Idaho National Laboratory Research & Development

Impacts

ON THE COVER

A fuel graphite matrix for the Transient Reactor Test Facility

Idaho National Laboratory

FROM THE Director

This edition of R&D Impacts details how impactful and productive the year 2017 was at Idaho National Laboratory.

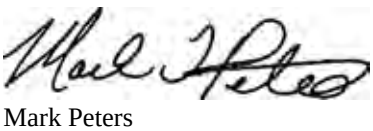
INL made news for all the right reasons. Consider the stories you will read about in this issue:

- INL became the first national laboratory to be visited by Energy Secretary Rick Perry. Secretary Perry spent two days on our 890-square-mile desert Site and in our in-town facilities. He left Idaho with an appreciation for the clean energy and national security work our 4,200 employees conduct daily in fulfillment of INL's mission and vision.
- Every commercial reactor in the country can trace its roots to our research and development.
- Add to that INL's world-class expertise and designation as the nation's lead nuclear R&D laboratory, and you understand why our desert Site was selected to host NuScale Power's first-of-its-kind small modular reactor. INL honored 50 years of valuable work and safe operation at the Advanced Test Reactor. Americans can expect ATR to continue serving the U.S. Navy, commercial nuclear energy industry, and our colleges and universities for decades to come.
- A bipartisan coalition of Idaho state lawmakers approved Senate Concurrent Resolution 105. This legislation allows the state to bond for and construct two new buildings on INL's Idaho Falls campus. These facilities will increase the laboratory's cybersecurity and super-computing capabilities, and enhance our valued partnerships with Idaho's colleges and universities.
- INL's Transient Reactor Test (TREAT) facility was restored to operational status for the first time since 1994. Restarting one of the world's most highly capable and flexible transient test reactors keeps our nation in a leading role to develop advanced nuclear fuels and reactor technologies. Restoration of this unique asset was completed 12 months ahead of schedule and $20 million under budget.

This edition of Impacts magazine also burrows below the surface, and highlights important clean energy and national security work you might not have seen on the front page including:

- Hybrid energy systems testing to stabilize the power grid and increase energy storage capabilities.
- Remote casting of metal nuclear fuels at INL's Materials and Fuels Complex.
- Completion of the 100th Industrial Control Systems Cyber Emergency Response Team cybersecurity training course, where participants learn defensive and mitigation strategies for control system networks.
- Development of a new metric called "self-discharged current," which can detect internal shorts in lithium-ion batteries before they reach a stage that can lead to catastrophic failure.
- Advances in the establishment of electric vehicle corridors in the western United States.

These are but a few of the topics you will find in this year's R&D Impacts. Just know, as you read about the work conducted by our talented and dedicated staff, it is borne of a shared desire to serve the American taxpayer and leave future generations a world that is safer, more secure, clean, and prosperous.



Mark Peters
Director, Idaho National Laboratory

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A sample prepared at the Center for Advanced Energy Studies' Advanced Materials Laboratory. It shows a fuel graphite matrix for the Transient Reactor Test facility, which resumed operation in November 2017. Read more on page 4.

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INTRODUCTION AND Overview

Fiscal year 2017 was a year of milestones for Idaho National Laboratory: Recognition at an international level, a visit from a newly sworn in energy secretary, historic honors on the 50th anniversary of the Advanced Test Reactor, and a total eclipse of the sun.

At the 2016 American Nuclear Society (ANS) winter meeting, the ATR Complex was named an ANS Nuclear Historic Landmark. The designation recognizes the many contributions the facility has made to nuclear research. ATR, along with its predecessors, the Materials Testing Reactor and Engineering Test Reactor (now both decommissioned), has produced much of the world's data on the behavior of materials and fuels in nuclear power reactors. This information has contributed significantly to the safety of commercial nuclear power plants worldwide as well as the outstanding performance of the U.S. Navy's nuclear fleet.

In May, ANS President Dr. Andy Klein visited the ATR Complex to dedicate a plaque commemorating the Nuclear Historic Landmark designation. ATR first went live on July 2, 1967, and INL celebrated the birthday by bringing 30 retired employees back for a plant tour and lunch. The next day, nearly 100 visitors came, representing the U.S. Department of Energy, U.S. Navy, Idaho's congressional delegation, state and local elected officials, and Idaho education and business leaders. Special guests included the children of Deslonde de Boisblanc, the original designer of ATR's unique cloverleaf core, and Frank Fogarty, former captain of the USS Nautilus (the first nuclear-powered submarine) and twice director of ATR programs.

"This is a tremendous honor recognizing the critical work being conducted at DOE's Oak Ridge and Idaho national laboratories, and it highlights the importance of our nuclear research facilities and the scientific and nuclear security contributions they bring to the world."

—Energy Secretary Rick Perry on the ICERR designation for ORNL and INL

The Great American Solar Eclipse on Aug. 21, 2017, attracted hundreds of thousands of people to the region. INL felt the event most acutely at Experimental Breeder Reactor-I, which recorded 3,600 visitors from five continents, 25 countries and 46 states. World-famous astrophysicist Neil deGrasse Tyson even dropped in.

At the international level, the International Atomic Energy Agency (IAEA) recognized INL as an International Centre based on Research Reactors (ICERR). This put the United States in the company of France and Russia as one of only three countries possessing unique capabilities and excellence in nuclear research. INL's facilities were recognized for their support of scientific discovery, medical and industrial isotope applications, and the advancement of nuclear fission, fusion energy, and global security technologies.

In May, INL was the first national lab to be visited by Energy Secretary Rick Perry, who spent two days touring facilities at the INL desert Site and the Research and Education Campus. Perry said DOE is committed to revitalizing the nation's nuclear infrastructure and that INL has a big role to play, especially with regard to keeping nuclear plants safe and up to date. Perry also gave a nod to the lab's growing focus on cybersecurity and supercomputing, stressing the need for the United States to lead the world in those areas.

"I cannot tell you how honored I am to be associated with men and women who do what you do, who truly have the potential to change the world on any given day," Perry said, speaking to INL employees gathered at the Energy Innovation Laboratory.

The pages that follow highlight some of the important work INL completed this past year. We describe projects on which the lab is providing national or regional leadership and embarking on notable collaborations. We spotlight new research capabilities and technological innovations. Recognizing that people are our most important asset, we recognize a small handful of our experts and show efforts to feed the talent pipeline.

All national laboratories have defined areas of expertise and areas in which they excel. INL has 13 of these core capabilities, and two other emerging capabilities. Throughout this publication, these icons highlight INL core capabilities that underlie the projects described.

- Advanced computer science, visualization, and data
- Applied materials science and engineering
- Biological and bioprocess engineering
- Chemical and molecular science
- Chemical engineering
- Condensed matter physics and materials science
- Cyber and information sciences
- Decision sciences
- Environmental subsurface science and analysis
- Large-scale user facilities and advanced instrumentation
- Mechanical design and engineering
- Nuclear and radiochemistry
- Nuclear engineering
- Power systems and electrical engineering
- Systems engineering and integration

NATIONAL Leadership

INL is a multiprogram national lab that supports deployment of new energy solutions and critical infrastructure protection. The lab's unique capabilities position us to lead several national research, demonstration and assessment efforts that help protect the nation's resources and security.

On Nov. 15, 2017, DOE announced the resumption of operations at INL's Transient Reactor Test (TREAT) Facility.

Restoring a national nuclear research asset

INL achieved a significant milestone by completing all readiness activities to restart the Transient Reactor Test (TREAT) facility. TREAT's testing capability gives researchers the ability to test nuclear fuel systems within sealed capsules and prototypical test loops under a wide range of dynamic conditions, including extreme accident scenarios that can melt fuel. Transient testing is a vital component of determining the safety envelope of new nuclear fuel systems.

INL's Resumption of Transient Testing Program completed its work 12 months ahead of its baseline schedule and nearly $20 million under the baseline budget of $75 million. The accelerated restart activities place the U.S. at the forefront of nuclear fuel safety research by restoring a national capability for understanding the response of nuclear fuel materials and designs to the conditions experienced during unexpected events.

Integrating cybersecurity assets
The Cybercore Integration Center is an INL strategic initiative focused on scalable and sustainable control system cybersecurity solutions that protect the U.S. grid, other critical infrastructure and military systems. The center will create and align national science and engineering resources, technical expertise, and collaborative partnerships to emphasize a holistic R&D strategy for control system cybersecurity innovation. Its solutions aim to protect energy infrastructure through deploying advanced technologies, implementing enhanced engineering and operational processes, and developing a highly skilled workforce.

Grid stability through global power sharing
INL led a team of researchers from around the world to demonstrate an eight-lab grid simulator system. The Global Real-Time Super Lab allows researchers to study how electricity can be rerouted across vast distances to address disruptions. The ability to move electricity around the globe, rather than only within isolated regional networks, could lead to vast savings on infrastructure and energy consumption. The effort builds on work done between INL and the National Renewable Energy Laboratory and included researchers from Sandia National Laboratories and five universities (two of which are from Europe).

Idaho has "...a long standing leadership role to establish cybersecurity best practices and innovative technologies for government and industry partners..."

—Congressman Raul Labrador remarks for the March 17, 2017, Congressional Record

Dozens of people visited INL in September for a demonstration of the Global Real-Time Super Lab research tool.

NATIONAL Leadership

Supporting advanced reactor development

INL leads the U.S. Department of Energy's Gateway for Accelerated Innovation in Nuclear (GAIN) initiative. Its mission is to provide access to technical, regulatory and financial support that the nuclear energy industry needs in order to quickly and cost-effectively move innovative nuclear energy technologies toward commercialization. During FY 2017, GAIN convened important discussions on the structure of federal regulations, research and financial assistance programs related to advanced nuclear energy systems. In June, a second round of the GAIN Vouchers Program awarded $4.2 million to 14 applicants, more than double the FY 2016 award funding. The vouchers provide access to the extensive nuclear research capabilities and expertise available across the U.S. DOE national laboratory complex.

Meeting national bioenergy cost goal

INL's bioenergy researchers met a major milestone by reducing the modeled cost of harvesting, storing, transporting and preprocessing biomass to $82.86 per dry ton (down from a 2013 estimate of $149.58 per dry ton). The modeled cost beats a DOE performance goal of $84.45 per dry ton from harvest to the biorefinery reactor throat, including the grower payment. The success resulted from the combined efforts of multiple INL projects. One project implemented efficiencies to reduce the cost of biomass grinding and pelleting operations; another used adaptive controls to improve processing plant throughput; a third considered biomass characteristics to optimize blends and least-cost formulations.

INL engineers helped improve biomass processing efficiency to meet a DOE cost goal.

Integrating nuclear security with cybersecurity

INL led the development and implementation of initiatives intended to strengthen cybersecurity expertise for nuclear energy. The effort involves training, threat analysis and program planning for leaders and personnel at the National Nuclear Security Administration (NNSA) Office of Defense Nuclear Nonproliferation (DNN). INL serves as the lead laboratory for the DNN's nuclear-cybersecurity program plan to integrate cybersecurity with nuclear security among the international nuclear energy community. DOE and INL are committed to the global implementation of INL's transformative concepts for cybersecurity as they apply to the nuclear security and industrial control systems.

INL works with the international nuclear community to assess cyber and physical security risks and to develop mitigation strategies suitable for a nuclear operations environment.

Testing at INL provided information that SAE International (formerly the Society for Automotive Engineers) needed to approve an international standard for electric vehicle wireless chargers. SAE leads efforts to establish common standards for the technology.

NOTABLE Collaborations

National labs exist to conduct research and development that is beyond the scope and capabilities of industry or academia. Close partnerships with these entities provide access to public research capabilities and national laboratory expertise. Such collaborations also help INL advance nationally relevant energy research.

Recreating reactor test station role

Small modular reactors (SMRs) will provide a bridge to future advanced nuclear reactors. INL's work to support SMR development is recreating the lab's historic role as a nuclear reactor test station. Utah Associated Municipal Power Systems (UAMPS), NuScale and DOE have created a private-public partnership to deploy NuScale's commercial small modular reactor power plant at the INL Site. INL has technically supported NuScale in numerous ways including developing a proprietary version of its Reactor Excursion and Leak Analysis Program (RELAP-5-3D) to perform safety calculations for the Nuclear Regulatory Commission design certification application.

More importantly, the industry initiative and DOE support allowed INL to provide critical technology and site characterization expertise to enable reactor siting. This capability established INL as a site being considered for more than 18 nuclear reactor projects that include additional

The NuScale SMR is an advanced light-water reactor containing up to 12 modules, each of which is a self-contained unit that operates independently.

SMR reactors, fast reactors, high-temperature gas-cooled reactors, test reactors, a U.S. Department of Defense reactor, molten salt reactors, micro reactors and fusion projects.

Assessing advanced reactor fuel performance

A Cooperative Research and Development Agreement (CRADA) with Pebble Bed Modular Reactor Ltd. of South Africa enables INL to conduct post-irradiation examination and safety testing of PBMR nuclear fuel. Four compacts containing Tristructural Isotropic (TRISO) coated particle fuel were irradiated in INL's Advanced Test Reactor. The testing and examination will help assess fuel performance during high-temperature reactor accident conditions.

Fortifying reliability with microgrids

A northern California Native American reservation launched a community microgrid built in collaboration with INL. The Blue Lake Rancheria microgrid provides resilience to the power supply in the area, which is also a designated Red Cross evacuation route. Pacific Gas & Electric, an industry partner in the project, nominated it for a "Projects of the Year Award," an honor sponsored by the publications Power Engineering and Renewable Energy World. The projects are selected based on technological innovation, local impact, logistical challenges and creativity, and capacity.

Testing for a California microgrid was conducted at INL's Power and Energy Real-Time Laboratory.

"One of the lessons learned in this project is the absolutely essential role of testing at INL."

— Jana Ganion, Blue Lake Rancheria Sustainability Director

NOTABLE Collaborations

DHS Science & Technology explored jamming vulnerabilities in communications systems during the Jam X 17 exercise at INL. *Image courtesy of the U.S. Department of Homeland Security*

Providing critical data to first responders
INL played a critical role in advancing the scientific data gathering for an important U.S. Department of Homeland Security exercise. Jam X 17 provided an opportunity to assess the impacts of intentional radio frequency interference on first responder equipment used for communications, navigation and timing. Hundreds of participants from first response organizations across the country gathered on INL's unique test ranges to collect critical data for the DHS, Department of Defense, Department of Justice, Federal Communications Commission, Federal Aviation Administration, and state and local first responder agencies.

Automating grid threat response
INL is collaborating with California Energy Systems for the 21st Century (CES-21), a research partnership that includes Lawrence Livermore National Laboratory, New Context Services, Inc., and California utilities. INL is working with CES-21 to develop an innovative concept for machine-to-machine automated threat response. The research aims to provide utilities with access to automated threat and exploit prioritization capabilities. These tools will reduce the time for discovery and recovery from illicit behavior, ultimately resulting in increased resiliency of the electric grid in California and beyond.

Training for a radiological response
INL served as the lead exercise planner for a joint U.S.-Canada post-detonation nuclear event emergency response exercise in Nova Scotia. The simulated nuclear detonation supported the National Nuclear Security Administration (NNSA) Office of Counterterrorism and Counterproliferation. The exercise enabled nuclear forensics experts from the U.S. and Canada to respond during a radiological event.

Modernizing nuclear control rooms
INL is helping modernize a control room at Arizona's Palo Verde Nuclear Generating Station. Legacy analog instrumentation and control technologies represent a key challenge to the long-term sustainability of the existing fleet of light water reactors due to aging, obsolescence, reliability and familiarity to a future workforce. Working with Palo Verde staff, INL completed a preliminary design

and business case for a modernized commercial nuclear power plant control room. The design was implemented and tested in INL's Human System Simulation Laboratory, with an accompanying human factors engineering review.

Nuclear Science User Facilities awards In June, DOE's Nuclear Science User Facilities based at INL announced 14 awards through the Consolidated Innovative Nuclear Research (CINR) Funding Opportunity Announcement. The winning teams will take advantage of NSUF capabilities to investigate important nuclear fuel and material applications. All 14 projects will be supported with more than $10 million in facility access costs and expertise for experimental neutron and ion irradiation testing, post-irradiation examination facilities, synchrotron beamline capabilities, and technical assistance for design and analysis of experiments through the NSUF.

Testing a full-sized fuel element INL and the Korean Atomic Energy Research Institute (KAERI) are working together to qualify the fuel for South Korea's new Ki-Jang Research Reactor (KJRR). A full-sized KJRR fuel element has completed irradiation in ATR and is being transferred to MFC to begin post-irradiation examination. Safe irradiation of a full-size element introduced many challenges that were successfully addressed; that success will open doors for new and innovative irradiation opportunities in the future.

Who's leading the NSUF award teams?

FIVE UNIVERSITIES

5 INDUSTRY PARTNERS

FOUR NATIONAL LABORATORIES

$2.3 MILLION SIX PROJECTS WILL BE SUPPORTED BY DOE RESEARCH FUNDS

The Human System Simulation Laboratory, which allows safe testing of new instrumentation and control technologies, was featured on the cover of Nuclear News in June 2017.

GROWING Capabilities

INL continues to acquire infrastructure and advanced tools for state-of-the-art research capabilities. Our diverse capabilities allow INL to respond to today's nuclear energy challenges and to serve as a multiprogram laboratory with broad energy and national security competencies for addressing current and future challenges.

INL's Power Grid Test Bed was optimized to represent a majority of the nation's grid voltage distribution systems. It enables research on distributed energy resources and grid scale energy storage technologies.

Enhancing the Power Grid Test Bed
INL enhanced its existing distribution infrastructure to expand the types of testing that can be conducted and increase flexibility for testing configurations. The Power Grid Test Bed Enhancement Project established a national capability for development and full-scale testing of smart-grid-related technologies and smart devices. For example, researchers can explore testing interoperability, operational performance, reliability, and resiliency at 15-kV, 25-kV and 35-kV distribution voltage classes.

Remote casting of metal fuels
INL has established the capability to study fuel recycling using small batches of irradiated fuels. Carried out remotely in shielded hot cells, the capability involves reducing oxide fuel to metal, melting, alloying, then casting metallic fuels. Electrochemical recycling studies of several irradiated fuel types can be performed in this equipment using convenient batches on the scale of 2 kg to 10 kg. Interchangeable components in the remote casting system allow injection or gravity-fed casting with small batches of up to 1 kg of fuel material. These flexible research systems now enable MFC programs to address important advanced fuel cycle research questions.

Specialized welding for advanced fuel testing
INL scientists are researching nuclear fuels that are more tolerant to accident conditions, utilize energy resources more efficiently and leave fewer long-lived waste isotopes behind. To enable irradiation testing of these advanced fuels, a new capability was needed to perform welding on small-diameter, thin-walled cladding. A new welding system at the ATR Complex's Test Train Assembly Facility provides a concentrated beam, allowing for narrow, deep welds and high welding rates while minimizing the heat-affected zone of the test components. The laser welder is equipped with a 700-watt continuous fiber laser, a major improvement for fuel rods requiring a hermetic seal for irradiation testing in ATR.

Nuclear research facility engineers analyze samples using Electron Probe MicroAnalysis (EPMA).

Analyzing irradiated metallic fuel
Researchers at the Irradiated Materials Characterization Laboratory have demonstrated the ability to perform accurate microchemical analysis of irradiated fuel. They performed Electron Probe MicroAnalysis (EPMA) on a full cross section of an irradiated fuel sample from the FUTURIX/DOE-1 experiment, conducted jointly with the French nuclear energy agency. The EPMA analysis provided first-of-a-kind information on a minor-actinide-bearing fast reactor fuel, which represents some of the first detailed information on the behavior of this complex fuel type.

GROWING Capabilities

Improving energy storage
INL's Nondestructive Battery Evaluation Laboratory (NOBEL) enables researchers to study in detail how batteries perform in aggressive environments. This state-of-the-art laboratory allows researchers to push energy storage devices to levels of stress short of catastrophic failure and gather information about their long-term performance prospects. The capability could, for example, help engineers understand how electric vehicle batteries are affected by rough roads or extreme temperatures.

On a larger scale, two new flow battery units at INL's microgrid test bed now allow researchers to study the ability to stabilize renewable energy within microgrids and to integrate with the larger-scale grid. Two zinc-iron flow batteries from ViZn Energy Systems are capable of generating 128 kilowatts at full power for 2.5 hours. The data collected from real-world conditions at INL will allow researchers to model and demonstrate energy use and storage scenarios.

INL researchers in the Nondestructive Battery Evaluation Laboratory (left) and operating flow batteries at INL's microgrid test bed (above).

Mimicking commercial reactor environments

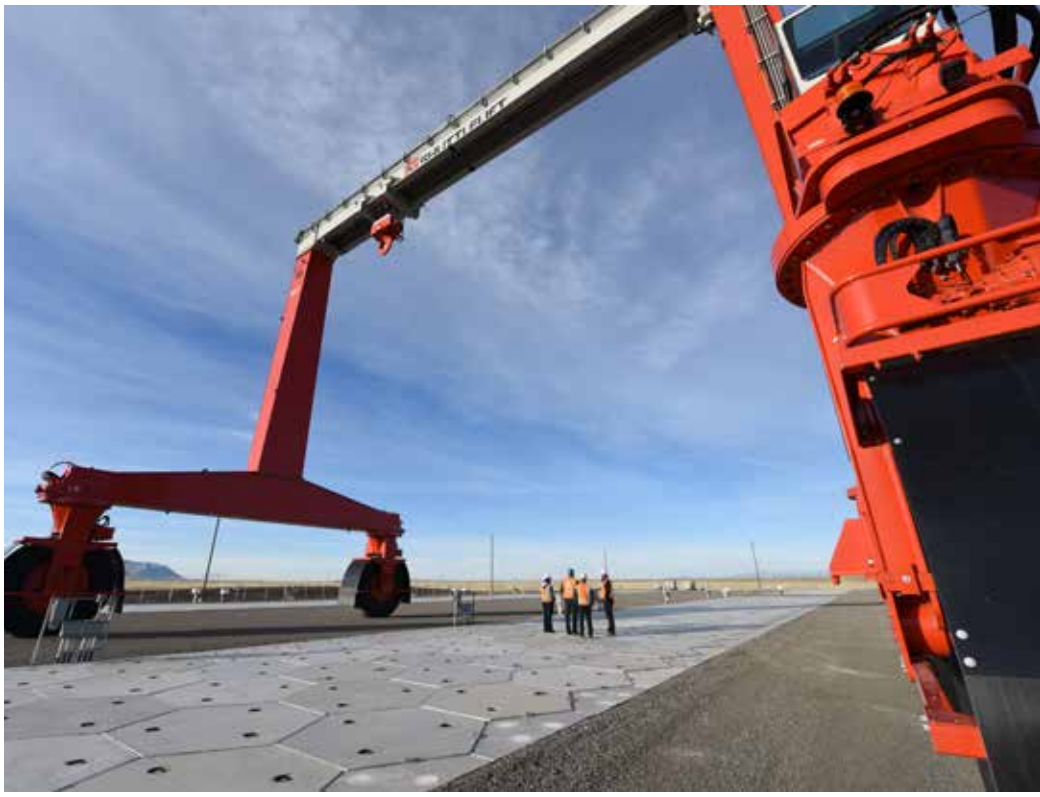
INL's Advanced Test Reactor allows researchers to test how fuels and materials withstand prolonged radiation. Its unique design makes it possible to tailor each experimental environment to match specified real-world conditions. A boron addition system reinstalled in one ATR test loop now provides a more accurate chemistry environment to match commercial pressurized water reactor conditions. The installation was a large effort by a number of groups at INL and represents an expanded research capability for the nuclear research community.

Expanding cobalt production

The ATR is an important source of the isotope cobalt-60, which is used for sterilization, food preservation, radiography and cancer treatment. In FY 2017, the number of ATR core positions available to make cobalt-60 expanded from 14 to 22, representing a 57 percent increase in production capacity. A shielded cask is now available for shipping cobalt between ATR and customer facilities such as Idaho Falls-based International Isotopes Inc.

Demonstrating environmental stewardship

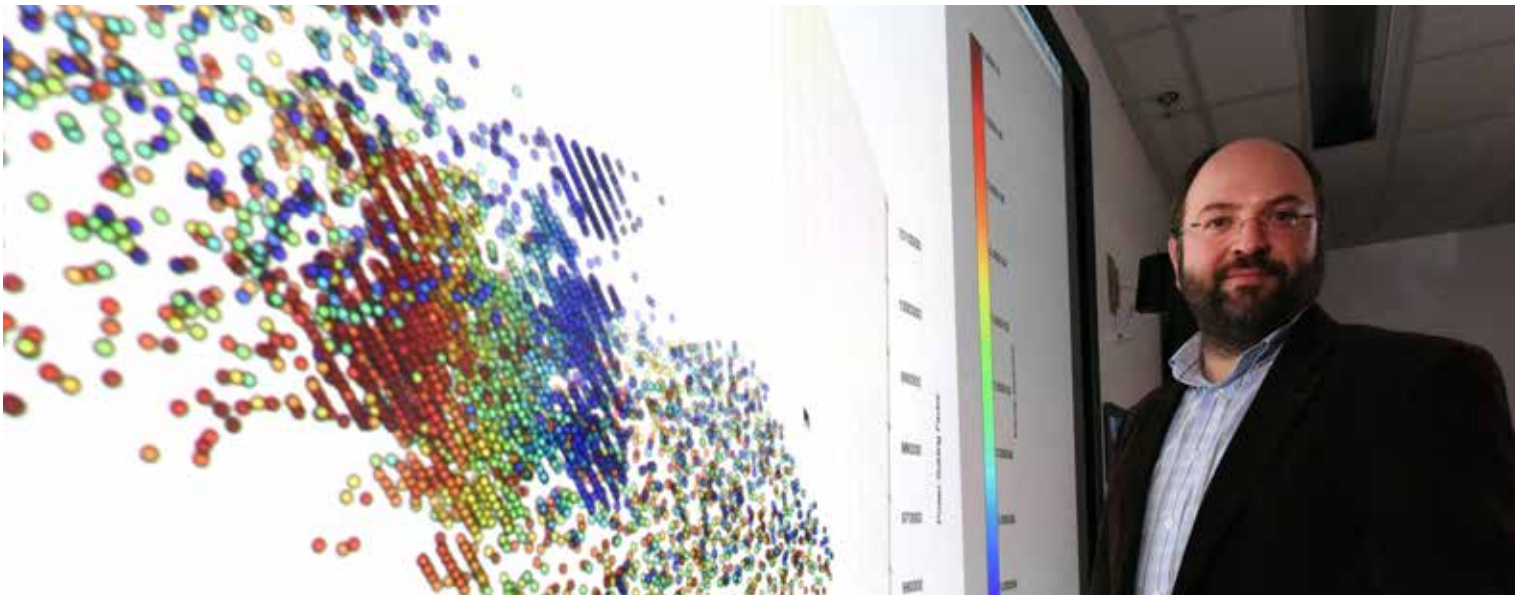
INL completed construction of the Remote-Handled Low-Level Waste Disposal Project. The new facility provides replacement disposal capability that is critical for continuing INL research and Naval Reactors missions at DOE's Idaho Site. As of fiscal year end, the project was approximately 90 percent complete, with activities shifting from construction to operational readiness. The project demonstrated the ability to successfully complete DOE-NE's and BEA's first line-item capital project, which will help shape INL's future and its capabilities.



The new Remote-Handled Low-Level Waste facility provides long-term stability by placing waste in stainless steel containers loaded into below-ground concrete vaults.

Technology INNOVATION & DEPLOYMENT

Through research innovation, testing and evaluation, INL helps industry apply new energy solutions. The following pages describe cutting-edge developments from the past year, as well as the people behind INL innovation.

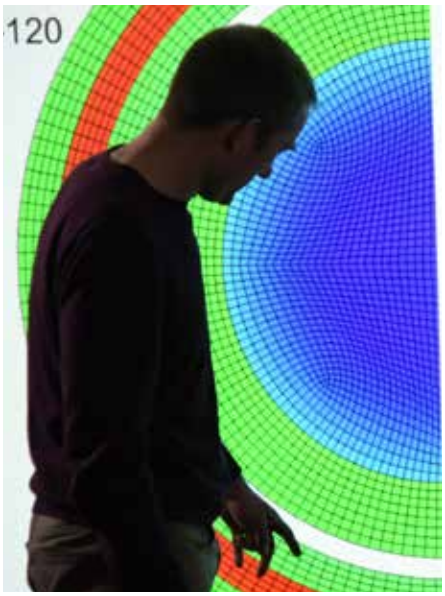


INL engineers developed the RAVEN code for probabilistic risk analysis.

Developing advanced nuclear modeling software

INL has expanded its library of open-source modeling and simulation software. Now both the MASTODON and the RAVEN modeling codes are available on INL's GitHub website (https://github.com/idaholab/). (Developers are naming these applications for indigenous Idaho animals, but are not trying to devise a meaningful acronym for each new modeling code.)

The Risk Analysis and Virtual ENvironment (RAVEN) code is a flexible and multipurpose probabilistic analysis capability allowing users to conveniently perform a variety of analyses, data mining and model optimization tasks. RAVEN is a powerful tool for risk analysis, offering capabilities not currently available in other software. The MASTODON code helps scientists and engineers design buildings and other structures to better withstand seismic events. The finite element application calculates the realistic response of soil and structures to earthquakes in three dimensions. MASTODON is based on the INL-developed Multiphysics Object-Oriented Simulation Environment (MOOSE), while RAVEN is compatible with the MOOSE environment. MOOSE is a computer simulation framework that simplifies the process for predicting the behavior of complex systems.



Validating loss-of-coolant simulations

INL used the BISON fuel performance code to simulate a real Loss-of-Coolant-Accident experiment performed on a pressurized water reactor fuel rod. BISON results were compared with experimental data for a number of material properties including rod pressure, ballooning, time to rupture and end-of-life cladding surface roughness. Researchers also compared BISON's results with those from other advanced fuel performance codes from nations participating in the International Atomic Energy Agency's ongoing Fuel Modeling Under Accident Conditions exercise. By comparing BISON predictions with results from actual experiments and the best codes from other nations, INL can improve its fuel performance modeling.

The BISON team (left) continues to advance the fuel performance modeling code (above left).

Cataloguing modeling and simulation tools

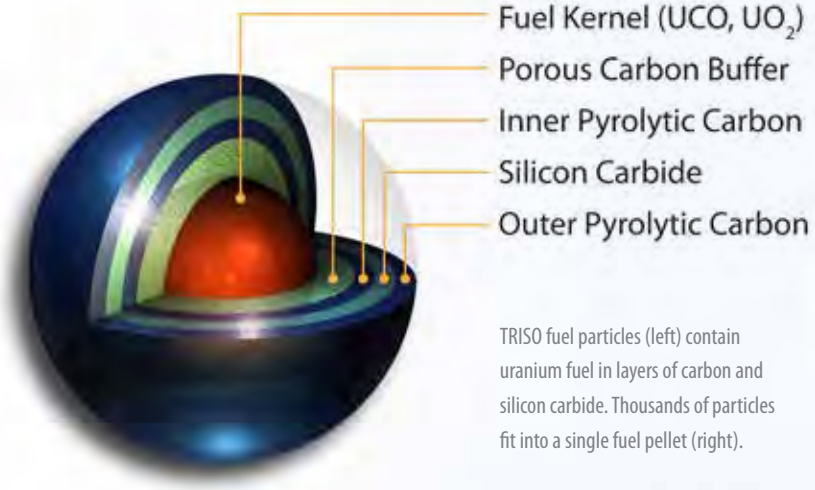
INL developed an electronic catalog for MOOSE and MOOSE-based applications and made it available to industry. The resource contains a description and a set of demonstration problems for each MOOSE application. The MOOSE "Electronic Catalog" (available at https://gain.inl.gov) now provides easy access to information on advanced nuclear modeling and simulation tools being developed at INL. It also provides contact pages on most of the tools so users can ask questions and obtain more information.

Understanding properties of uranium

Uranium has long been the key component of fuel for nuclear power plants, but scientific advances are now enabling new discoveries about its magnetic properties in various forms. New INL-led research has made it possible to better understand the thermal, elastic and magnetic properties of both uranium dioxide (UO_2) and uranium nitride (UN). The research led to the discovery that UO_2 is one of the few, and the hardest, "piezomagnetic" materials known, and can lead to improved predictive modeling and safer, more efficient advanced fuel designs. Papers on these topics were published in the prestigious journal Nature.

Optimizing TRISO fuel performance

INL reported detailed findings from analyses of tristructural-isotropic (TRISO)-coated fuel particles — a safer, more efficient, next-generation nuclear fuel. Containment of the radioactive material is built right into the fuel itself via layers of carbon and silicon carbide around the uranium center where the energy-releasing fission happens. The reported findings suggest particle fabrication strategies that could improve retention of radioactive fission products in TRISO fuels. Throughout the research campaign, numerous advanced microscopic techniques were developed and applied for the first time to TRISO fuels.



TRISO fuel particles (left) contain uranium fuel in layers of carbon and silicon carbide. Thousands of particles fit into a single fuel pellet (right).

Recognizing Expertise

Cathy Riddle was selected as one of the 2017 Idaho Business Review Women of the Year, which honors Idaho's most successful women from public and private sectors.

Terry Todd and **Mark DeHart** were recognized as fellows, the highest membership grade, in the American Nuclear Society. On Oct. 18, 2016, U.S. senators Mike Crapo and Jim Risch (Idaho) congratulated them with a statement in the Congressional Record.

Jack Law won the American Institute of Chemical Engineers Robert E. Wilson Award for outstanding chemical engineering contributions to the nuclear industry.

Giuseppe Palmiotti co-wrote a paper named the Most Popular Article for 2016 by the Journal of Nuclear Science and Technology (JNST).

Rick Demmer won the American Nuclear Society's Best Oral Paper/ Presentation Award for his Waste Management 2017 Conference presentation.

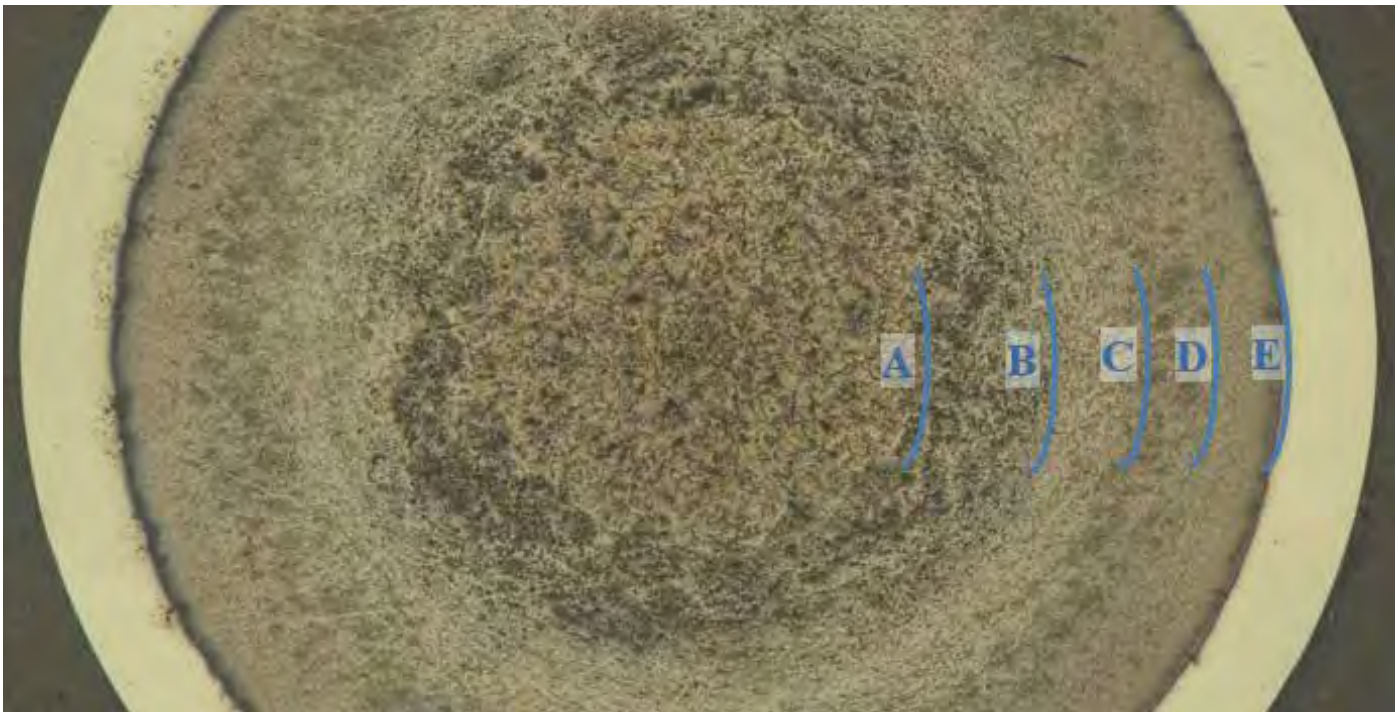
Technology INNOVATION & DEPLOYMENT

Developing accident-tolerant fuels
INL is working with industry to develop fuels with enhanced tolerance to accident conditions. The multiyear effort has been preparing to introduce three experimental fuels into INL's Advanced Test Reactor. In FY 2017, engineers established the conditions and chemistry to mimic a commercial pressurized water reactor. A sensor for the experiments was also tested at the Westinghouse Advanced Loop Tester Facility to ensure it could withstand the conditions inside ATR, where the sensor is now being tested. INL also continued fabrication of industry silicide fuel for use in ATR irradiations.

The Experimental Fuel Facility where INL experts demonstrated the ability to produce fuel slugs using extrusion.

TerraPower fuel extrusion
INL is working cooperatively with Washington-based TerraPower to demonstrate the ability to produce fuel slugs using extrusion — a process of shaping material by forcing it through a die. TerraPower is developing a Traveling Wave Reactor (TWR) concept, a new type of fast reactor. In collaboration with TerraPower, INL achieved the first successful extrusion of a TerraPower fuel design, restoring a metallic fuel fabrication capability that has not been used in the U.S. since the 1980s.

Recovering Fast Flux Test Facility fuel
The Joint Fuel Cycle Studies Integrated Recycling Test aims to electrochemically recycle used nuclear fuel by reducing the material from oxide form to metal form, then recovering uranium and transuranium elements for recycled fuel fabrication tests. A milestone in that work was the "Complete Decladding Test of the First Irradiated FFTF Element." The effort involved 14 mixed oxide (MOX) fuel rods from the Fast Flux Test Facility (FFTF) at the DOE's Hanford site. INL experts successfully removed the protective cladding material in the Hot Fuel Examination Facility hot cell at INL's Materials and Fuels Complex. The oxide materials recovered are being used to support subsequent oxide reduction and electrorefining tests.



Researchers are using high magnification images to study the radial (as marked) microstructural zones of this fuel sample irradiated in a French fast reactor.

Testing fast reactor fuels in ATR

Fast reactors could use uranium resources more efficiently and can greatly reduce the amount and the hazards of used fuel that has to be disposed. But domestic research on fast reactor fuel is challenging because the U.S. doesn't have a fast reactor available for testing. INL is leading a national initiative to design a new Versatile Fast Test Reactor to re-establish this important capability for the long term.

In the meantime, INL researchers conducted fuel tests under modified conditions in ATR that can reproduce important aspects of a fast reactor environment. Comparison of samples irradiated in the modified ATR conditions and those irradiated in a French fast reactor showed that these conditions could be used on a stop-gap basis to begin some development and testing of proposed fast reactor fuels.

Supporting diverse nuclear energy experiments

Experiments at ATR include Advanced Graphite Characterization for materials that will be used in advanced reactors, an Advanced Fuels Campaign to develop new types of nuclear fuel and Electric Power Research Institute studies to better understand how the protective zirconium cladding can affect a fuel's ability to transfer heat. Two new ATR experiments include the Tritium Producing Burnable Absorber Rod Materials Irradiation Separate-Effects Test and a Lithium Aluminate Capsule Experiment (LACE) for Pacific Northwest National Laboratory and Savannah River National Laboratory.

INL and DHS completed the 100th Industrial Control Systems Cyber Emergency Response Team (ICS-CERT) Red/Blue cybersecurity training course. The hands-on training helps participants discover who and what is on the network, identify vulnerabilities, understand how those vulnerabilities may be exploited, and learn defensive and mitigation strategies. More than 4,000 attendees from national and international government, industry and academia have completed the course to date.

Learning from cyberattack experience

After helping investigate a June cyberattack against Ukraine's power grid, INL turned the experience into training for others. Laboratory experts combined firsthand knowledge from the event with cyber forensics results and threat analysis. The resulting training course included an innovative tool to hone the skills within U.S. utilities to respond to a similar event. These novel "Ukraine-Event-in-a-Box" devices fit on a desktop and are designed to challenge course participants to cyber-defend the equipment they routinely encounter within their power generation systems and power distribution substations.

Helping U.S. utilities boost cybersecurity

A pilot study of INL's proprietary Consequence-driven, Cyber-informed Engineering (CCE) methodology was completed with the delivery of cybersecurity mitigations and recommendations to the chief executive officer and executive directors of a major U.S. electric utility. As a result of this cooperative research and development (CRADA) project, the utility is implementing changes to internal processes, engineering practices, system architecture designs and cybersecurity culture.

Using geo-mapping to protect critical infrastructure

INL signed a CRADA with Environmental Systems Research Institute (Esri), a leading international supplier of geographic information software. The project intends to enhance the use of geo-mapping for critical infrastructure protection by providing better information to the federal, state and local officials who are responsible for restoring operations during a major disruption. The Christian Science Monitor and Energywire published articles explaining how the collaboration will better "… predict how an attack on a U.S. electricity company could rapidly spread to water and sewer systems, telecommunications, finance, health care and other critical sectors that depend on electricity…"

Verifying international treaty cooperation
INL and Advanced Measurement Technology Inc. entered into a licensing agreement for On-Site Inspection Radio Isotopic Spectroscopy (OSIRIS). The gamma-ray spectrometer is designed to detect specific radionuclides whose presence is certain evidence of nuclear explosions, in support of the provisions of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). A celebration in Washington, D.C., recognizing 60 years of the treaty's success highlighted OSIRIS for its capability to verify international cooperation with the CTBT. Hundreds of attendees included the energy secretary, NNSA principal deputy administrator, several U.S. senators, CTBT representatives and several DOE laboratory directors.

Improving nuclear forensics
INL radiochemists and nuclear forensic researchers successfully demonstrated chemical synthesis methods leading to the discovery of new compounds of neptunium. This research, funded by the U.S. Department of Homeland Security, provides a unique capability to help the international nuclear forensics community deploy effective on-site measurement equipment and validate laboratory forensic analyses. In collaboration with Washington State University, the structure and purity of several neptunium β-diketone compounds were validated.

Recognizing Expertise

Andy Bochman won EnergySec's Cybersecurity Leader of the Year 2017. He also spoke on a panel of experts before U.S. Senate members on the cybersecurity of energy delivery systems.

Scott Thompson earned a Joule Award from DOE for work that boosts International Atomic Energy Agency (IAEA) confidence in nondestructive assay measurements of certain containers.

Craig Rieger co-authored a paper about Intelligent Buildings of the Future that earned Industrial Electronics Magazine's Best Paper Award for 2017.

INL researchers developed the noninvasive battery self-discharge metric, which is applicable to any battery chemistry or design.

Making batteries safer

Internal shorts in lithium-ion batteries can lead to thermal runaway, which can cause catastrophic failures such as fires and release of electrolyte vapors. One way of limiting such catastrophic failures is to detect flaws and short circuits inside battery cells before they reach critical levels. INL researchers developed a fast metric, called self-discharge (SD) current, as a way to detect shorts and assess battery safety. The findings were published in the Journal of the Electrochemical Society, and the technology was an Early Stage Innovation finalist for a 2017 Idaho Innovation Award.

Understanding confined fluid behavior

New computer simulations from INL researchers could one day lead to more efficient oil and gas extraction. The computational methods can be used to design technologies that improve recovery of oil and natural gas trapped in nanoporous shales. The research combines high-resolution imagery from University of Utah with novel modeling approaches that account for the small and scattered pore structure of shale, an area in which traditional approaches fail. The research was published in the journal Physics of Fluids, and a paper has been accepted for publication in Nature: Scientific Reports.

Realizing additional grid capacity
INL's General Line Ampacity State Solver (GLASS) was a finalist for a 2017 R&D 100 Award to recognize the top 100 innovations of the year. GLASS can unlock additional electric power capacity through existing power lines in and around wind farms. The software provides historical, real-time and forecast data to take advantage of environmental conditions such as the concurrent cooling of overhead transmission lines by the same wind that is generating wind power. Such cooling enables utilities to safely increase the amount of current a line can carry by 10 to 40 percent.

Commercializing battery diagnostic technology
INL has provided the energy storage industry with first-of-a-kind technology for advanced battery health diagnostics. The award-winning impedance measurement technology was exclusively licensed to Dynexus Technology Inc., which will commercialize INL's embedded wideband impedance technology for analyzing and forecasting the health, aging and safety characteristics of advanced energy storage devices. INL won the Federal Laboratory Consortium-Far West Award in the Outstanding Partnership category for its work toward commercialization of this technology with Montana Tech of the University of Montana.

Recognizing Expertise

Richard "Barney" Carlson and **Lee Walker** received awards from the U.S. Council for Automotive Research. Walker was on the U.S. Advanced Battery Consortium Test Methods Team selected as a USCAR Team Award winner. Carlson received a USCAR Research Partner Award and INL's 2016 Laboratory Director's Excellence Award for Mission Advancement.

Bishnu P. Bhattarai won a Green Talents 2017 award from Germany's Federal Ministry of Education and Research. The international competition recognizes young scientists working in sustainability R&D. Winners are selected based on demonstrated scientific skills and contributions to sustainability.

Victor Walker received the highest rated presentation and project of approximately 192 presented at the DOE's Bioenergy Technology Office Peer Review in March 2017. His update about the Bioenergy Feedstock Library was one of 14 INL bioenergy projects peer reviewed in 2017.




Technology INNOVATION & DEPLOYMENT

Energy I-Corps is a DOE program aimed at strengthening entrepreneurial culture at national labs. It focuses on cultivating small-team collaboration between researchers and private entrepreneurs. INL has been sending people to the program since it started in 2015. During seven weeks of training provided at the National Renewable Energy Laboratory, each team visits or calls company representatives in their specific market sectors, engaging directly with potential customers with a goal of 100 customer discovery interviews. At the same time, they also meet with and are scored by panels of industry experts.

INL's CellSage technology

CellSage: Team members: Kevin Gering (principal investigator), Josh McNally (entrepreneurial lead) and Frank Meijers (industry mentor). CellSage deploys software to support battery performance and life-cycle determinations in diverse applications.

Optiblend: Team members: Allison Ray (principal investigator), Hongqiang Hu (entrepreneurial lead) and Ryan Bills (industry mentor). This technology allows researchers to produce high-quality feedstock from grass, wood and agricultural residues.

E-RECOV: Team members: Tedd Lister (principal investigator), Luis Diaz Aldana and Leslie Ovard (entrepreneurial leads), and Jon Cook (industry mentor). This electrochemical recovery process retrieves critical and rare earth materials from such devices as cellphones and computers.

CDS: Team Members: Troy Unruh (principal investigator), Gregory Lancaster (entrepreneurial lead) and Sontra Yim (industry mentor). The Change Detection System is a computer software program that aligns digital images to detect changes over time for nuclear facility and national security applications.

Dry Cask Vital Signs: Team Members: Ahmad Al Rashdan (principal investigator), Carson McNair (entrepreneurial lead) and John Kessler (industry mentor). Noninvasive determination of the status and integrity of vented dry casks is possible with this technology.

INL's Electroplate technology

Electroplate: Team Members: Prabhat Tripathy (principal investigator), Jordan Argyle (entrepreneurial lead) and Steve Herring (industry mentor). This team developed an electroplating process that enables formation of a multilayered surface coating that is thick, uniformly pore-free and saves energy by operating at much lower temperatures than traditional plating methods.

AMAFT: Team Members: Isabella van Rooyen (principal investigator), George Griffith (entrepreneurial lead) and Ed Lahoda (industry mentor). This additive manufacturing technology provides a direct route to fabricating dense uranium silicide using a novel hybrid laser-engineered net shaping process.

EMRLD: Team Members: Steven Prescott (principal investigator), Ram Sampath (entrepreneurial lead) and Rob Sewell (industry mentorhav). EMRLD is a probabilistic risk assessment modeling and simulation tool that is ideal for dynamic time-dependent models and also makes coupling possible with other time-dependent, physics-based simulation models.

RE-LIGHT: Team Members: Donna Baek (principal investigator), Devin Imholte (entrepreneurial lead), and Robert Fox and James Hedrick (industry mentors). RE-LIGHT's technology safely separates mercury and rare earth elements from fluorescent lamps.

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INL TEAMS PARTICIPATED IN ENERGY I-CORPS COHORTS DURING FALL OF 2016 AND SPRING OF 2017.

REGIONAL Leadership

Diverse energy resources concentrated along the U.S. and Canadian Rocky Mountains and northern plains offer a wealth of energy solutions. INL works to build multidisciplinary research partnerships because regional engagement provides a foundation for advancing development of these resources.

INL is helping identify EV corridors on I-15, I-80, I-70, I-84, and the route between Yellowstone and Glacier national parks.

Helping EVs traverse the West

As electric vehicle usage grows, organizations such as utilities and government agencies are seeking to extend driving range via informed siting of charging stations. INL researchers provided technical support by analyzing locations for electric vehicle charging infrastructure. In FY 2017, they helped the state of Montana by identifying promising electric vehicle corridors, particularly between Yellowstone National Park and Glacier National Park. INL also is working with Rocky Mountain Power on an EV corridor project that covers interstate highways in Colorado, Utah and Idaho.

Boosting Idaho power plant efficiency

INL helped pioneer the concept of hybrid energy systems that integrate multiple energy sources to enhance efficiency. Researchers from INL are providing technical expertise to U.S. Geothermal through a $150,000 DOE-funded Small Business Voucher. The effort will help integrate solar energy into the company's Raft River Geothermal Power Plant. A similar approach at a plant in Nevada has increased efficiency by generating solar power on hotter days, when geothermal energy generation is less efficient. INL will help integrate concentrated solar power and binary geothermal energy at Raft River to provide a lower, stabilized cost of electricity.

The U.S. Geothermal plant is located in the Raft River community of southern Idaho.

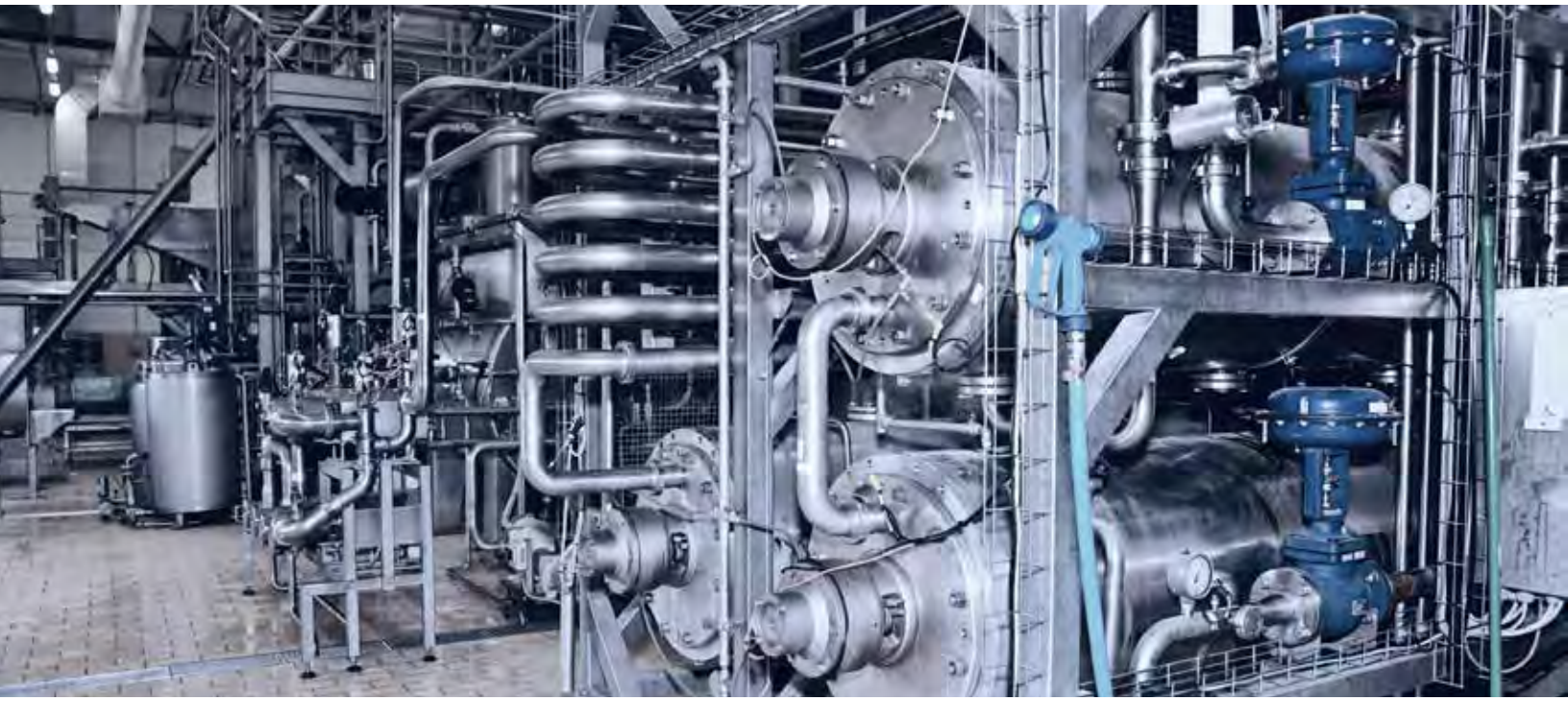
REGIONAL Leadership

DID YOU KNOW?

NWFPA IS A TRADE ASSOCIATION OF MORE THAN **140 PROCESSOR** COMPANIES AND **350 SUPPLIERS** IN IDAHO, OREGON AND WASHINGTON.

Finding solutions for food processors
The Center for Advanced Energy Studies at INL (CAES) is working with the Northwest Food Processors Association (NWFPA) to address challenges with wastewater treatment and energy consumption in food processing, one of the Northwest's biggest industries. A Boise meeting convened more than 30 researchers from government, national laboratories, industry and academic institutions to discuss challenges in wastewater management and energy efficiency.

Cutting energy and water use
CAES researchers at University of Idaho and INL are helping Idaho food processing companies reduce their energy and water use. A $93,600 grant from Avista Corp. funds a one-year project to evaluate North Idaho food processing plants. INL researchers will mentor the UI team, which will create in-depth models of a plant's energy and water use. The effort taps into expertise across UI's colleges and locations, connects to CAES' Energy-Water Initiative, and helps Avista meet the Idaho Public Utility Commission's



Real fruit processing plant in operation.

directive for utility companies to support reduced energy consumption by funding research and technology development.

Speeding tech transitions to market
INL partnered with the Northwest-based business accelerator program Cascadia CleanTech to launch the lab's pilot national lab accelerator training. Thirteen INL teams — all working with industry mentors — met at CAES to learn lean innovation-to-market techniques such as customer discovery and validation. This led to a "pitch competition" where teams gave presentations and answered questions from a six-judge panel.

Evaluating solar battery performance
Pocatello-based Inergy Solar makes portable solar energy collection and storage systems, and better performance hinges on more powerful, longer-lasting batteries. Researchers at INL's Battery Testing Center helped the company determine how an advanced generation of lithium-ion battery cells would perform under various conditions that mirror those seen in Inergy's products. Inergy's chief technology officer said INL's test results will figure into the company's plans, which may eventually involve building a li-ion battery factory in the Pocatello area.

Researchers at INL's Battery Testing Center helped Inergy Solar test its batteries' performance.

Turning waste to energy
INL researchers began working with Idaho Falls-based Cogent Energy Systems through a DOE-funded Small Business Voucher. The project aims to improve the company's small-scale gasifier for distributed waste-to-energy applications and markets. INL will help to properly homogenize and size the feedstock material so that it can be continuously fed into the gasifier and meet real-world feedstock processing requirements.

"...very interesting and educational, and a valuable effort missing in the electric industry."

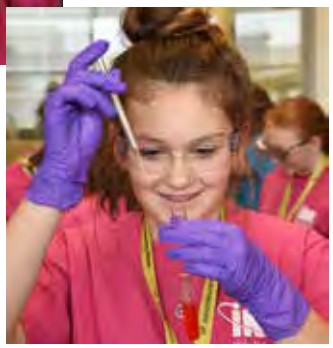
– Technical collaborator regarding an on-site cybersecurity assessment at Washington state's Snohomish Public Utility District (SnoPUD).

TALENT Pipeline

Planning for the future

Supporting the next generation of scientists and engineers is a priority at INL. The lab's education programs support K-12 students and teachers, college undergraduate interns, graduate students, and university research efforts. Academic institutions and researchers across the nation benefit from access to INL resources, capabilities and expertise.

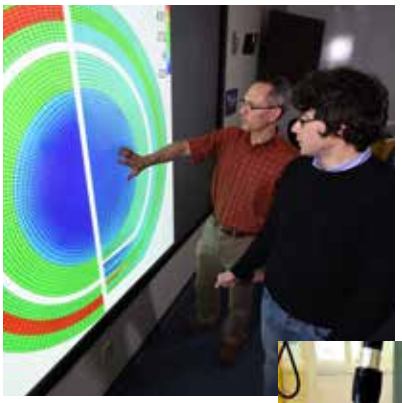
In FY 2017, INL led 152 K-12 STEM activities that reached more than 24,000 educators and parents.



STEM outreach directly benefited 85,000 students, 56 percent of whom were from rural communities or underserved populations.

In FY 2017, INL hosted 344 interns, 42 post-doctoral fellows and 242 employee continuing education participants.

Boise State University, Idaho State University and University of Idaho committed to develop more than 200 Cybercore interns, graduate fellows, postdocs, joint appointments, employee education students and new faculty by 2025.



INL created the University of Idaho Graduate Certificate in Critical Infrastructure Protection to familiarize students with the needs and issues related to protecting U.S. critical infrastructure.

INL collaborated with universities to develop a new Graduate Fellowship Program. The university covers tuition and fees during the first years of graduate school, and INL covers tuition, fees and a $60,000 annual salary during the last two years of doctoral research performed at the lab. Eleven fellows were selected in the first round.

INL created the Deslonde de Boisblanc distinguished postdoctoral appointments, which are competitively awarded to early career researchers who have leadership potential and embody de Boisblanc's spirit of ingenuity. De Boisblanc is most well-known for designing the Advanced Test Reactor's famous clover-leaf core.

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ABOUT INL

In operation since 1949, INL is a science-based, applied engineering national laboratory dedicated to supporting the U.S. Department of Energy's missions in nuclear and energy research, applied science, and national security.

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U.S. DEPARTMENT OF ENERGY