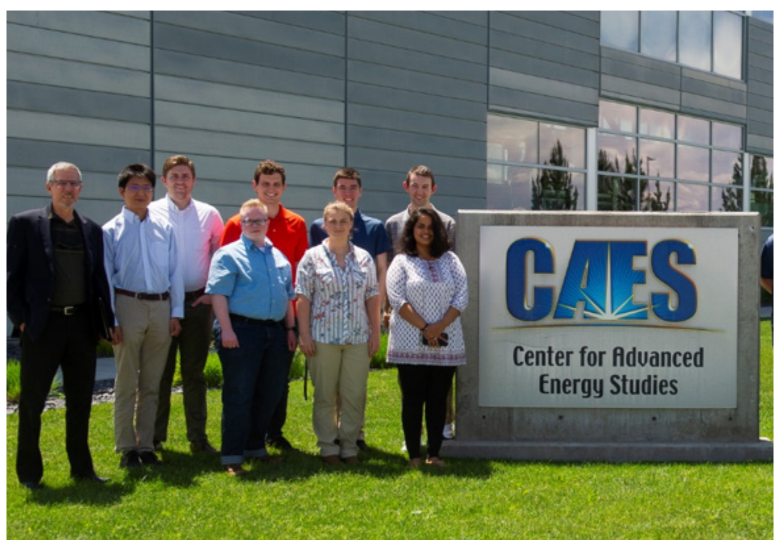
PRINCIPAL INVESTIGATOR:
Stephen Johnson, INL

COLLABORATORS:
Brigham Young University
Brigham Young University–Idaho
Georgia Institute of Technology
Idaho State University
North Carolina State University
Oregon State University
Purdue University
Stanford University
Texas A&M University
University of Idaho
University of Michigan

Methods for ATR to resume domestic production of plutonium-238 and provide understanding of the chemical processes taking place during the manufacture and operations of the radioisotope thermoelectric generators

The US has not produced significant quantities of ^{238}Pu since 1988 although the isotope continues to be used for explorations of the outer solar system and on Mars. It has been observed since radioisotope thermoelectric generators (RTGs) were first used in the 1970s that plutonium dioxide is slightly substoichiometric (PuO_2-x). The variation of x in the range 0.05 to 0.2 results in changes in the strength of the pellet material and the release of oxygen to multi-mission radioisotope thermoelectric generators' (MMRTGs') interior. The stoichiometry varies during manufacturing steps as well as during the multidecade operational lifetime of the MMRTG. This project modeled changes in the oxygen stoichiometry of $^{238}PuO_2$ used as the heat source in MMRTGs for the evaluation of manufacturing and operational scenarios. This project also continued the evaluation of using the Advanced Test Reactor for irradiating ^{237}Np targets to produce ^{238}Pu.

This research was undertaken during the 2019 Summer Program of the Center for Space Nuclear Research and focused on the use of radioisotope energy to provide electrical power to robotic spacecraft.

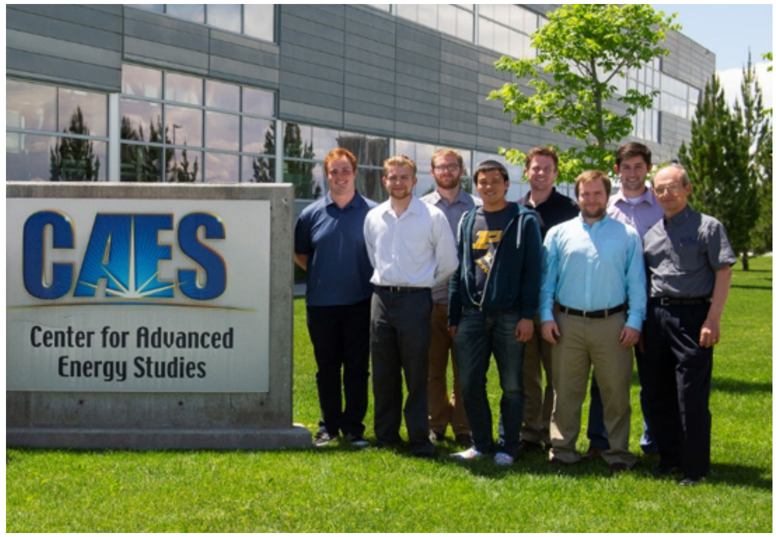


The student-interns supporting this research in front of the Center for Advanced Energy Studies.

TALENT PIPELINE:

Sixteen interns:

- Braden Burt,
  Brigham Young University–Idaho
- Spencer Ercanbrack,
  Idaho State University
- Reed Herner,
  Georgia Institute of Technology
- Quin Killian,
  University of Michigan
- Cole Nielsen,
  Purdue University
- Alex Perry,
  Purdue University
- Darrell Cheu,
  Purdue University
- Carpenter Logan,
  Brigham Young University–Idaho
- Emory Colvin,
  Oregon State University
- Justina Freilich,
  Oregon State University
- Chaitee Godbole,
  North Carolina State University
- Joseph Hafen,
  University of Idaho
- Kevin Judd,
  North Carolina State University
- Takanori Kajihara,
  Texas A&M University
- Andrew Lesh,
  Stanford University
- Jared Magnusson,
  Brigham Young University



The student-interns supporting this research in front of the Center for Advanced Energy Studies.

Rapid Field Chemical Detection and Determination of Actinides

PORTFOLIO COMPONENT:
FY 2018 Seed Call

PROJECT NUMBER:
18A40-001

PRINCIPAL INVESTIGATOR:
Catherine Riddle, INL

CO-INVESTIGATOR:
Rick Demmer, INL

New technology to evaluate and detect contamination of actinides of interest in real time

First responders, military personnel, and forensic investigators need simple, rapid, and reliable field equipment to detect radionuclide contamination. When responding to an event, handheld detectors may provide adequate screening for beta-, gamma-, or neutron-emitting radionuclides, but lack the field sensitivity and adaptability for alpha emitting radiological species like uranium and plutonium. This research experimentally analyzed new selective colorimetric techniques for actinides, specifically U and Pu, to be used by response personnel. Colorimetric analysis that gives a visual color change in the presence of U and Pu contamination could be used during a field contamination event or everyday maintenance testing at nuclear facilities. Experimentation focused on optimizing selectivity and sensitivity to demonstrate the viability of these techniques. Research emphasis was placed on colorimetric indicators, or combinations of indicators, specific for uranium and plutonium. Proof-of-concept work has shown success with the first of multiple colorimetric agents identified for uranium at parts-per-billion (ppb) levels. Multiple colorimetric studies were achieved using U and Pu; candidate colorimetric compounds used in U determination were successful at parts-per-billion (ppb) and parts-per-million (ppm) concentration levels.

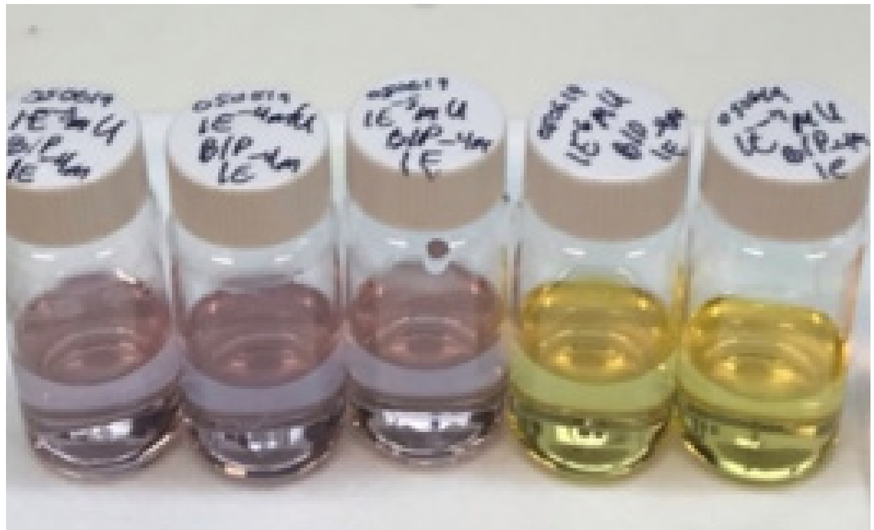
This novel chemical-detection method will allow civilian and military first responders to more effectively assess a radiological event's magnitude, dimensions, and severity early, thereby helping on-scene coordinators make crucial decisions quickly. For the nuclear energy industry, this work could provide a simple screening test for detection of low-level spills and leaks for nuclear-reactor facilities.

INTELLECTUAL PROPERTY:

One provisional patent filed by DOE: S-150,742, "Rapid Field Chemical Detection Method for Actinides"

PRESENTATIONS:

Riddle, C. 2019. "Rapid Field Chemical Detection Method for Actinides for Forensic Investigation." 43rd Actinide Separations Conference held 20–23 May 2019 in Kingsport, TN.



1 × 10-3–1 × 10-7 M uranium contacted with Br-PADAP:peroxyacytyl nitrate (PAN) in a 2:1 ratio at 1 × 10-5 M uranium. The visible color range for concentrations of ppm to ppb uranium indicates both a large potential detection range and a color enhancement using the Br-PADAP:PAN mixture over Br-PADAP alone. No counter-anion was needed for stabilization of the U:Br-PADAP:PAN complex.

A Novel 3D Quasi-Static Discrete Element Model for Complex Fracturing of Tight Rocks and Polycrystalline Solids

PORTFOLIO COMPONENT:
FY 2019 Seed Call

PROJECT NUMBER:
19A42-013

PRINCIPAL INVESTIGATOR:
Jiaoyan Li, INL

COLLABORATOR:
George Washington University

The market-unique simulator for field-scale geothermal systems is based on the newly developed three-dimensional quasi-static discrete element model and high-order finite volume method

Dynamic crack propagation with a complex pattern is inherently a challenging multiscale and multiphysics problem. To date, various numerical methods are available to predict this behavior, yet all current methods show limited success and insufficient reliability due to crude assumptions and simplifications of physics. INL researchers developed a novel 3D quasi-static discrete element model (QS-DEM) to simulate the complex fracturing process in heterogeneous, low-permeability, tight rocks and other polycrystalline solids under hydraulic and thermal stimulation. The developed simulator, Hydro-Thermal-Mechanical Solver for 3D Problems (HTM3D), is equipped with fully coupled mechanical, thermal, and hydraulic solvers to study the hydraulic-fracturing and thermal-cracking processes. This simulator fully couples mechanical, hydraulic, and thermal studies, which opens the door to explore the complex fracturing behaviors in many other energy-related fields such as enhanced shale-oil and gas production, and safety evaluation of nuclear-reactor infrastructure.

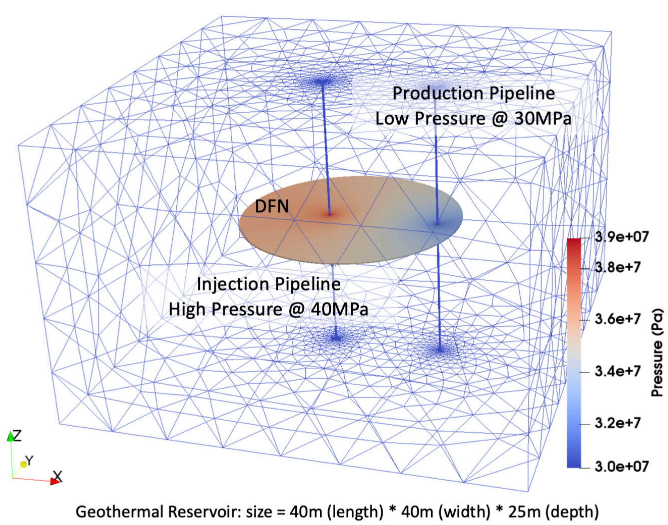
HTM3D will be employed to support the DOE Geothermal Technology Office (GTO) project, Frontier Observatory for Research in Geothermal Energy (FORGE) in FY2020.

TALENT PIPELINE:
One Intern:

- Lingquan Li from North Carolina University

INTELLECTUAL PROPERTY:
A code repository: HTM3D

PUBLICATIONS/PRESENTATIONS:
Li, J., Y. Xia, and H. Huang. 2019. "Coupled DEM-FVM for Complex Fracturing of Tight Rocks under Hydraulic and Thermal Stimulations." Engineering Mechanics Institute Conference (EMI), June 18-21, 2019, Pasadena, CA. (INL/CON-19-52703)



A benchmark case for simulation of a geothermal reservoir, with size of 40m × 40m × 25m; the figure represents pressure distribution on a natural discrete fracture network (DFN), in which high pressure is prescribed for an injection pipeline, and low pressure is prescribed for a production pipeline. HTM3D can predict the variance of a pressure field on DFNs under different in situ stresses induced by the varied underground depths of geothermal reservoirs.

Advanced Manufacturing of Metallic Fuels and Cladding by Equal-channel Angular Pressing

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-150

PRINCIPAL INVESTIGATOR:
Cheng Sun, INL

CO-INVESTIGATOR:
Thomas Lillo, INL

COLLABORATORS:
Texas A&M University
University of Houston
Missouri University of Science and Technology

Irradiation-tolerant fuel-cladding material through nanoengineering

The development of irradiation-tolerant fuel-cladding materials is critical for the lifetime extension of current LWRs and development of future advanced nuclear reactors. Irradiation damage can significantly degrade the performance of materials in nuclear reactors. Through a nanoengineering approach, INL enhanced irradiation tolerance in stainless steel fuel cladding. Researchers developed the equal-channel angular pressing (ECAP) system and refined the microstructure of T91 stainless steel fuel cladding through multiple ECAP passes. The T91 stainless steel produced through this novel process exhibits enhanced tolerance to bubble swelling over its coarse-grained counterpart.

This project contributed to two graduate students' master's thesis research.

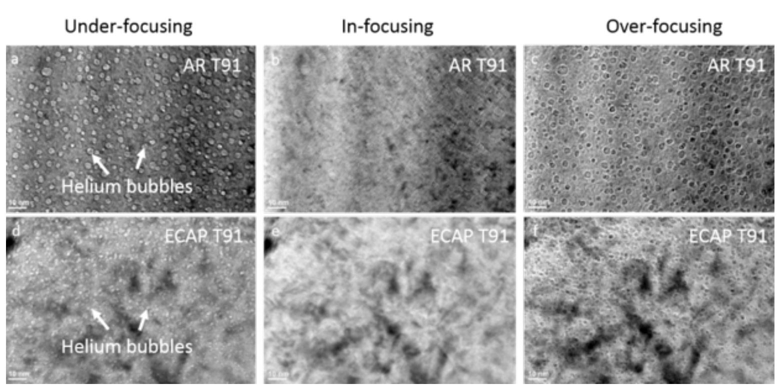
TALENT PIPELINE:
Four interns:
- Fei Teng, Oregon State University (transitioned to INL staff)
- ChingHeng Shaiu, Texas A&M University
- Ryan Carnahan, Idaho State University
- Chintah Shah, Texas A&M University

PUBLICATIONS/PRESENTATIONS:

Carnahan, R. 2018. "Microstructure characterization and thermal stability of equal channel angular pressing processed Grade 91 stainless steel." M.S. thesis, Idaho State University.

Shah, C. 2018. "Quenching and partitioning process of Grade 91 stainless steel." M.S. thesis, Texas A&M University-Kingsville.

Carnahan, R., M. Wilding, M. Gougar, T. Lillo, C. Sun. 2018. "Microstructural characterization of equal channel angular processed G 91 during in-situ annealing," 2018 Annual Meeting of the American Nuclear Society, held 9–13 June 2019 in Minneapolis, MN.



Transmission electron microscopy (TEM)-produced micrographs show helium bubbles observed in the microstructure of as-received (AR) and ECAPed T91 stainless steel. The much smaller bubble size in the ECAPed T91 stainless steel points to its increased tolerance to bubble swelling.

Advanced Probabilistic Risk Assessment through Continuous Fault Trees using R Functions

ADDITIONAL CORE CAPABILITIES
Applied Mathematics
Computational Science

PORTFOLIO COMPONENT:
FY 2018 Seed Call

PROJECT NUMBER:
18A40-029

PRINCIPAL INVESTIGATOR:
Andrei Gribok, INL

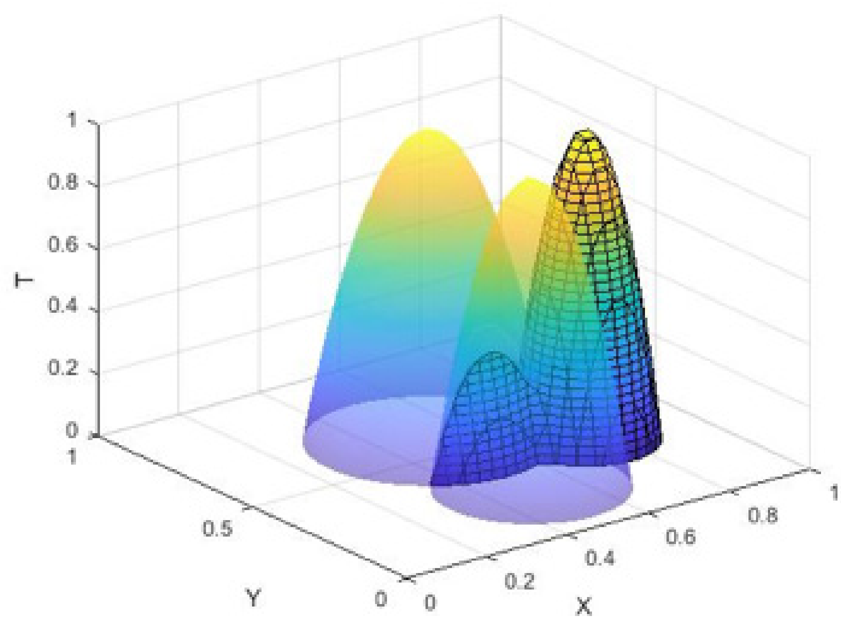
CO-INVESTIGATOR:
Ted Wood, INL

Suitability of risk-analysis tools for highly complex, dynamic, hybrid systems with tight hardware-software integration

Classical binary Level 1 probabilistic risk assessment (PRA) has inherent and fundamental limitations to model risk scenarios with partial (partially open valve), incomplete (wall thinning), and poorly understood (pump loss of power) failures. In addition, discovering the risk scenarios and optimization of the reliability of a system is difficult in the binary PRA framework. INL developed a mathematically rigorous methodology using continuous fault trees instead of binary choices. These well-developed optimization techniques are suitable for reliability design and analysis of a system for current—as well as next-generation—reactors. For example, using the methodology, a station blackout accident can be analyzed under a condition where some diesel generators are partially available. This methodology enables analysis in a continuous domain and application of all available analytical tools, including differentiation and integration, to study the properties of the function and optimize it with respect to the total probability of the system's failure.

This project developed a proof-of-principle that a mathematically rigorous methodology can use continuous fault trees, instead of binary choices, for probabilistic risk assessments.

PUBLICATIONS/PRESENTATIONS:
Gribok, A. and T. Wood. 2019. "Advanced Probabilistic Risk Assessment through Continuous Fault Trees using R Functions," 29th European Safety and Reliability Conference, held 22–26 September 2019 in Hannover, Germany.



Probability of partial system failure in comparison to complete failure.

Deep-learning Approaches for the Analysis of Synchrotron Data of Materials Used in Energy and Environmental Applications

ADDITIONAL CORE CAPABILITY:
Nuclear Physics

PORTFOLIO COMPONENT:
FY 2018 Seed Call

PROJECT NUMBER:
18A40-049

PRINCIPAL INVESTIGATOR:
Donna Post Guillen, INL

CO-INVESTIGATORS:
Jeff Terry,
Illinois Institute of Technology
Shlomo Argamon,
Illinois Institute of Technology

COLLABORATORS:
Illinois Institute of Technology
Boise State University

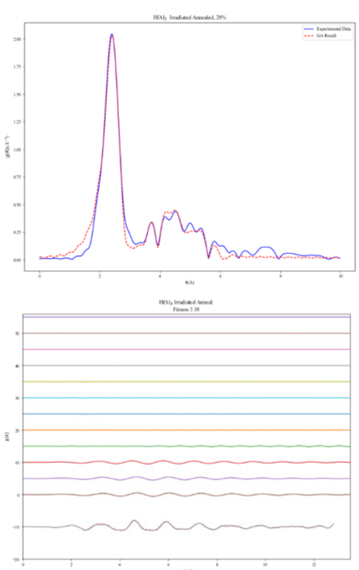
Proof-of-concept for automated processing of extended X-ray-absorption fine-structure data using machine learning

The ability to automatically analyze experimental data is essential to support analysis of scientific measurements from high-throughput data generators such as a synchrotron facility, where large amounts of data are collected at extremely high rates. The ability to process such data *in situ* would optimize the use of these user facilities and enable users to rapidly adjust data-collection parameters and automate the data-collection process. X-ray absorption fine structure (XAFS) has been shown to be very useful in understanding the local atomic structure of materials of interest in applications, such as materials synthesis and design of batteries, assessment of material performance for energy materials, and evaluation of radiation damage for nuclear energy applications. INL researchers developed a proof of concept for automated processing of extended XAFS data using machine learning.

The developed genetic algorithm analyzed hundreds of "operando" spectra from a cycling lithium-ion battery to study the chemistry that can shorten the life of the battery. Through this technique, it was possible to observe the changes due to lithium ions moving throughout the battery.

TALENT PIPELINE:
Eight graduate students:
- Sanchayni Bagade, Illinois Institute of Technology
- Shail Shah, Illinois Institute of Technology
- Priyanka Makhijani, Illinois Institute of Technology
- Aditya Karantha, Illinois Institute of Technology
- Travis Boltz, Illinois Institute of Technology
- Max Oellien, Illinois Institute of Technology
- Miu Lun, Boise State University
- Mike Griffel, Idaho State University (INL staff getting Ph.D.)

Four undergraduate students:
- Julia Kise, Illinois Institute of Technology
- Bryan Hendricks, Illinois Institute of Technology
- Chang Xu, Illinois Institute of Technology
- Chandler Sun, Illinois Institute of Technology



Results for the irradiated, annealed $HfAl_3$-Al material (a) peak fitting with genetic algorithm compared to experimental data, and (b) paths used to generate fit (bottom curve is the sum of all paths).

Development of a Complete Kinetic Model for Free-radical-induced Degradation of Formic and Oxalic Acids

ADDITIONAL CORE CAPABILITY
Computational Science

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-086

PRINCIPAL INVESTIGATOR:
Peter Zalupski, INL

CO-INVESTIGATORS:
Gregory Horne, INL
Bruce Mincher, INL (retired)
Simon Pimblott, INL
Dayna Daubaras, INL
Cathy Rae, INL
Stephen Mezyk, California State University at Long Beach

COLLABORATORS:
California State University at Long Beach
Idaho State University

Understanding the chemistry of final, universal molecular transformations

Ionizing radiation interacts with matter, producing highly reactive ionic and radical species, initiating chemical-bond rupture, and causing molecular damage. Such degradation "scissors" eventually transform all organic molecules into smaller and smaller species until only water and carbon dioxide remain. Small organic acids, such as formic and oxalic acid, are typical remaining "molecular pieces" prior to their complete mineralization. The understanding of the chemistry of those final, universal molecular transformations developed through this project offers mechanistic explanation to researchers studying wastewater treatment, environmental remediation, nuclear-fuel reprocessing, and both atmospheric photolytic and interstellar chemistry.

This project supported the establishment of Center for Radiation Chemistry Research at INL. It strengthened and formalized INL's internationally recognized leading role in the field of radiation chemistry.

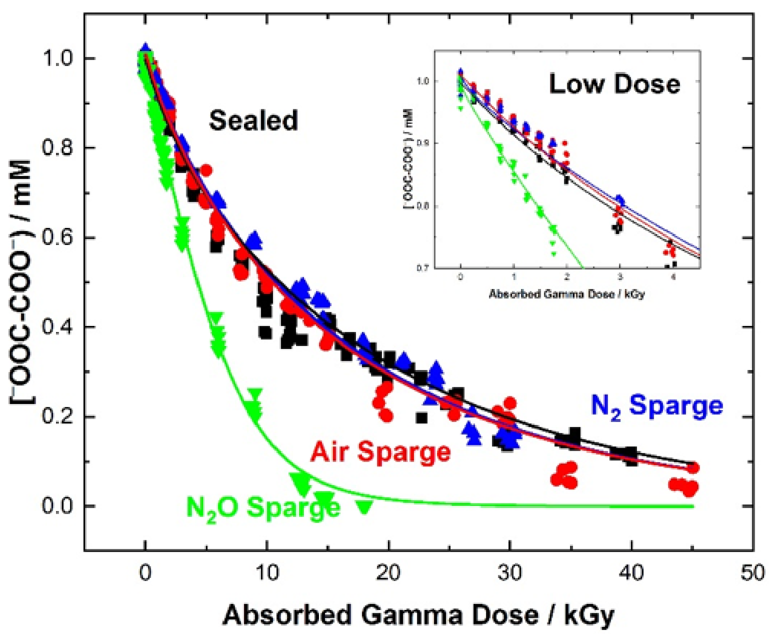
TALENT PIPELINE:

One early career scientist hired:
- Gregory P. Horne

One graduate student:
- David Meeker, Florida State University

PUBLICATIONS/PRESENTATIONS:

Zalupski, P., G. Horne, D. Daubaras, C. Rae, S. Pimblott, B. Mincher, and S. Mezyk. "En Route to Complete Mineralization of Organic Species: Free Radical Induced Degradation of Small Carboxylic Acids." RB2018: Second edition of the Radical Behaviour Workshop, held 19–20 April 2018 in Wurzburg, Germany. (INL/CON-18-45175)



Oxalate as a function of absorbed gamma dose for pH 9 1 mM sodium oxalate: sealed (■), air sparged (●); N_2 sparged (▲); and N2O sparged (▼). Solid curves are predicted values from modeling calculations.

Modeling and Simulation of Advanced Manufacturing Techniques: Additive Manufacturing and Laser Welding

ADDITIONAL CORE CAPABILITY
Computational Science

PORTFOLIO COMPONENT:
FY 2018, Out of Cycle

PROJECT NUMBER:
18P37-019

PRINCIPAL INVESTIGATOR:
Larry Aagesen, INL

CO-INVESTIGATORS:
Sudipta Biswas, INL
Stephanie Pitts, INL
Alexander Lindsay, INL

COLLABORATOR:
Kansas City National Security Campus

Additional capability in MOOSE to model the effects of microstructure of components developed through advanced manufacturing processes

With increasing frequency, product manufacturing relies on material design to optimize component performance. For example, by controlling grain size and orientation, it is possible to minimize mass diffusion, maximize fracture toughness, or limit corrosion. INL's MOOSE framework is a general-purpose partial-differential-equation solver that has been proven to be successful in modeling material structure, property, and performance. Additional capability in MOOSE was developed to allow investigation of the effects of advanced manufacturing by AM and laser welding on the microstructure of components and to link the resultant microstructure to properties.

TALENT PIPELINE:

The modeling and simulation capabilities developed in this project will enable optimization of manufacturing processes in a much more cost-and time-effective manner than trial and error with repeated experiments.

One intern:

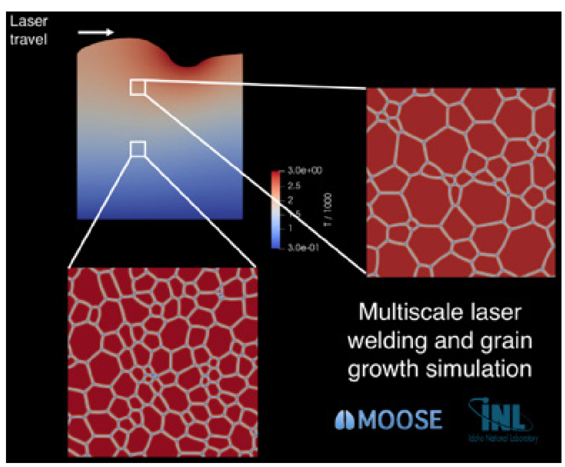
- Stephanie Pitts, conferred Ph.D. in Mechanical Engineering (transitioned to INL technical staff)

PUBLICATIONS/PRESENTATIONS:

Aagesen, L., S. Biswas, A. Lindsay, and S. Pitts. 2019. "Phase-field modeling of dendritic solidification for additive manufacturing applications." 149th Annual Meeting of the Minerals, Metals, and Materials Society, held March 10–14, 2019 in San Antonio, TX.

Pitts, S. 2019. "Modeling and Simulation of Microstructure Evolution and Deformation in an Irradiated Environment," Ph.D. thesis, Washington State University.

Biswas, S. and L. Aagesen. 2020. "Solidification and grain formation during additive manufacturing process: A grand-potential based phase field study." 150th Annual Meeting of the Minerals, Metals, and Materials Society Annual Meeting, held 23–27 February 2020 in San Diego, CA.



Multi-scale coupled simulation of laser welding and resulting grain growth in the heat-affected zone of the weld. The top left subfigure is the domain being welded, with the laser incident on the top surface and traveling left to right in time. The color bar indicates temperature at the end of the simulation time. White boxes indicate where the microstructural evolution is being simulated. The upper white box is closer to the laser and, thus, hotter, so the grain size of the resulting grain structure (subfigure at right) is larger than the size of the grain structure in the lower white box (subfigure at bottom).

Robust Algorithm Development for Mechanical Contact

ADDITIONAL CORE CAPABILITIES
Computational Science
Applied Mathematics

PORTFOLIO COMPONENT:
FY 2018 Out of Cycle

PROJECT NUMBER:
18P37-023

PRINCIPAL INVESTIGATOR:
Alexander Lindsay, INL

CO-INVESTIGATORS:
Benjamin Spencer, INL
Derek Gaston, INL
Fande Kong, INL

Additional MOOSE capability for nonlinear-complementarity problems formulation of mechanical contact for nuclear fuel predictive simulation capabilities

Accurate, efficient solution to solid mechanical contact problems is critical to INL's ability to deliver predictive simulation capabilities for nuclear fuel. Numerical solution of mechanical contact is historically difficult because of the nonsmooth nature of the mathematics describing contact physics. A nonlinear-complementarity problems (NCPs) formulation of mechanical contact was added to MOOSE. Combined with automatic differentiation (AD) technology, NCP formulation resulted in a factor of two reduction in the number of nonlinear iterations required to solve frictional-contact problems compared to preexisting best methods in MOOSE. More realistic and difficult contact problems, like those solved by the fuel performance application BISON, may experience even more dramatic improvements. The addition of automatic differentiation has resulted in Nuclear Energy Advanced Modeling and Simulation program funding support for its proliferation through the MOOSE module system and BISON. AD has also spread rapidly through the MOOSE community, with application developers throughout the U.S., Europe, and Australia embracing the technology. AD is now a centerpiece of training for new MOOSE users.

The automatic differentiation technology within MOOSE can be used for any type of physics, from heat conduction to fluid flow to mechanical contact. Because of its generality and extreme utility, this feature has become the hottest concept for MOOSE development, as measured in terms of pull requests into the MOOSE repository, after only nine months of existence.

INTELLECTUAL PROPERTY:
Released as part of MOOSE, MOOSE released via open source. https://github.com/idaholab/moose/

PUBLICATIONS/PRESENTATIONS:
Lindsay, A. 2019. "Automatic Differentiation in MOOSE," CSE19: SIAM Conference on Computational Science and Engineering, held February 25–March 1, 2019 in Spokane, WA.

Color map of the x-component of displacements for two bodies coming into contact. Contact physics is described using NCP formulation.

Separation of Fragile Chemical Species using Carbon-nanotube Emitters at Very Low Electrical Potential

PORTFOLIO COMPONENT:
FY 2018 Seed Call

PROJECT NUMBER:
18A40-020

PRINCIPAL INVESTIGATOR:
Gary Groenewold, INL

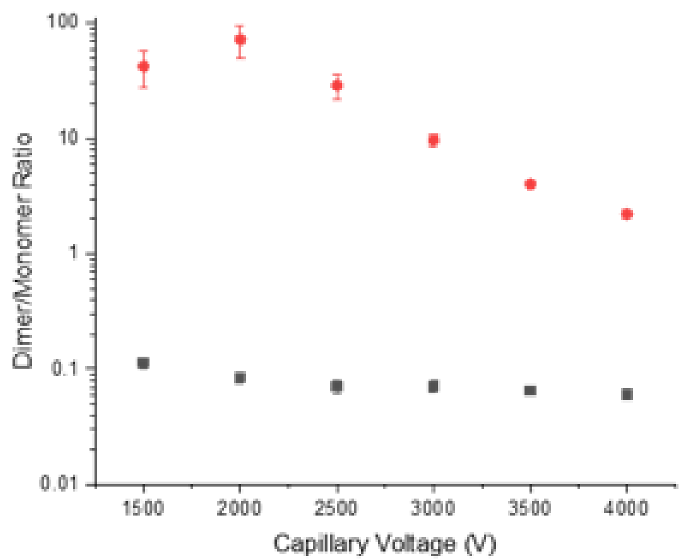
CO-INVESTIGATORS:
Josh Kane, INL
Chris Zarzana, INL
Brittany Hodges, INL

Methodology to generate and trap weakly bound complexes for investigation of transient species

A dearth of characterization approaches capable of interrogating transient species exists during chemical separation and conversion processes. This is a critical shortcoming because pathways and kinetics for the formation and subsequent reaction of these species will largely control process efficacy. Thus, the ability to produce representative weakly bound species and trap them in a mass spectrometer would open new avenues for exploring fundamental reaction chemistry involving these transient species. This project investigated the use of electrified carbon nanotubes (CNTs) for generating weakly bound ionic complexes in the gas phase for study with mass spectrometry. It was hypothesized that these weakly bound species would be representative of chemical intermediates that are rate-controlling in metals-separation processes and that are intermediates in the reactions involved in conversion of low-value feedstocks into higher-value products. An apparatus was developed to couple CNTs impregnated in a paper support to a trapping mass spectrometer demonstrated that the CNT-impregnated paper is better-suited for generating weakly bound clusters than traditional atmospheric-pressure ionization techniques.

These methods and technology will enable new ways of studying transient species, ultimately leading to techniques for controlling these processes.

TALENT PIPELINE:
One strategic hire:
- Brittany Hodges



Ratio of sodiated dimers to sodiated monomers of N,N,N′,N′-tetraoctyl diglycolamide (TODGA) generated by electrospray ionization (black solid squares), and CNT-impregnated paper spray ionization (red solid circles) versus ionization voltage. Error bars are standard deviations of 150–200 measured ratios of the peak heights of [(TODGA)2Na]+ (m/z = 1184.0) and [TODGANa]+ (m/z = 603.6) ions. CNT-impregnated paper spray ionization significantly increases the percentage of ions present as sodiated dimers, which are weaker-bound species than the sodiated monomers.

Systematic Error Control in Cross-section Library Generation for Novel Reactors

ADDITIONAL CORE CAPABILITY
Computational Science

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-124

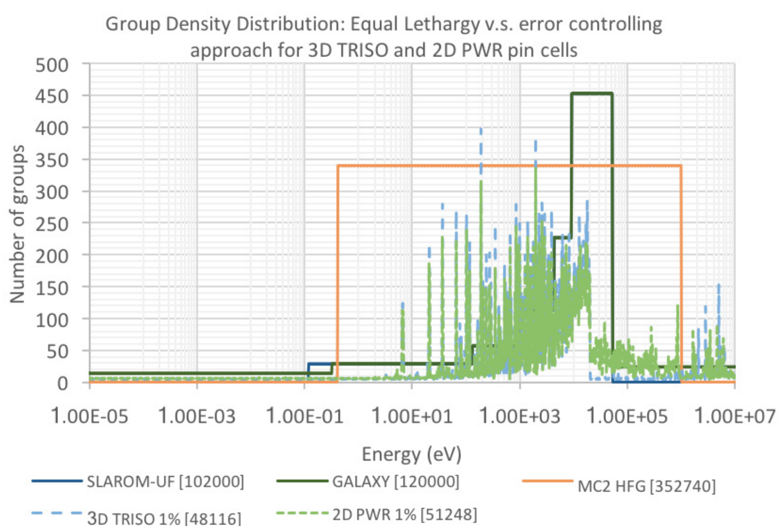
PRINCIPAL INVESTIGATOR:
Abderrafi Ougouag, INL

CO-INVESTIGATORS:
Gerhard Strydom, INL
Kostadin Ivanov,
North Carolina State University
Maria Avramova,
North Carolina State University

COLLABORATOR:
North Carolina State University

Set of methods and codes that efficiently treat the preparation of cross sections for reactor-physics calculations in a way that quantifies and controls the error are suitable for analysis, design, and modeling of first-of-a-kind reactor concepts

Cross sections are probabilities of interaction between neutrons and nuclei. They are used in methods and codes that predict behavior and performance of nuclear reactors. The preparation of cross sections, especially in the multigroup form that is most practical for use in full-core reactor-physics codes, has heretofore been an inexact science. This project identified sources of error in conventional cross-section-generation procedures in both the energy and spatial extents and developed novel solutions based on adherence to, and implementation of, the correct physics. This resulted in enhancing fidelity of modeling, improving accuracy, and controlling error in the resulting prepared multigroup cross sections. First, a novel and rigorous method was devised and implemented for quantifying and controlling systematic error arising from the computational process of preparing multigroup cross-section libraries. This was achieved by selecting energy-group structures that are sufficiently fine. A rigorous definition of "sufficiently fine" group structure naturally results from the error-control theory. Second, a method for the explicit treatment of strong heterogeneities and another for the identification of spectral zones were also developed and implemented. The test results show superior performance and significant improvements over the traditional approaches when strong heterogeneities are present.



Group-density distribution resulting from the new theory ensures error control at minimal computational cost while commonly used codes based on equal lethargy intervals result in excessive computational work and insufficient coverage, depending on the energy range.

TALENT PIPELINE:

One intern at INL

- Jui-Yu Wang,
  North Carolina State University

Two postdoctoral researchers at INL and NCSU

- Paolo Balestra,
  North Carolina State University
  (transitioned to INL technical staff)
- Pascal Rouxelin,
  North Carolina State University

PUBLICATIONS/PRESENTATIONS:

Ougouag, A., and J. Wang. 2018. "Preliminary Results on an Ultra-Fine Energy Group Structure that Quantifies and Controls the Error in Multigroup Cross Sections." PHYTRA4, held Sep. 17–19, 2018 in Marrakech, Morocco.

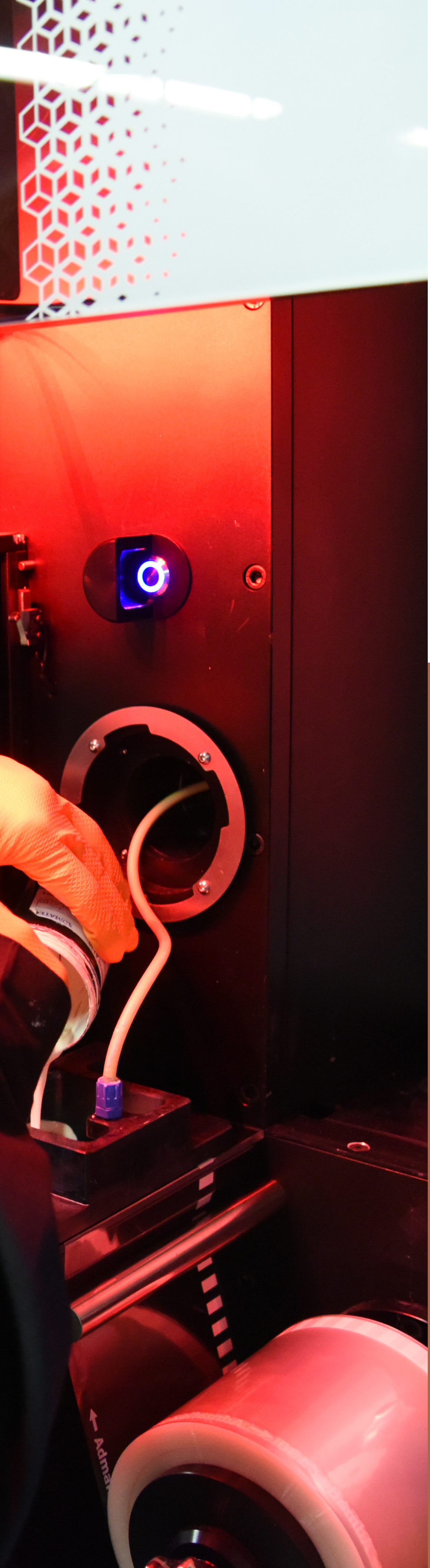
Wang, J., and A. Ougouag. 2018. "Incomplete Homogenization for Explicit Treatment of Burnable Poisons, Control Rods and Localized Strong Heterogeneities." PHYTRA4, held Sep. 17–19, 2018 in Marrakech, Morocco.

Ougouag, A., H. Gougar, and J. Wang. 2018. "Methods for Neutronics of High Temperature reactors: Drivers, Recent Progress at INL and Outstanding Problems." PHYTRA4, held Sep. 17–19, 2018 in Marrakech, Morocco.

Ougouag, A., H. Gougar, and R. Sonatsen. 2018. "Identification of Spectral Zone Boundaries in Pebble Bed Reactors." Proceedings of HTR 2018, held Oct. 8–10, 2018 in Warsaw, Poland.

Portions of the developed codes are currently in use in INL's suite of codes, and continued development will enhance INL's overall ability to model the physics of novel nuclear reactors, including small modular reactors and microreactors.


Thickness
Repeat
Delay before exposure
Delay after exposure
Transport speed
Transport acceleration
Transport distance margin
Up/down distance
Up/down speed
Up/down acceleration
Slow up distance
Slow up speed
Slow down distance
Slow down speed
Led power part 1-9
Pixel value part 1-9
Exposure time part 1-9
500 ms
20 000 µm/s
20 000 µm/s²
50 000 µm
8 000 µm
1 500 µm/s
1 000 µm/s²
1 500 µm
200 µm/s
200 µm
200 µm/s
500 %
1 000 %
8 000 ms
Slice 1-20
50 µm
1 x
Thickness
Repeat
Current slice: 7
ADMATEC
Additive Manufacturing Technologies
NATIONAL LABORATORY
IDAHO
MFC



ADVANCED MATERIALS AND MANUFACTURING FOR EXTREME ENVIRONMENTS

INL is transforming and integrating advanced manufacturing capabilities for the supply chains of energy and security components designed for extreme environments. The projects aligned with this strategic initiative advance high-temperature materials, catalysts, electrical, and electrochemical processes, sensors and controls—integrating nuclear energy into industrial manufacturing to eliminate manufacturing supply barriers for advanced energy and security systems components.

SUCCESS STORY

INL's LDRD program enables research programs to bring on new talent through internships and postdoctoral appointments. High-performing students and postdocs are transitioned to INL technical staff. Dr. Ryan Bratton exemplifies this talent pipeline; he was hired as a full-time INL technical staff member upon the conclusion of "Investigation of Dual Material Shaped-Charge Liners" (18A40-021) and his graduate internship at INL.

Chemically Mediated Rare-earth Metallization

PORTFOLIO COMPONENT:
FY 2019 Seed Call

PROJECT NUMBER:
19A41-004

PRINCIPAL INVESTIGATOR:
Mary Case, INL

CO-INVESTIGATORS:
Robert Fox, INL
Donna Baek, INL
Tedd Lister, INL

Process to lower the temperature and energy used to metallize rare-earth elements

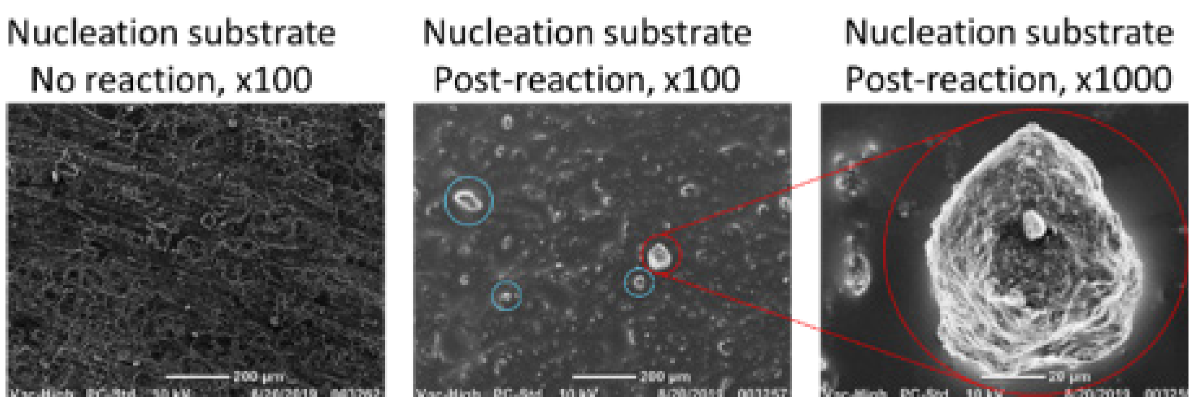
Currently, the rare-earth element (REE)-metallization market is monopolized by China, which uses obsolete U.S. metallurgical technology (molten-salt electrolysis at >600°C) to convert rare-earth salts and oxides into functional metallic forms. Developing a domestic, metallic REE materials-processing capability using advanced metallurgical processes will break the current market monopoly held by China and stabilize materials supply chains that serve many different market sectors that rely on metallic REEs as functional materials. This research successfully examined a proof-of-principle for a novel low-temperature (i.e., less than 300°C) chemically mediated reduction chemistry. The reduction chemistry immediately targeted conversion of rare-earth compounds from oxidation state to the corresponding zero-valent metallic form. Ionic REE was successfully converted to metallic REE.

Currently, no commercially viable material substitutes are available that can perform the same functions as REEs in their metallic state at the same level of proficiency.

TALENT PIPELINE:
One intern:
- Emma Pollock, Westminster College

One postdoctoral researcher transitioned to INL technical staff:
- Mary Case

INTELLECTUAL PROPERTY:
One IDR



Scanning electron microscopy (SEM) images of the nucleation substrate prereaction at 100× magnification (left), the nucleation substrate at 100× magnification post-reaction (middle), and a 1000× magnification of a growth of metallic neodymium (right).

Investigation of Dual Material Shaped-charge Liners

ADDITIONAL CORE CAPABILITY
Computational Science

PORTFOLIO COMPONENT:
FY 2018 Seed Call

PROJECT NUMBER:
18A40-021

PRINCIPAL INVESTIGATOR:
Jeffrey A. Anderson, INL

CO-INVESTIGATOR:
Henry Chu, INL

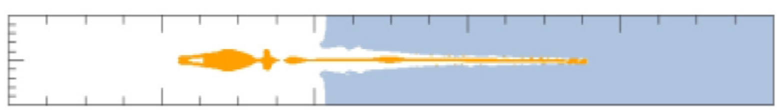
Multimaterial shaped-charge device for hazardous-material destruction

Armed conflicts, both past and present, leave behind residual threats that must be disposed of in a safe manner. These threats may include chemical weapons, biological agents, and unexploded ordnance. For each of these threats, some container must be breached to permit destruction of the contents. Insensitive munitions, by their very design, can pose a unique challenge for safe disposal. Multimaterial shaped charges could provide one potential solution. Since the Second World War, the lined shaped charge has been an effective anti-armor device capable of penetrating up to nearly 1-m thick steel armor plate. Despite the excellent penetration capability of the lined shaped charge, the capability for follow-on damage once the target has been penetrated is relatively benign. This research enhanced the aftereffects of the shaped charge by augmenting the existing technology. Using computer simulations, this research demonstrated that a shaped charge can be enhanced after a target is penetrated. Proof-of-principle analysis was completed using the Sandia National Laboratories hydrocode, CTH, to model the formation of the jet, penetration capability, and service environment.

This project successfully leveraged INL's modeling and simulation capabilities and experience in energetic materials to demonstrate that a multimaterial shaped-charge device can be created that has both excellent penetration capability and post-penetration effect.

TALENT PIPELINE:
One intern:

- K. Ryan Bratton, Texas Tech University (transitioned to INL staff)



Generic simulation snapshot of a copper shaped-charge jet penetrating semi-infinite steel.

Multiwire Arc Additive Manufacturing

PORTFOLIO COMPONENT:
FY 2019 Seed Call

PROJECT NUMBER:
19A42-015

PRINCIPAL INVESTIGATOR:
Thomas Lillo, INL

CO-INVESTIGATORS:
Eric Larson, INL
Denis Clark,
DECLark Welding Engineering, PLLC

COLLABORATOR:
DECLark Welding Engineering, PLLC

A prototype multiwire arc additive manufacturing technique for rapid additive manufacturing of near-net-shaped components will allow large components to be fabricated quickly using reduced raw materials compared to traditional casting techniques

AM techniques can efficiently and cost-effectively fabricate components with both geometrical and compositional complexities, where functionally graded compositions in a component allow local service requirements, such as corrosion and high-temperature structural requirements, to be addressed. High-cost alloy compositions for, say, corrosion resistance need only be deposited in areas where the operating conditions are especially severe. Current AM approaches, especially powder-based 3D printing techniques, are not economical to produce very large components, such as those typically used in commercial power-generation plants based on fossil-fuel or nuclear energy. INL developed and demonstrated a multiwire arc additive manufacturing system to enable fabrication of functionally graded, AM of large complex structures that are near-net shaped. The system is based on arc welding and uses multiple filler wires of different alloys, allowing controlled deposition of metals and composition gradients in the component during fabrication.

A cast valve body, with a finished weight of 6,000 lb, requires an initial casting weighing 17,500 lb and requires 6–12 months to fabricate. The INL system will be capable of fabricating the same valve body using less than 7,000 lb of material in about 600 hours.

Sublime Temperature Sensor

PORTFOLIO COMPONENT:
FY 2018 Seed Call

PROJECT NUMBER:
18A40-007

PRINCIPAL INVESTIGATOR:
Richard Skifton, INL

CO-INVESTIGATOR:
Lance Hone, INL

AWARD WINNER

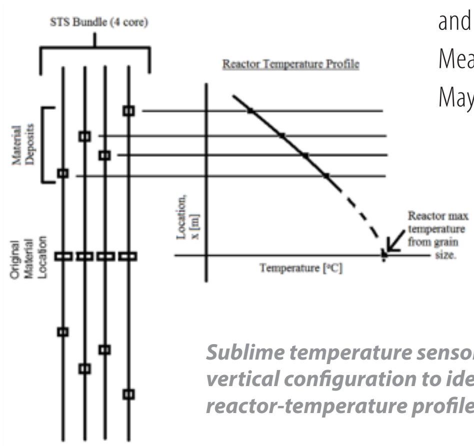
INL Poster Competition top poster for Advanced Materials and Manufacturing for Extreme Environments initiative

Vacuumed materials to identify temperature locations along a thermal gradient

Discovering, demonstrating, and ultimately deploying temperature sensors with maximum temperatures greater than 1,800°C are of concern to nuclear, aerospace and metallurgical industries. Currently, temperature gradients are measured by staggered thermocouples, followed by interpolating between two thermocouples along that temperature profile. Interpolating or extrapolating can lead to large uncertainties, especially if thermocouples are far apart. The sublimation temperature sensor (or "sublime sensor") provides a continuum of measurement locations in which certain maximum-temperature locations are achieved during a heating and cooling cycle. In short, the sublime sensor essentially prints temperatures where they occur and pinpoints exactly where a temperature of interest is located along any gradient. In addition, the sublime-sensor approach provides greater detail to validate and verify modeling and simulation.

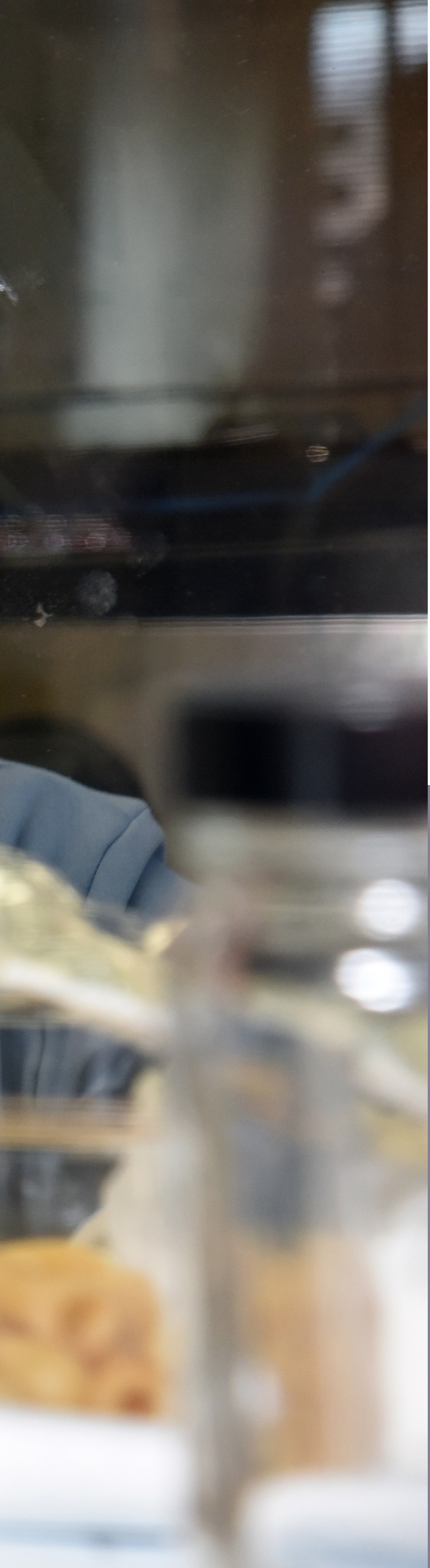
The sublime sensor pushes current state of the art of measuring temperatures by printing at specific temperature locations. This is seen as a paradigm shift in how temperature is measured: measuring locations of desired temperatures, rather than measuring temperatures at known locations.

INTELLECTUAL PROPERTY:
- One nonprovisional U.S. patent application: 16/193,366, "Sublime Temperature Sensor"
- One IDR



Sublime temperature sensor in the vertical configuration to identify the reactor-temperature profile.

PUBLICATIONS/PRESENTATIONS:
Skifton, R. 2019. "E20.96 on Temperature Measurement Techniques Open Forum Workshop/Formal Colloquium," ASTM E20, Biannual meeting of American Society for Testing and Materials (ASTM) E20 Temperature Measurements subcommittee, held May 2019 in Denver, CO.



INTEGRATED ENERGY SYSTEMS

The purpose of the Integrated Energy Systems strategic initiative is to increase access to low-cost, reliable, and resilient electricity and other energy services. Projects aligned to this initiative (1) demonstrate the use of high-density energy products via industrial processes and microgrid infrastructure; (2) enable thermal-energy products and nuclear-energy attributes to balance generation and consumption to enhance the stability and economics of power systems; (3) manage risk and complexity of tightly coupled energy systems through cyberinformed rapid systems-monitoring capabilities, big-data analytics, and cybersecure control systems, and (4) use thermal energy and power from low-emissions energy resources to upgrade and transform natural resources, carbon-based feedstocks, waste streams, intermediate chemicals, and water sources into higher-value building-block molecules, chemicals, or materials.

SUCCESS STORY

Fundamental research conducted under INL's LDRD program explores new paths for U.S. competitiveness and leadership in clean-energy technologies. Projects like "Electro-Reduction of Metals in Supercritical Fluid-Room Temperature Ionic Liquids" (17A1-055) improve the state of the art in the production and environmental sustainability of key energy components, such as REEs, which are not produced in the U.S. because of high temperatures needed and toxic waste yielded by current methods.

A Reactive Molecular-dynamics Simulation Approach to Understand Interfacial Interactions of Lithium and Graphite Under Extreme High-rate Conditions

ADDITIONAL CORE CAPABILITY
Computational Science

PORTFOLIO COMPONENT:
FY 2018 Out of Cycle

PROJECT NUMBER:
18P37-027

PRINCIPAL INVESTIGATOR:
Gorakh Pawar, INL

CO-INVESTIGATORS:
Boryann Liaw, INL
Chase Taylor, INL
Sean Wood, INL

COLLABORATORS:
Penn State University
University of California
San Diego

AWARD WINNER

INL Poster Competition top poster for Integrated Energy Systems initiative

Coupled computational and experimental framework to investigate the reactive events at electronic, atomic, and molecular scales for nuclear energy systems, advanced manufacturing, and energy storage systems

An efficient lithium intercalation in graphite is a key step in advancing extreme fast-charging (XFC) technology for the electrification of vehicles. To charge Li-ion batteries (LIB) within 10 minutes or less using XFC, it is important to understand the complex interfacial processes in XFC and acquire detailed insight of the kinetics and the pathway of the Li intercalation in graphite in the presence of the electrolyte. INL developed a unique approach, based on reactive-force-field (RFF) modeling and experimental techniques to significantly advance the fundamental understanding of complicated interfacial phenomena in electrochemical systems subjected to high-rate conditions. Kinetics plays a key role in defining the reaction pathway observed, where the classical thermodynamics-based models such as density function theory (DFT) cannot predict such process. Understanding the kinetic pathway can help the design of a more-effective energy-transfer mechanism to increase efficiency of Li-graphite interactions, thus minimizing solid-electrolyte interphase formation, lithium plating, the and the amount of heat generated, which altogether is crucial to overcome the fundamental barriers in advancing the XFC technology.

The fundamental understanding of an energy-transfer kinetic pathway in energy conversion from this project will impact many other applications in catalysis, integrated energy systems, and chemical processing.

PUBLICATIONS/PRESENTATIONS:

Pawar, G., B. Liaw, and E. Dufek. 2019. "Lithium Metal Electrode—Understanding Its Unique Characteristics and Functions."The 236th Electrochemical Society Meeting, held in Atlanta, GA 2019. (INL/CON-19-53477)

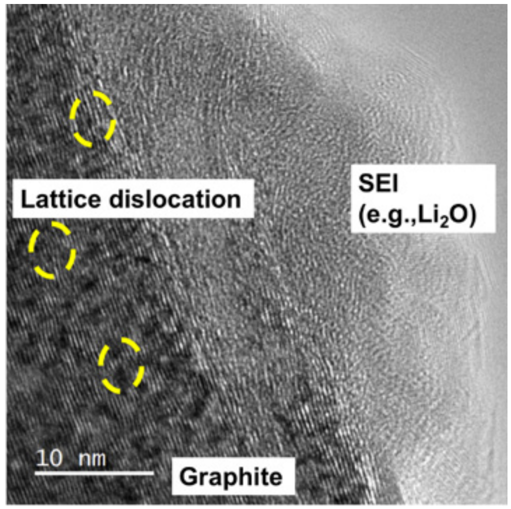
TALENT PIPELINE:

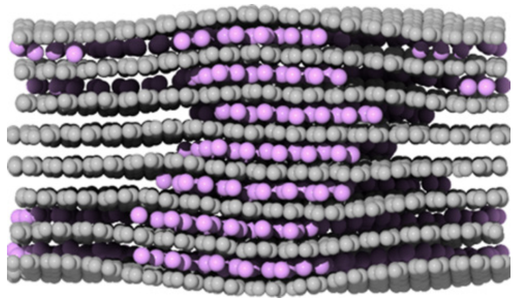
One postdoctoral researcher:

- Yuxiao Lin

Two interns:

- Jamil Hossain,
  Penn State University
- Rajni Chahal,
  University of Texas, Arlington





Coupled computational and experimental approach to resolve complicated Li-graphite interfacial reactions. A cryogenic electron microscopy characterization of Li-graphite interface in presence of ethylene carbonate/ ethyl methyl carbonate electrolyte with lithium hexafluorophosphate (LiPF6) showing the complex atomic scale Li-graphite interfacial processes (top). Characterization of Li diffusion in bulk Li-intercalated graphite and subsequent structural changes in the bulk of such compounds (bottom).

Electroreduction of Metals in Supercritical Fluid, Room-temperature Ionic Liquids

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-055

PRINCIPAL INVESTIGATOR:
Donna Baek, INL

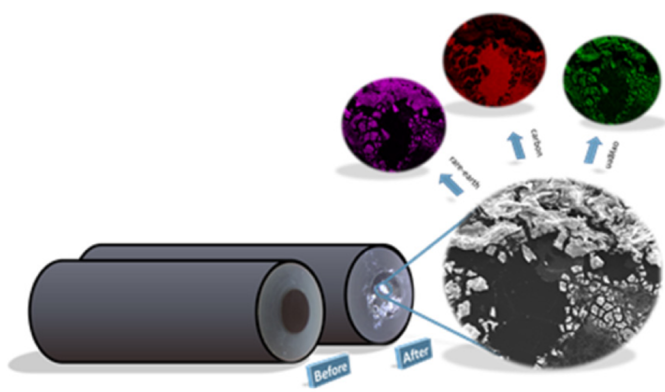
CO-INVESTIGATORS:
Robert Fox, INL
Tedd Lister, INL

COLLABORATORS:
University of Nevada, Las Vegas
University of Kansas
Florida International University
Idaho State University

A market-disruptive metallurgical technology targeted at the electrochemical reduction of metal ions to their metallic state in a room-temperature ionic liquid

Clean energy deployment relies on a secure source of REEs. REEs make up the key components found in high-tech devices, electric vehicles, and devices which convert renewable energy resources to electricity. Lanthanide-metal ions are currently reduced to the metallic state by using a molten-salt electrochemical process at high temperatures. That energy-intensive process gives rise to considerable quantities of toxic fluoride-salt waste. An immediate improvement over the state of the art is to replace the high-temperature molten-salt process with a low-temperature (i.e., less than 100°C) electrochemical process within an inherently waste-minimizing solvent system. This work explored and developed a supercritical-fluid/electrochemical coupled technique to electrochemically reduce lanthanide-metal ions to their metallic state from room-temperature ionic liquids for use in consumer-electronics products. This research resulted in the electrochemical conversion of praseodymium, europium, and holmium ions to metallic state from three different ionic liquids at temperatures <40°C and carbon dioxide pressures <100 psi.

Funding to explore the results of this LDRD was obtained from the Critical Materials Institute.



SEM image of Europium on a glassy carbon electrode.

TALENT PIPELINE:

Four graduate students:

- Brandon Day, University of Idaho (INL intern)
- Jason Mitchell, University of Idaho (INL intern)
- Cassara Higgins, University of Nevada, Las Vegas (INL intern)
- Tugba Turnaoglu, University of Kansas

Two undergraduate students:

- Stephanie Castro Baldivieso, Florida International University (INL intern)
- Luis Alaras, University of Kansas

Two postdoctoral researchers

- Ana Rita
- David Minnick

INTELLECTUAL PROPERTY:

- One non-provisional US patent application: 15/847,757 "An Electrowinning Process for Recovering High Purity Rare Earth Metals from Room Temperature Ionic Liquids"
- One IDR

PUBLICATIONS/PRESENTATIONS:

Morais, A., L. Alaras, D. Baek, R. Fox, M. Shiflett, and A. Scurto. 2019. "Viscosity of 1-Alkyl-1-Methyl-Pyrrolidinium Bis (trifluoromethylsulfonyl)imide Ionic Liquids saturated with Compressed CO2." J. Chem. Eng. Data, DOI: 10.1021/acs.jced.8b01237. (INL/JOU-18-52343)

Turnaoglu, T., D. Minnick, A. Morais, D. Baek, R. Fox, A. Scurto, and M. Shiflett, "High-Pressure Vapor Liquid Equilibria of 1-Alkyl-1-Methylpyrrolidinium bis(trifluoromethylsulfonyl)imide Ionic Liquids and CO2." J. Chem. Eng. Data. DOI: 10.1021/acs.jced.8b01236. (INL/JOU-18-52345)

Rodriguez, R., R. Fox, and D. Baek. 2019. "Investigative Studies toward the Extraction and Recovery of Praseodymium from Ionic Liquids Using Supercritical Carbon Dioxide," Spring 2019 ACS National Meeting, held 31 March–4 April 2019 in Orlando, FL. INL/CON-18-52013

Enabling Material Discovery for Waste Heat Recovery Systems using a Multimode Optical Sensor

PORTFOLIO COMPONENT:
FY 2017 Out of Cycle

PROJECT NUMBER:
17P11-001

PRINCIPAL INVESTIGATOR:
David Hurley, INL

CO-INVESTIGATORS:
Robert Schley, INL
Marat Khafizov, The Ohio State University

COLLABORATORS:
The Ohio State University
University of Maine, Le Mans, France

Methodology to provide new perspectives for optical characterization of ceramic materials

Expediting materials development for integrated energy systems requires new characterization techniques that can rapidly measure multiple properties in different samples having variable composition. This project developed a multimode optical sensor to facilitate the creation of new materials for hybrid energy systems. Specifically, coherent acoustic phonon spectroscopy was combined with diffusive-wave microscopy to simultaneously image grain-boundary structure and function in model ceramic materials used in hybrid energy systems.

This research was central to the successful DOE Energy Frontier Research Centers proposal for the Center for Thermal Energy Transport under Irradiation. Potential applications of this research include solid-state chemists investigating how subsurface grain boundaries mediate ion transport in fuel cell materials, materials scientists monitoring grain-boundary motion under extreme pressures, and condensed matter physicists probing how grain boundaries or domain walls influence carrier transport and recombination.

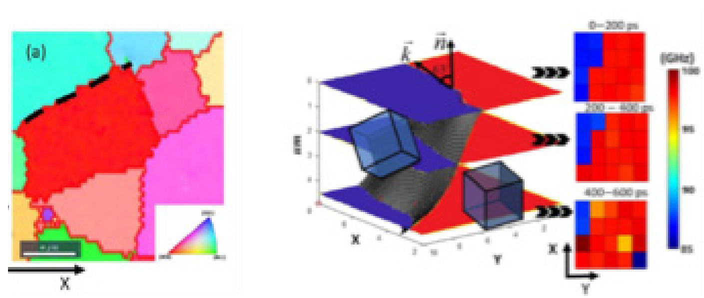
TALENT PIPELINE:
One intern:

- Yuzhou Wang, The Ohio State University

PUBLICATIONS/PRESENTATIONS:

Wang, Y., M. Khafizov, and D. Hurley. 2018. "Characterization of ultralow thermal conductivity in anisotropic pyrolytic carbon coating for thermal management applications," Carbon 129: 476–485.

Wang, Y., D. Hurley, Z. Hua, G. Sha, S. Raetz, V. Gusev, and M. Khafizov. 2019. "Nondestructive characterization of polycrystalline 3D microstructure with time-domain Brillouin scattering," Scripta Materialia 166:34-38.



Left: Electron backscatter diffraction micrograph of the region of interest in polycrystalline ceria. Right: The reconstructed subsurface grain boundary using time-domain Brillouin scattering data.

Production of Ethane to Ethylene Using Carbon Dioxide as a Soft Oxidant

PORTFOLIO COMPONENT:
FY 2018 Strategic R&D Fund

PROJECT NUMBER:
18A12-112

PRINCIPAL INVESTIGATOR:
Daniel M. Ginosar, INL

CO-INVESTIGATORS:
Chinmoy Baroi, formerly INL
Rebecca Fushimi, INL
John Klaehn, INL
Christopher Orme, INL
Frederick F. Stewart, INL

Lower energy selective catalytic reaction step and an efficient membrane separation platform to recover ethylene from unreacted ethane and other process gases

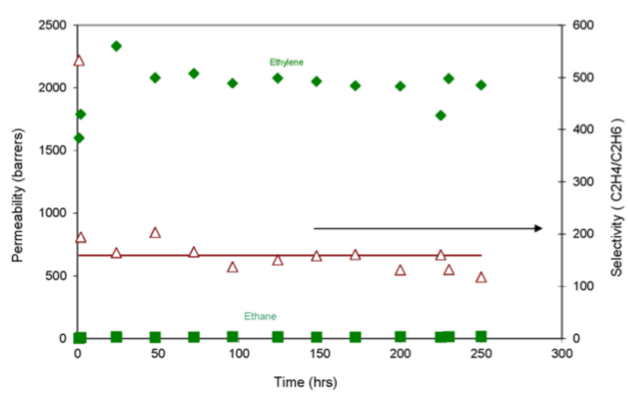
Ethylene production is the largest-volume and most energy-intensive chemical-manufacturing process in the U.S. The two most energy-intensive unit operations are the ethane cracking reaction and ethane/ethylene separations. The cracking reaction is endothermic and requires temperatures above 800°C. Separation of the alkane/alkene mix is complex due to similar physical properties of the gases. This project developed a lower-energy selective catalytic-reaction step and an efficient membrane separation platform to recover ethylene from unreacted ethane and other process gases. Novel catalysts were examined for their activity in carbon dioxide (CO_2)-mediated oxidative dehydrogenation (ODH) at temperatures less than 600°C. The catalysts explored were able to produce ethane conversion greater than 10% with selectivity to ethylene greater than 40% at industrially relevant reaction conditions. Additionally, several polymer membranes were tested for gas permeabilities of ethylene in various gas-feed streams that are found in ODH conditions. The new facilitated transport membranes (FTMs) showed long-term separations above the Robeson line (upper bound), and it has high ethylene throughput (200 gas-permeability units) with excellent ethylene selectivity over ethane ($\alpha = 150$). Preliminary results show that the FTMs are capable of equivalent ethylene separations from a mixture of gases (H_2O, CO_2, CO and ethane) without issues.

The FTM developed in this project is industrially relevant and can be scaled for pilot plant use, which provides a long-term ethylene separation.

TALENT PIPELINE:
One postdoc:
- Chinmoy Baroi

INTELLECTUAL PROPERTY:
Four IDRs

PUBLICATIONS/PRESENTATIONS:
Baroi, C., H. Rollins, and R. Fushimi. 2018. "Magnesium vanadate catalyzed oxidative dehydrogenation of ethane to ethylene using CO_2 as a soft oxidant." 2018 AIChE Annual Meeting, held 28 October–2 November 2018 in Pittsburgh, PA. ISBN: 978-0-8169-1108-0.



Long-term performance of the FTM for ethylene separations.

Treatment of Ammonia Wastewater using Flowing Electrode-capacitive Deionization

PORTFOLIO COMPONENT:
FY 2019 Seed Call

PROJECT NUMBER:
19A41-005

PRINCIPAL INVESTIGATOR:
Tedd Lister, INL

CO-INVESTIGATOR:
Luis Diaz, INL

COLLABORATOR:
Boise State University

Improved capability performance of ammonia removal from wastewater to a lower-volume concentrate stream

The removal of ammonia from process streams is a major issue for many industries including wastewater treatment facilities, steel production, and agricultural runoff. This project addressed the treatment of ammonia-containing wastewaters using flowing electrode-capacitive deionization (FE-CDI). A major technical advantage over conventional capacitive deionization (CDI) is that FE-CDI allows continuous operation and avoids cross-contamination of streams, a common issue in systems which adsorb and strip in static electrode systems. INL researchers targeted stripping ammonia from process wastewaters, commonly produced from sludge digesters, landfill leachate, and industrial wastewaters. The FE-CDI facilitates ammonia removal from wastewater to a lower-volume concentrate stream. The concentrated stream could be used for energy recovery via fuel cell, converted into hydrogen (H_2) gas, or treated appropriately.

This project accomplished a significant breakthrough in application of a material with very high surface area to extend performance beyond the current state-of-the-technology material.

TALENT PIPELINE:

One intern:

- Naqsh Mansoor,
  Boise State University

INTELLECTUAL PROPERTY:

One IDR

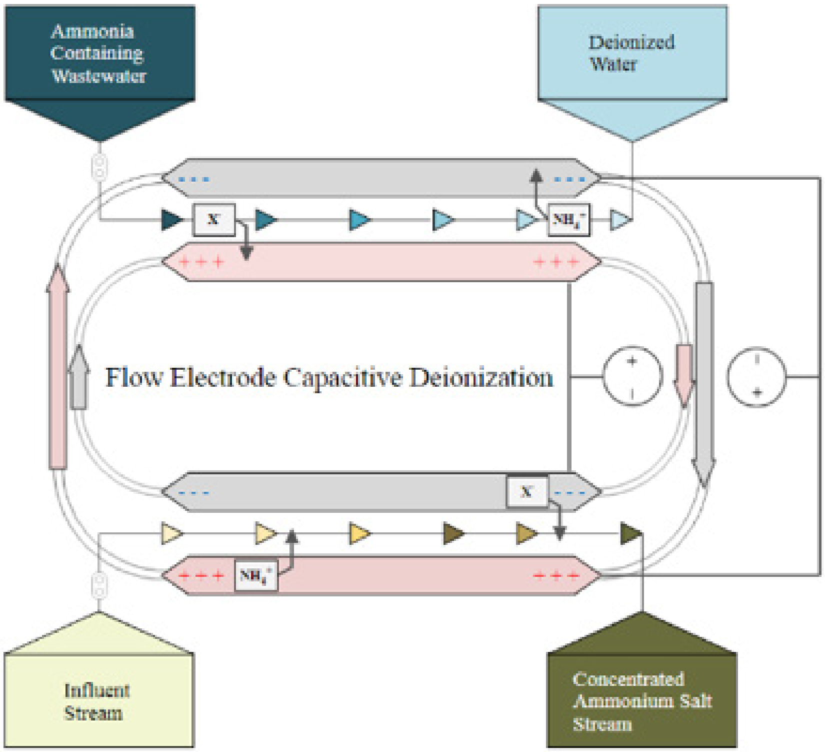
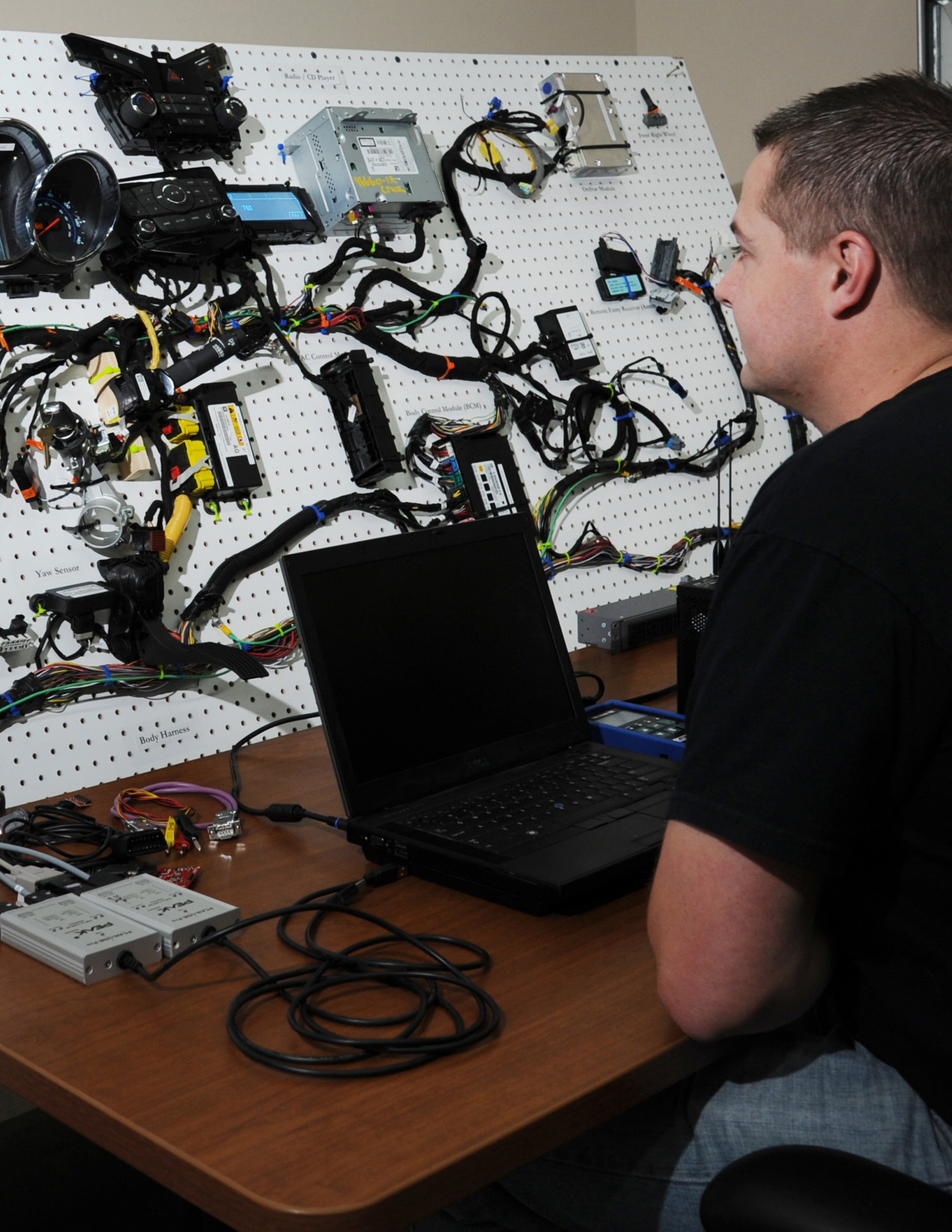


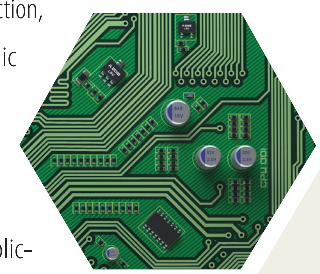
Diagram of FE-CDI system for removing ammonia and potentially other ions from wastewaters. The top cell shows a water feed where ions are collected in the slurry electrodes. The slurry electrodes are pumped to the bottom discharge cell (at reverse polarity) where ions are removed to a concentrate stream.



Radio / CD Player
Front Right Wheel
OnStar Module
Body Control Module (BCM)
Yaw Sensor
Body Harness

SECURE AND RESILIENT CYBER-PHYSICAL SYSTEMS

INL conducts RD&D that enables the deployment of technologies that enhance the security of the U.S. economy, energy supply, and critical infrastructure; provide protective and force-multiplying capabilities for our military and emergency responders; and eliminate the global threats of weapons of mass destruction, terrorism, and cyberattack. Projects aligned to this strategic initiative support national security objectives of the DOE, National Nuclear Security Administration (NNSA), Department of Defense (DoD), Department of Homeland Security (DHS), U.S. intelligence community (IC), and public-safety and emergency-response organizations.



SUCCESS STORY

LDRD projects like “Building Systems: Access, Management & Automation” (17A1-152) and “Forensics of Embedded Devices” (17A1-178) enhance INL’s and DOE’s reputations as leaders in control-system analysis and R&D. These projects advanced capabilities in identifying the cyber-risk prior to intrusion and effectively responding to cyberattacks on the nation’s critical infrastructure and its components.

A Study of Fission Modes to Improve Nuclear Forensics

ADDITIONAL CORE CAPABILITY
Accelerator Science and Technology

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-106

PRINCIPAL INVESTIGATOR:
Mathew Kinlaw, INL

CO-INVESTIGATOR:
Ari Foley, INL

COLLABORATOR:
Johns Hopkins University

New or improved production methods for isotopes of interest to treaty verification, nuclear forensics and safeguards communities, and methods to provide improved nuclear data for isotopes of interest to the nuclear forensics and nonproliferation communities

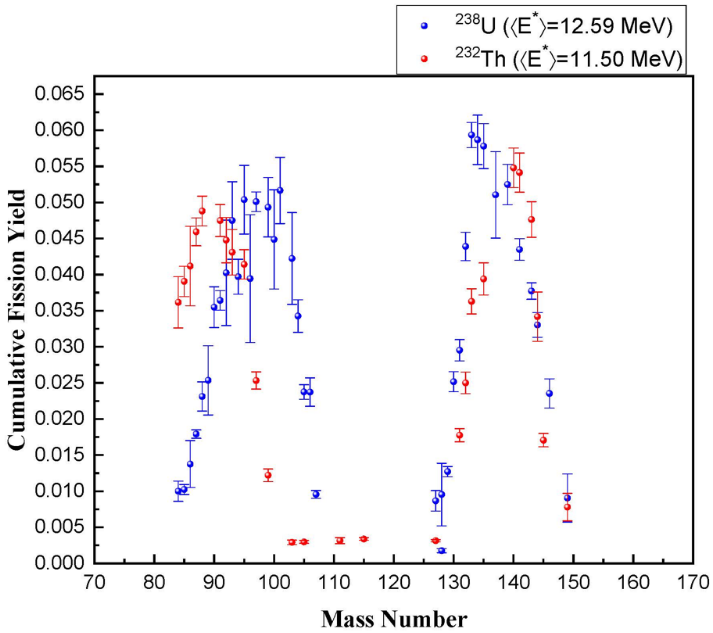
The nuclear forensics community continues to seek timely and cost-effective methods for producing low-fission-yield isotopes, in particular isotopes with masses that fall within the valley of the fission-fragment mass distribution. One method to produce these isotopes that is of great interest to the community is the use of photofission-based isotope production. This research focused on providing an in-depth examination of mass-yield distributions and fission modes that result from photon-induced fission through the examination of the contribution of the various fission modes and their influence on mass distributions and, consequently, their influence on valley isotope production. Natural uranium and thorium targets were irradiated with bremsstrahlung photons (with nominal endpoint energies of 8, 14, and 20 MeV), generated via impingement of high-energy electrons on a tungsten electron-to-photon radiator. Gamma-ray spectroscopy was used to observe and identify the decay of the resulting fission fragments. The photofission yields of up to 91 fission fragments were measured for each of the targets at the three endpoint energies. These fragments included masses ranging from A = 84 to A = 149, with half-lives as short as 1.07 seconds and exceeding 64 days. The compilation of the measured fission-fragment distributions enabled the determination of the relative energy-dependent contributions of the symmetric and asymmetric fission modes.

To the research team's knowledge, the results from this LDRD represent the largest compilation of photofission product yields for uranium-238 and thorium-232 that currently exists.

TALENT PIPELINE:

One Graduate Fellow:

- Ari Foley,
  Oregon State University

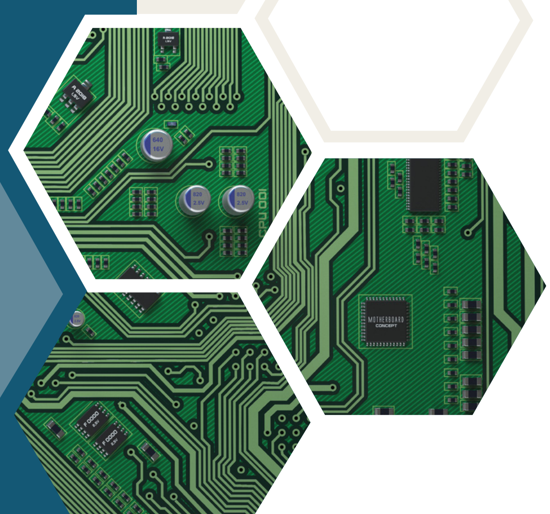


Cumulative photofission yields for select mass numbers from ^{238}U (blue data) and ^{232}Th (red data) with average excitation energies of 12.59 MeV and 11.50 MeV, respectively."

PUBLICATIONS/PRESENTATIONS:

Foley, A., M. Kinlaw, and H. Yang. "Novel Temporal Gamma Spectroscopy Instrumentation and Analytical Method in Determining Photofission Products." Nuclear Materials Science, Processing and Signature Discovery Workshop, held 1–2 May 2018 at Pacific Northwest National Laboratory. https://www.inmm.org/INMM/media/Documents/Events/2018%20Annual%20Meeting/Foley,-Ari-inmmposter.pdf

Foley, A. 2019. "Short-lived Photofission Product Yields and Analytical Methods for Nuclear Forensic Application," Distinguished Master's Thesis of the Year, Oregon State University School of Nuclear Science and Engineering.



Building Systems: Access, Management, and Automation

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-152

PRINCIPAL INVESTIGATOR:
Jonathan Chugg, INL

CO-INVESTIGATOR:
Kenneth Rohde, INL

COLLABORATOR:
Honeywell

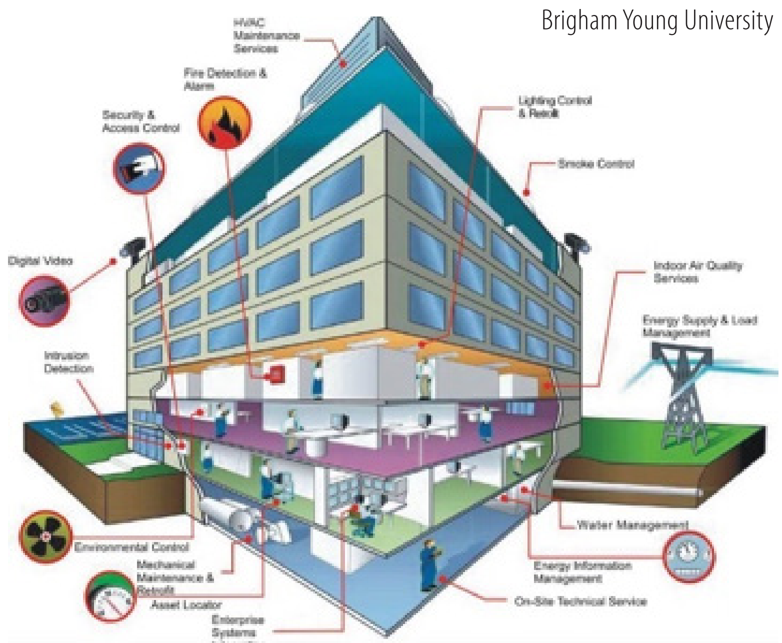
Vulnerabilities analysis and proof-of-concept mitigation code to cyber-harden building management-control systems

Building systems present a huge target for cyberattack due to the heavy integration of building automation into newer smart buildings and large critical data centers that will ultimately be connected to the smart grid. This project investigated the cybersecurity of building management-control systems (i.e., heating, cooling, power, lighting, physical access) for inherent cybersecurity strengths and vulnerabilities as weaknesses viewed from the perspectives of system defenders and adversarial hackers. Integrated building-management, access-control, and energy-management systems, and their respective communication protocols and networks were evaluated. The researchers were able to identify multiple security findings. They conducted experiments with developed proof-of-concept mitigation code and shared the findings with the industry reviewers to explore the potential for future mitigations and cyber-hardened products. This research begins to characterize the future of cyber-research and engineering designs that can enhance the operational security of control systems that manage environmental and access controls of smart buildings that support critical infrastructure.

The results of this research are currently being leveraged to jump-start a new modular research platform for building automation with DHS. Other areas of interest to the research team are national-defense-facility and nuclear-facility protection.

TALENT PIPELINE:
One intern:

- Oliver Reed, Brigham Young University



To properly manage cyber-risk to critical-infrastructure buildings, access-control systems and building-management and automation systems must be evaluated.

Community of Learning for Cyberadversary Activity

PORTFOLIO COMPONENT:
FY 2018 Strategic R&D Fund

PROJECT NUMBER:
18A12-133

PRINCIPAL INVESTIGATOR:
Sarah Freeman, INL

Methodology for collection of publicly available forum information related to the hacking of industrial control systems

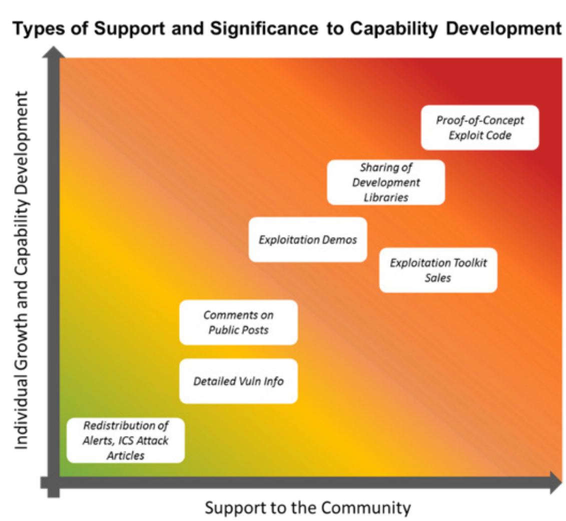
The cyberintelligence field is built on the foundational definition of risk: Risk = threat × vulnerability × impact. Proper assessment of risk then requires that threat-analysis organizations throughout the U.S. government maintain visibility into threat-actors' capabilities and their research objectives. Without this contextual information, it is difficult, if not impossible, to develop the situational awareness that cyberdefenders require for proactive protection of industrial control-system operational technologies and embedded systems and, when authorized, to support an effective federal response to impact an adversary's capability development. This research used real-world, publicly available data to develop a new scale to define industrial control-systems hacking, specifically as related to non-state actor activity. In the future, further development and validation of this this scale, and its corresponding data, will assist user communities across the government to better assess and anticipate a threat actor's capability and timeline for attack-tool development.

This research provides key context regarding the capabilities of non-state actors to conduct attacks against critical infrastructure and industrial control systems (ICSs).

TALENT PIPELINE:
One intern:
- Stephanie Parkins

PUBLICATIONS/PRESENTATIONS:
Freeman, S. 2019. "Challenges of Cyber Attribution." Intelligence Community Forum, held 20 June 2019 in Erie, Pennsylvania.

A notional model of the types of support that are available to cyber-researchers and hackers within Internet-based informal communities.



Forensics of Embedded Devices

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-178

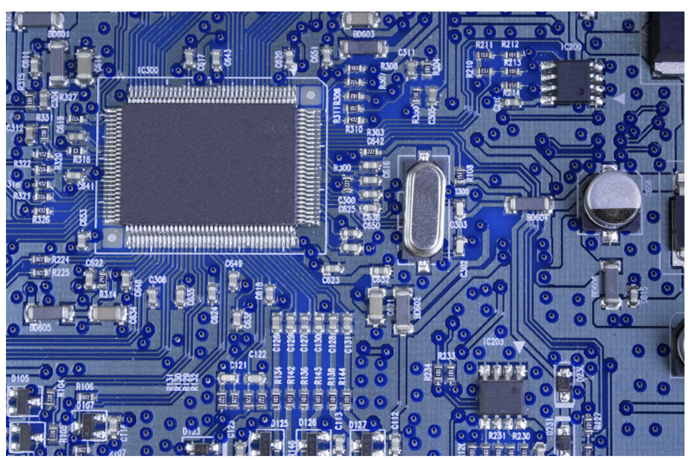
PRINCIPAL INVESTIGATOR:
Ray Fox, INL

Set of cyber-incident forensics capabilities to extract and analyze embedded systems firmware

The advent of the network-connected ICSs brought a world of efficiencies and precision that transformed U.S. critical infrastructure. As part of that transformation, control systems became increasingly vulnerable to attacks that were historically aimed at traditional personal computers (PCs) and internet protocols. Even though cyberincident-response and forensics organizations in regard to cyberattacks on traditional PCs continue to grow, national capabilities to do the same for embedded systems within an ICS environment are woefully behind. This project developed innovative forensic capabilities relevant to embedded systems to enable cyberincident responders to extract firmware and analyze it to mitigate the growing cyberthreat to vital embedded systems within critical infrastructure. The research analyzed higher level host and network-based data and revealed more pieces of the puzzle that may be paramount in defining the breadth of an intrusion.

LogixDumper, a software developed through this project, can retrieve firmware and validate whether it was modified.

TALENT PIPELINE:
Two interns:
- Jordan Jenkins, Brigham Young University-Idaho
- Daniel Nodine, University of South California, San Bernardino



One example of an embedded system is the programmable logic controllers (PLCs) that manage waste-water plants, factory assembly lines, or oil-refinery processes and the network devices that allow the PLCs to communicate.

Industrial Control System Vulnerability Analysis

PORTFOLIO COMPONENT:
FY 2018, Out of Cycle

PROJECT NUMBER:
18P37-036

PRINCIPAL INVESTIGATOR:
Briam Johnson, INL

CO-INVESTIGATOR:
Lyle Roybal, INL

A classified project, this research focused on identifying vulnerabilities in key and sensitive ICS equipment

ICSs are the components that govern and execute complex processes within chemical, critical-manufacturing, energy, nuclear, transportation, defense, waste, and wastewater sectors.

Improved Industrial Control Systems Resilience through Automated Detection and Response

ADDITIONAL CORE CAPABILITY
Computational Science

PORTFOLIO COMPONENT:
FY 2017 Out of Cycle

PROJECT NUMBER:
17P11-005

PRINCIPAL INVESTIGATOR:
Craig Rieger, INL

CO-INVESTIGATORS:
Jonathan Chugg, INL
Todd Vollmer, INL
Timothy McJunkin, INL
Michael McCarty, INL
Edward Springer, INL

COLLABORATORS:
Pacific Northwest National Laboratory
Sandia National Laboratories
Rockwell Automation

Field-control device characterization methodologies for resilient cyberanomaly detection and automated mitigation designs

For all network connected systems, but specifically for ICS cybersecurity where expert cybersecurity resources can be limited, human response times will never be "quick enough." That is, the time for the human to recognize and mitigate a cyberattack will always be a limitation to compromise prevention from a persistent threat. While such responses can be defined for different parts of an ICS architecture, such as the network, HMIs, etc., field-control devices (FCDs) host the critical control logic that directly interacts with the physical systems, such as a power or chemical plant, and are a research priority for INL. Characterization methodologies were developed based on reverse-engineering methods, including packet analysis, debug-port characterizations, pin voltages to collect relevant indicators, and, additionally, characterization of command streams. These allow for modifying control commands, memory mapping, and other characteristics of FCDs. This research resulted in a means to integrate resilient anomaly detection and automated mitigations not currently available in any FCD.

Software tools developed during this project were transitioned to the CyberPARC team for direct use in ongoing projects that include the lab partners.

TALENT PIPELINE:

One graduate fellow:

- Jacob Ulrich, Iowa State University

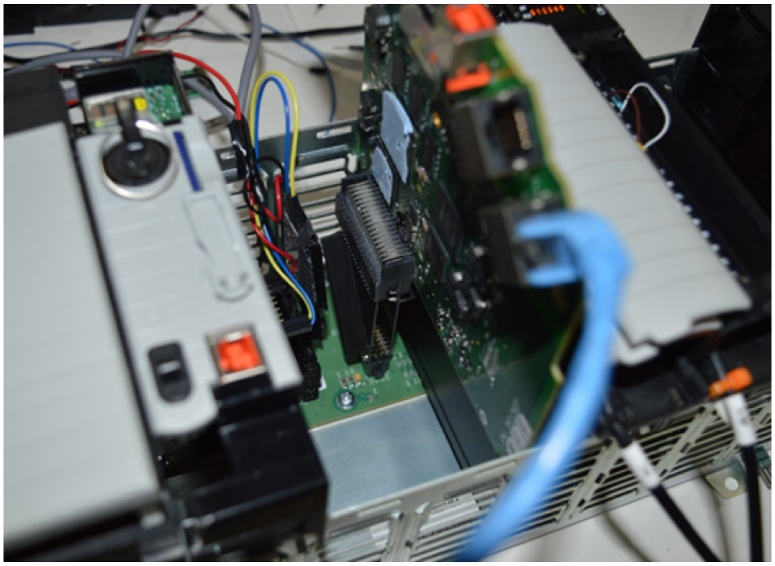
INTELLECTUAL PROPERTY:

- One copyright asserted: "Industrial Control System Diagnostics (ICSD) Web Scraper"
- One SDR

PUBLICATIONS/PRESENTATIONS:

Rieger, C., I. Ray, Q. Zhu, and M. Haney. Chapter on Resilience Metrics and Lead Editor for a book to be published in October 2019 titled, Industrial Control Systems Security and Resiliency: Practice and Theory, eds. Cham, Switzerland: Springer Nature, 2019, ISBN 978 3 030 18214 4.

Vaaggensmith, B., T. McJunkin, K. Vedros, J. Reeves, J. Wayment, L. Boire, C. Rieger, and J. Case. 2018. "An Integrated Approach to Improving Power Grid Reliability: Merging of Probabilistic Risk Assessment with Resilience Metrics," Proceedings of Resilience Week 2018, held 21–23 August 2018 in Denver, CO: 139–146.



The Plug-n-Play Appliance for Resilient Response of Operational Technologies prototype development interface connected to a control system vendor module for analysis. The adapter is designed as an interface to critical control modules that occupy an ICS backplane.

Large-scale Log Analysis for Control-system Networks

ADDITIONAL CORE CAPABILITY
Computational Science

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-206

PRINCIPAL INVESTIGATOR:
Ryan Hruska, INL

CO-INVESTIGATORS:
Jonathan Chugg, INL
Michael Haney, University of Idaho

COLLABORATOR:
University of Idaho

Data model for host and network log storage and analytics

Modern security information and event management systems leverage advances in big-data storage and analytics capabilities to collect, store, and analyze system and network logs in an attempt to detect intrusions and other potential threats. This project advanced the state of the art in log, netflow, and packet analysis of relevant security information and event management systems. Specifically, this project developed an advanced database architecture and analysis methodology for host-log and netflow analyses for historical and incident investigation. This included the integration of a scalable computational database with machine-learning methodologies to enable in-database analytics. The database was designed to enable real-time loading of event data in both raw and aggregate form. This capability has the potential to eliminate the need to perform computational expensive extract, transform, load processes required for in-depth analysis.

This research developed a valid solution to detect low-and-slow attacks, as well as advanced persistent threats, while advancing the state of the art in comprehensive log and netflow analysis for incident response and forensic analysis of control-systems networks.

TALENT PIPELINE:
One doctoral researcher for INL staff:
- Ryan Hruska

Two interns:
- Shawna Gladden, Idaho State University
- Raymond Hardy, University of Idaho

Novel host-log and netflow storage and analysis methodology for detecting network behaviors associated with advanced, persistent threat activities.

Modeling and Spatial-temporal Analysis of Cyber-physical Impacts

ADDITIONAL CORE CAPABILITIES
Applied Mathematics
Computational Science

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-142

PRINCIPAL INVESTIGATOR:
Tim Klett, INL

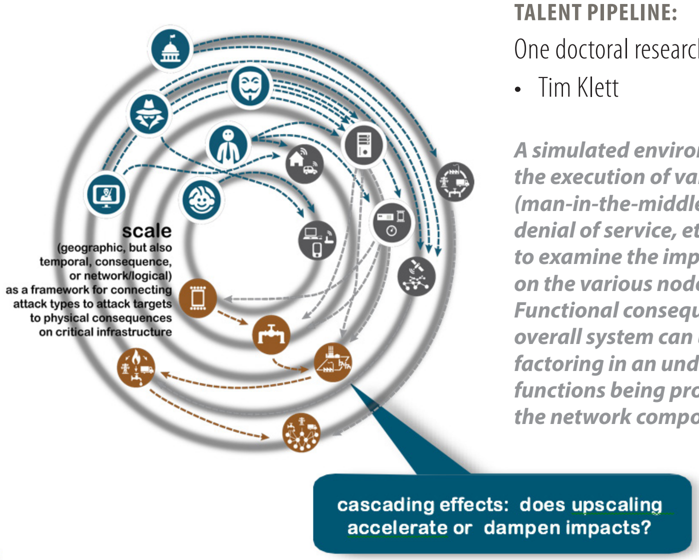
CO-INVESTIGATORS:
Michael Overton, INL
Robert Edsall, INL

COLLABORATORS:
Critical Infrastructure Research Institute
University of Illinois

Simulated environment that emulates various and complex critical-infrastructure network topologies to allow for the execution of various cyberattack types with the ability to examine the impact an attack has on the various nodes of the network

Multiple U.S. government agencies and programs have a common challenge associated with addressing the security posture of these infrastructures when considering cyberthreats. They are charged with identifying the impact on critical-infrastructure sectors from specific vulnerabilities or threats, specific functional processes within these sectors that may be affected, and the cascading impacts (including cross-sector impacts) that may occur associated with a potentially successful exploit. Without the ability to quickly answer these questions, organizations find it increasingly difficult to respond to events in a timely manner or to effectively prioritize their limited resources. This research developed a capability that emulates (models) various and complex network topologies, to include notional representations of control-system networks of a water treatment and water distribution systems. Functional consequence to the overall system can be identified by factoring in an understanding of the functions being provided by each of the network components. Knowledge of the consequence to the operations of an impacted infrastructure is then applied to the regional system within which the infrastructure resides. Through this emulation, impacts can be assessed to the downstream assets relying on the commodity being provided.

DHS National Risk Management Center uses this simulated environment to examine infrastructure sectors and processes in terms of susceptibility to emerging cyber vulnerabilities and threats associated with operational technology, and to understand potential consequences to infrastructure, missions, and critical functions.



TALENT PIPELINE:
One doctoral researcher:
- Tim Klett

A simulated environment allows for the execution of various attack types (man-in-the-middle, distributed denial of service, etc.) with the ability to examine the impact the attack has on the various nodes of the network. Functional consequence to the overall system can be identified by factoring in an understanding of the functions being provided by each of the network components.

PUBLICATIONS/PRESENTATIONS:

Edsall, R. "Constructing Data Sets for Dependency Analysis of Critical Infrastructure: Bridging Knowledge Gaps through Spatial and Semi-Automated Analysis" at the American Association of Geographers (AAG) Annual Meeting in Boston, MA.

Klett, T. 2019. "Modeling and Spatial-Temporal Analysis of Cyber-Physical Impacts," 87th Military Operations Research Society (MORS) Symposium, held 17–20 2019 in U.S. Air Force Academy, CO (INL/CON-19-54218).

Nuclear Instrumentation and Methods for Emergency Response

ADDITIONAL CORE CAPABILITIES
Applied Mathematics
Computational Science

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-101

PRINCIPAL INVESTIGATOR:
David Chichester, INL

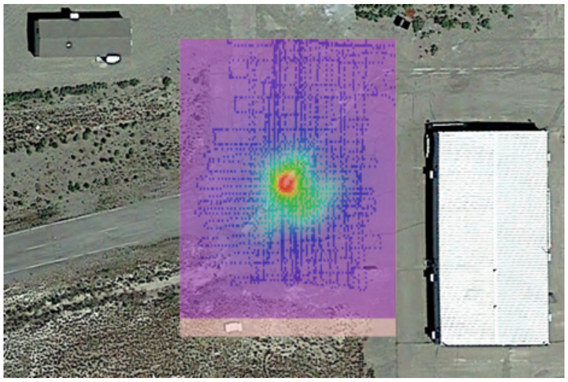
CO-INVESTIGATORS:
Jay Hix, INL
Scott Thompson, INL
Nick Mann, INL
James Johnson, INL
Scott Watson, INL

COLLABORATORS:
University of Michigan
University of Illinois

New instruments and methods for emergency-response management, nuclear safeguards, nuclear nonproliferation, nuclear counterproliferation, and nuclear forensics

This project addressed gaps in nuclear instrumentation available to nuclear-emergency responders related to their ability to detect, locate, and characterize radiological and nuclear materials. New equipment was developed and tested for mapping distributed radiation fields via air and ground surveys and for assessing neutron energy spectra during search operations. Specifically, this project developed (1) practical instrumentation for operations personnel for the search and characterization of radiological and nuclear materials and (2) instruments and methods for characterizing post-blast radiological-dispersal-device environments for contamination mapping, and source-term reconstruction. A mobile, multi-energy neutron-sensor system was developed to detect, locate, and identify bare, reflected, and moderated fission-spectrum neutron sources in the environment. Additionally, unmanned ground-system and unmanned aerial-system platforms were developed that incorporate real-time, kinematic global-positing system (GPS) tracking capabilities, radio-tethered telemetry modules, radiation sensors, and chemical sensors.

This project contributed to the doctoral dissertation research for Dr. Charles Sosa. Dr. Sosa's research focused on optimizing scintillation radiation detectors through scintillator geometry and surface treatment.



An unmanned ground system with high-resolution GPS, telemetry, and on-board radiation detection capabilities is shown in the photograph (top); a heat-map generated by this system while performing a radiation survey around a heavily-shielded radioactive source at an INL test area (bottom).

TALENT PIPELINE:

Two interns:

- Stuti Surani, University of Illinois
- Charles Sosa, University of Michigan

PUBLICATIONS/PRESENTATIONS:

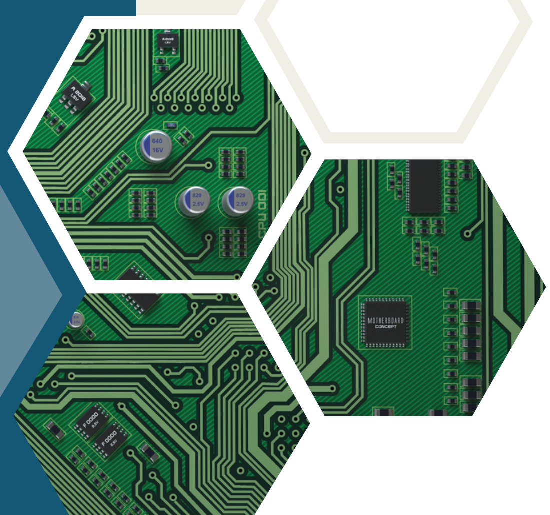
Sosa, C., S. Thompson, D. Chichester, P. Schuster, S. Clarke, and S. Pozzi. 2019. "Improved Neutron-Gamma Discrimination at Low-Light Output Events Using Conical Trans-Stilbene." Nucl. Inst. Meth. Phys. Res. A 916: 42-46.

Sosa, C., S. Thompson, D. Chichester, S. Clarke, A. Di Fulvio, and S. Pozzi. 2018. "The Energy Resolution Experiments of Conical Organic Scintillators and a Comparison with Geant4 Simulations." Nucl. Inst. Meth. Phys. Res. A 898: 77-84.

Chichester, D., J. Johnson, S. Watson, J. Hix, and S. Thompson. 2018. "Observation of Natural Background Radiation Changes during the Great American Eclipse," App. Rad. Iso. 142: 151-159.

Sosa, C., D. Chichester, S. Thompson, S. Clarke, and S. Pozzi. 2017. "Improvements in Energy Resolution using a Stilbene Crystal in Conical Geometry," Proceedings of the IEEE Nuclear Science Symposium Conference, held 21–28 October 2017 in Atlanta, GA.

Chichester, D., et al. 2016. "Post-Blast Radiological Dispersal Device Source Term Estimation," Proc. IEEE Nucl. Sci. Symp., held 29 October–5 November 2016 in Strasbourg, France (INL-CON-16-38673).



Resilient, Scalable Cyberstate Awareness of Industrial Control Systems to Threat

ADDITIONAL CORE CAPABILITY
Applied Mathematics

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-114

PRINCIPAL INVESTIGATOR:
Craig Rieger, INL

CO-INVESTIGATORS:
Tim McJunkin, INL
Brian Johnson, University of Idaho
Milos Manic,
Virginia Commonwealth University

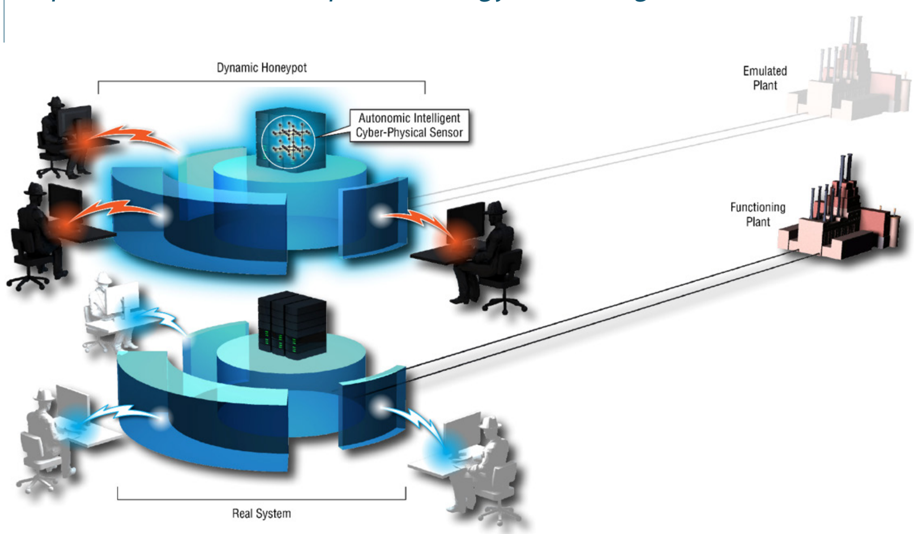
COLLABORATORS:
Virginia Commonwealth University
University of Idaho

The application of cyber- and physical-data sets provides both fidelity and context to address ongoing challenges with intrusion-detection systems. The fidelity provides a richer data set, which in the aggregate, provides more-sensitive indications of malicious versus benign action. The context is provided through an association of cyberalerts with the physical system affected, allowing for operators to then correlate consequences and respond appropriately.

A scalable, diverse technology to determining and benchmarking ICS behaviors as a methodology for implementing a tiered approach to identifying malicious anomalies

Supervisory control and data-acquisition (SCADA) and distributed control systems are two ICS architectures widely used for industrial process control in the power sector, the former for grid implementation, and the latter for generation. Initially designed to work separately with connectivity to external networks, ICS systems are being integrated with information technologies and communication networks to improve efficiency and reliability of the power system. An unintended consequence of this integration is the creation of more opportunities for cybersecurity incidents and risks associated with the electric-power grid and SCADA systems. This project developed methodologies to characterize diverse performance behaviors on ICS networks and use these to apply directly scalable methodologies to achieve a measured level of resilience. Based upon cyber and physical characterizations of both host and network patterns, novel proofs of concept were developed that can exclusively recognize a cyberattack and distinguish it from benign, unintended actions or physical failure. The final operationally tested real-world prototype was provided in a matured, intelligent anomaly-detection platform designed for advancing monitoring of ICS networks. This anomaly-detection system prototype consists of cyber- and physical-detection components. The cybercomponent detects abnormal communication which happens in cybercommunication whereas physical component identifies possible abnormalities in physical data communication.

This research provides solutions for legacy ICSs and physical context for cyberanomalies, in addition to characterizing whether recognized alerts or alarms are malicious or benign. This LDRD project led to direct funding from the DOE Office of Solar Energy Technologies.



TALENT PIPELINE:

Seven interns:

- Kasun Amarasinghe, Virginia Commonwealth University
- Hari Challa, University of Idaho
- Ananth Jillepalli, University of Idaho
- Daniel Marino, Virginia Commonwealth University
- Ibukun Oyewumi, University of Idaho
- Philip Richardson, University of Idaho
- Chathurika Wickramasinghe, Virginia Commonwealth University

INTELLECTUAL PROPERTY:

- One nonprovisional U.S. patent application: 16/204,983, "ICS Resilient Security Technology (IReST)"
- One IDR

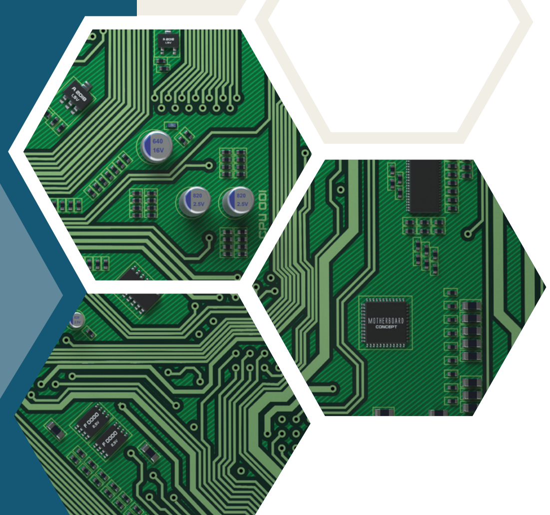
PUBLICATIONS/PRESENTATIONS:

Marino, D. "Cyber-Physical Disturbance Detection using Machine Learning: Design and Experiments in a Smart-Grid Testbed." Resilience Week 2019 Symposium, held 4–7 November 2019 held in San Antonio, TX.

Damiano, A., C. Rieger, V. Vyatkin, and M. Manic. 2019. "Guest Editorial: Resilience in Energy Industries—Recent Advances, Open Challenges, and Future Directions." IEEE Transactions on Industrial Informatics 15 (7): 4315–4318. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8755903.

Marino, D., C. Wickramasinghe, C. Rieger, and M. Manic. "Data-driven Stochastic Anomaly Detection on Smart-Grid communications using Mixture Poisson Distributions." Industrial Electronics Conference, held October 14-17 2019 in Lisbon, Portugal.

Amarasinghe, K., C. Wickramasinghe, D. Marino, C. Rieger, M. Manic. 2018. "Framework for Data Driven Health Monitoring of Cyber-Physical Systems." Proceedings of Resilience Week 2018, held 21–23 August 2018 in Denver, CO: 139–146. https://ieeexplore.ieee.org/xpl/conhome/8458247/proceeding.



Scalable Binary Analysis

ADDITIONAL CORE CAPABILITIES
Applied Mathematics
Computational Science

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-109

PRINCIPAL INVESTIGATOR:
Jared Verba, INL

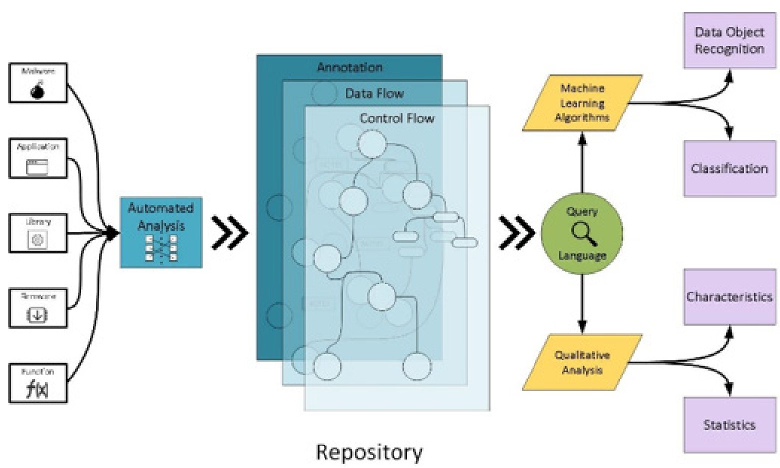
CO-INVESTIGATORS:
Gordon Rueff, INL
Jed Haile, INL
May Chaffin, INL

Reverse-engineering platform that allows storage and recall of binary analysis data for future machine-learning efforts in binary analysis

Much of cybersecurity research relies on reverse engineering of software, hardware, and firmware for custom platforms within ICSs. Current binary reverse-engineering tools require a human in the loop to find vulnerabilities, a very time-consuming, tedious process that is more an art than a science. For any given vulnerability that a researcher might find, dozens may still lie dormant in the application. Furthermore, apparent vulnerabilities may be constrained by code that removes it from a vulnerable path, resulting in hours or days of time to eliminate false positives. This project transformed an application or firmware images into a more natural, searchable storage structure that enables a single computer or supercomputing cluster to process the information in parallel. This platform uses a graph database to combine and store analysis from multiple tools and allows practitioners of reverse engineering to gain better insight into the behavior of an application or firmware.

This project directly supports the utilization of artificial intelligence in multiple facets, and results are being leveraged for DOE projects to generate datasets for machine-learning tasks.

TALENT PIPELINE:
One intern:
- Sean Salinas (transitioned to graduate fellow)



Scalable binary analysis provides a means of transforming different binary formats into a common data-storage platform to enable automation of reverse-engineering tasks.

V2X Communications Security

PORTFOLIO COMPONENT:
FY 2017 Strategic R&D Fund

PROJECT NUMBER:
17A1-183

PRINCIPAL INVESTIGATOR:
Samuel Ramirez, INL

CO-INVESTIGATORS:
Kurt Derr, INL
Edward Springer, INL
Jonathan Chugg, INL
Kenneth Rohde, INL

COLLABORATORS:
Utah Department of Transportation
Department of Homeland Security

WAVE Technologies:
University of Utah
Louisiana University

AWARD WINNER

INL Poster Competition top poster for Secure and Resilient Cyber-Physical Systems initiative

If vehicle communication intrusions or disruptions can be reduced or eliminated, then vehicles connected to the power grid, such as electric vehicles, will remain cybersecure, thereby reducing risks to the electric grid and vehicle accidents and, ultimately, saving lives.

Cybersecurity analysis of vehicle-to-vehicle, -infrastructure, and -person communications

Tens of thousands of deaths on the road, create a need for increased vehicle communications for safer driving capabilities. With more ways to communicate—cellular, satellite, WiFi, and others—more ways are found to inform the driver of potential hazards on the road. However, another potential hazard is introduced in the cybersecurity of the communications. This project explored vehicle-to-vehicle (V2X), infrastructure, and personal communications disruptions that might take over or compromise communication in a single vehicle or the communications infrastructure. Leveraging prior vehicle research in controller area network and V2X implementations completed at INL and at other research institutions, the project studied the possible mitigations and countermeasures to vulnerabilities and the interoperability of V2X communications among different manufacturers. Through this intensive study, researchers found potential weaknesses, such as security-certificate processing that must occur for digital signatures and encryption and the potential of a denial of service if a network is flooded with basic safety messages.

This research will ultimately benefit all entities that use vehicle communications and will help to reduce the risk of cybersecurity breaches within vehicle infrastructure as they become more connected to each other and the internet.

TALENT PIPELINE:
Five interns:
- Christopher Becker, University of Utah
- Aniqua Basett, University of Utah
- Jordan Mussmann, Florida State University
- Rizwan Merchant, Louisiana University
- Armando Juarez, New Mexico Institute of Mining and Technology

2019 LDRD POSTER SESSION

LDRD principal investigators and co-investigators of the projects ending in fiscal year 2019 shared their work with INL leadership and staff at the annual LDRD poster session on August 29, 2019, at the Center for Advanced Energy Studies. A total of 45 posters were presented. Posters were judged by a cross-cutting group of researchers and managers. Four top posters were selected and are:

Nuclear Reactor Sustainment and Expanded Deployment & Integrated Fuel Cycle Solutions

Design of Low-activation Retrievable Sample Holder for Transient Test Reactor Irradiation of Science-based Specimens

PRINCIPAL INVESTIGATOR:
Nicholas Woolstenhulme

Advanced Materials and Manufacturing for Extreme Environments

Sublime Temperature Sensor

PRINCIPAL INVESTIGATOR:
Richard Skifton

Integrated Energy Systems

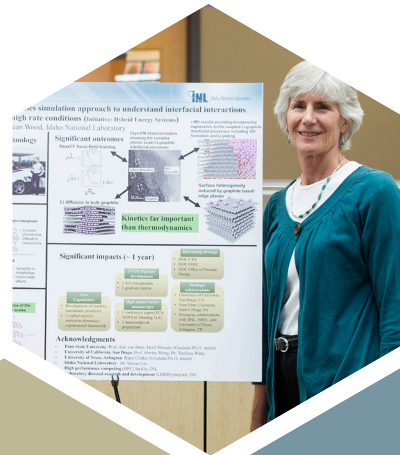
A Reactive Molecular-dynamics Simulation Approach to Understand Interfacial Interactions of Lithium and Graphite under Extreme High-rate Conditions

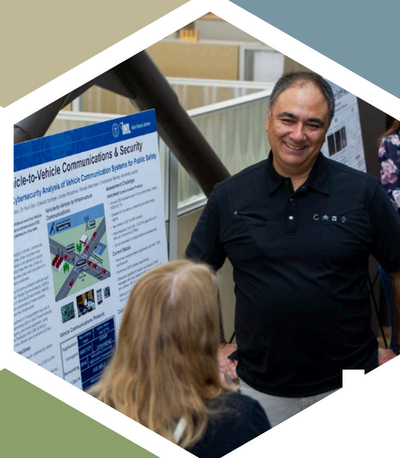
PRINCIPAL INVESTIGATOR:
Gorakh Pawar

Secure and Resilient Cyber-Physical Systems

V2X Communications

PRINCIPAL INVESTIGATOR:
Samuel Ramirez


Significant outcomes
Kinetics far important than thermodynamics
Significant impacts (~ 1 year)
Acknowledgments


Cybersecurity Analysis of Vehicle Communication Systems for Public Safety

Idaho National Laboratory

19-50528