SAND2021-9407R

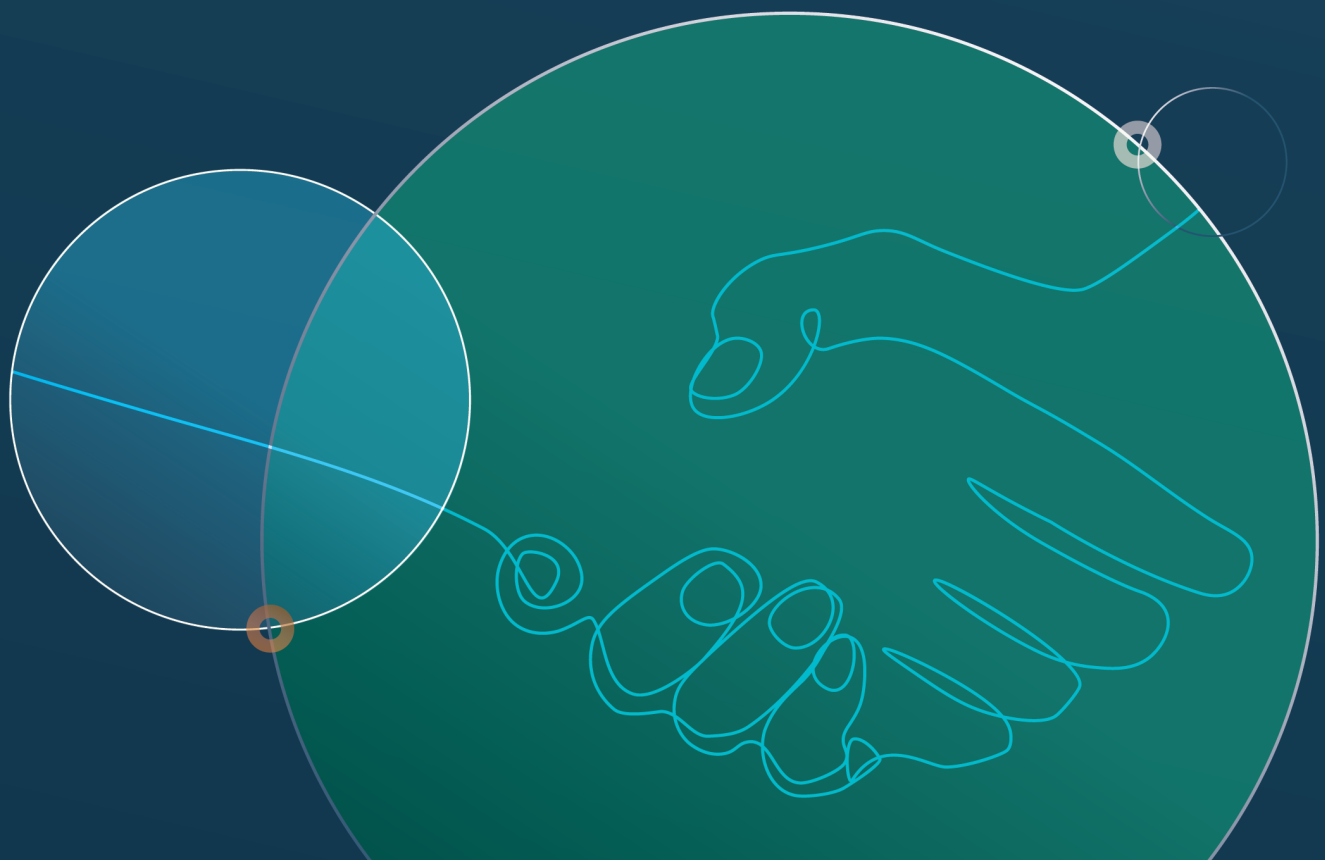
SANDIA ACADEMIC ALLIANCE PROGRAM

COLLABORATION REPORT

Sandia Labs Edition

2020-2021 Accomplishments

Sandia's academic alliances establish strategic partnerships to solve science and technology problems of national importance.



The Sandia Academic Alliance (SAA) program takes a deliberate approach to building partnerships with universities that combine strengths in key academic disciplines, contain sizable portfolios of relevant research capabilities, and demonstrate a strong institutional commitment to national security.

The SAA program aims to solve significant problems that Sandia could not address alone, sustain and enrich Sandia's talent pipeline, and accelerate the commercialization and adoption of new technologies.

Thank you
TO ALL OF OUR SAA PARTNERS

The Georgia Institute of Technology • Georgia Tech

Purdue University • Purdue

The University of Illinois Urbana-Champaign • U of Illinois

The University of New Mexico • UNM

The University of Texas at Austin • UT Austin

THE VALUE OF THE SANDIA ACADEMIC ALLIANCE PROGRAM

University partnerships play an essential role in sustaining Sandia's vitality as a national laboratory. The SAA is an element of Sandia's broader University Partnerships program, which facilitates recruiting and research collaborations with dozens of universities annually.

The SAA program has two three-year goals. SAA aims to realize a step increase in hiring results, by growing the total annual inexperienced hires from each out-of-state SAA university. SAA also strives to establish and sustain strategic research partnerships by establishing several federally sponsored collaborations and multi-institutional consortiums in science & technology (S&T) priorities such as autonomy, advanced computing, hypersonics, quantum information science, and data science.

The SAA program facilitates access to talent, ideas, and Research & Development facilities through strong university partnerships. Earlier this year, the SAA program and campus executives hosted John Myers, Sandia's former Senior Director of Human Resources (HR) and Communications, and senior-level staff at Georgia Tech, U of Illinois, Purdue, UNM, and UT Austin. These campus visits provided an opportunity to share the history of the partnerships from the university leadership, tours of research facilities, and discussions of ongoing technical work and potential recruiting opportunities. These visits also provided valuable feedback to HR management that will help Sandia realize a step increase in hiring from SAA schools.

THE 2020-2021 COLLABORATION REPORT

The 2020-2021 Collaboration Report is a compilation of accomplishments in 2020 and 2021 from SAA and Sandia's valued SAA university partners. To learn more about the SAA program, visit www.sandia.gov.

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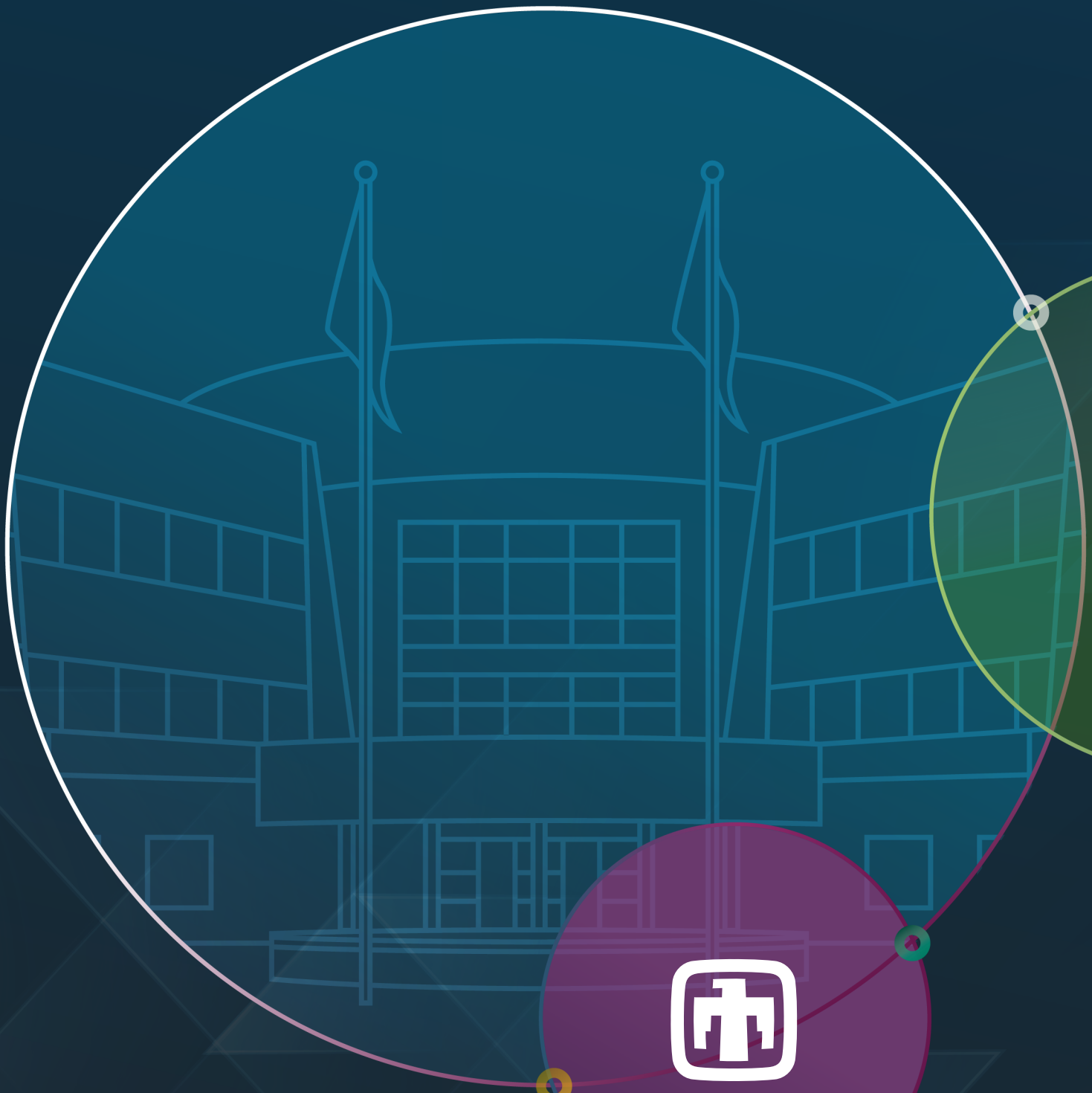


SANDIA LABS

ALBUQUERQUE, NM

OVERARCHING ACCOMPLISHMENTS

POSITIVE OUTCOMES. SUCCESSFUL ENGAGEMENT. STUDENT SUCCESS.

Everyone wants to see good triumph, but there can't be a victory without a difficulty to overcome. The antagonist of 2020 was, undoubtedly, COVID-19. The challenges brought by the pandemic extended to every facet of life, including academic collaborations and educational growth. At Sandia, these activities are paramount to research innovation and to developing the workforce of the future, so it was critical that the Academic Programs team help them continue during a time of remote work. Through the team's ingenuity, they found ways to connect postdocs effectively with the Sandia resources they needed for their research, facilitated successful remote summer internships, and assisted year-round interns in engaging meaningfully with their teams.

Through great cooperation between Sandia and many universities, the talent pipeline and research collaborations continued to thrive.

During 2020-2021, the out-of-state schools in Sandia's Academic Alliance (SAA):

- Assisted with 20 regular hires, including conversions from temporary positions.
- Facilitated 16 post-doctoral positions.
- Enabled 40 internship opportunities.
- Filled 62 year-round student intern positions, as of last September.

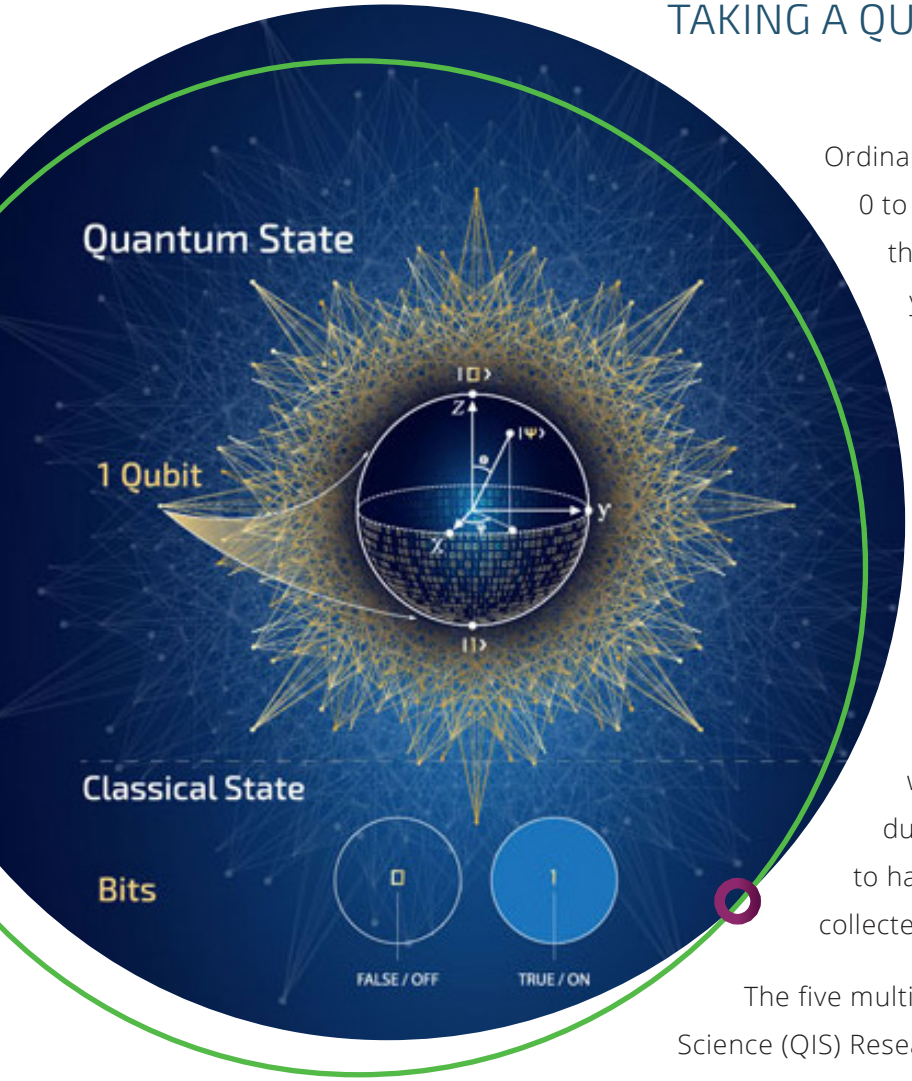
OUTSTANDING SCIENCE. COOPERATIVE RESEARCHERS. STRONG ALLIANCES.

Since President Harry S. Truman commissioned Sandia in 1949, one guiding principle from his letter continues to echo through every effort—exceptional service in the national interest. During 2020, Sandia responded to the needs of the nation by putting out a call out to the entire workforce for rapid response Laboratory Directed Research and Development (LDRD) ideas that could positively impact the pandemic, irrespective of fields. Likewise, universities around the country began working on COVID-related projects, and at times, Sandia and academic partners collaborated on these efforts.

Through a Memorandum of Understanding (MOU) between Sandia and the University of New Mexico Health Sciences Center, UNM Hospital provided used personal protective equipment, specifically N95 respirators, to Sandia for evaluation of fit, performance, and integrity of the masks following sterilization procedures. Multiple decontamination methods were assessed for degradation, and the make and model of respirators evaluated for performance. In turn, UNM Hospital allowed Sandia to use de-identified patient data in a project focused on applying artificial intelligence (AI) to predict virus progression and anticipate hospital capacities and resource loads.

COVID was a formidable adversary in 2020, but it was met by determined groups of people who found a way to surmount significant obstacles.

TAKING A QUANTUM LEAP...TOGETHER



Pictured: *Quantum bits of information, or qubits, have the potential to make powerful calculations that classical bits cannot.*

Ordinary computer chips use a discrete binary 1 or 0 to indicate on or off respectively. But in nature, things aren't just in one state or another. When you look at the smallest constituents on the smallest possible scales, uncertainties begin to occur. To accurately study objects at foundational levels, the qubits in quantum computers are needed to simulate biological, chemical, or physical events. Only qubits can be in both off and on states at the same time allowing for uncertainty, and only they can handle the most complicated reactions. This is why quantum computers were so beneficial during the recent pandemic – they were able to handle the immense amounts of data being collected and exponentially accelerate progress.

The five multidisciplinary National Quantum Information Science (QIS) Research Centers, which network together the U.S. national labs, academia and industry, are the result of the National Quantum Initiative Act passed by Congress in 2018. Sandia serves as the leading partner for one of the research centers—the Quantum Systems Accelerator (QSA)—comprising dozens of researchers from 15 labs and universities working to transform rudimentary quantum computers and related technologies into machines that perform valuable work for the U.S. Department of Energy (DOE) and the nation. Such work could include advances in scientific computing, discoveries in fundamental physics, and breakthrough research in materials and chemistry. QSA will receive $115 million over five years to co-design advanced algorithms, devices and engineering solutions; foster collaboration with industry and nongovernmental organizations and lay the groundwork to train a future workforce.

"The QSA combines Sandia's expertise in quantum fabrication, engineering and systems integration with Lawrence Berkeley National Laboratory's lead capabilities in quantum theory, design, and development, and a team dedicated to meaningful impact for the emerging U.S. quantum industry," said Sandia's Rick Muller, deputy director of the Quantum Systems Accelerator. "The Sandia LDRD program can take major credit for this win in quantum," Muller said. "It's unlikely we would be here without the intense and sustained support we've received for more than 10 years."

Sandia is also collaborating on the National Science Foundation (NSF) Quantum Leap Challenge Institute, called Q-SEnSE, and the QIS Program. Many of Sandia's academic partners are also participating in the quantum research centers including the following SAA schools: U of Illinois, UNM, and UT Austin.

Pictured: *Rick Muller helps coordinate Sandia's portfolio in quantum information sciences.*

CYBER INNOVATION TO SECURE U.S. MANUFACTURING FOR DECADES

The Cybersecurity Manufacturing Innovation Institute (CyManII) was formally launched in November 2020. Funded by DOE, CyManII is focused on bolstering U.S. manufacturing competitiveness, energy efficiency, and innovation by addressing early-stage R&D to advance cybersecurity in energy-efficient manufacturing. The Institute brings together 59 member institutions in cybersecurity, smart and energy efficient manufacturing, and deep expertise in supply chains, factory automation, and workforce development. Led by The University of Texas at San Antonio, CyManII leverages the strongest DOE national labs in this area, with Sandia Labs leading in cybersecurity of supply chain management, Oak Ridge National Laboratory leading in advanced manufacturing, and Idaho National Laboratory leading in cybersecurity of industrial control systems and physical infrastructure.

According to Dahlon Chu, Sandia senior manager of Emerging Cyber Capabilities, "CyManII is about applying the nation's premier capabilities and resources to further strengthen and defend our public and private infrastructure for manufacturing and power delivery." David M. Nicol, CyManII Vice President for Securing Automation and the Herman M. Dieckamp Endowed Chair in Engineering at the U of Illinois, agreed: "Modern manufacturing processes are automated and controlled by computers. It's essential that we protect those computer systems in order to ensure the safe and energy-efficient operation of those processes." The participation of Purdue, another SAA partner, will be directed by Dongyan Xu, director of the Center for Education and Research in Information Assurance and Security (CERIAS) and the Samuel Conte Professor of Computer Science. Xu noted that understanding evolving technology threats will help secure

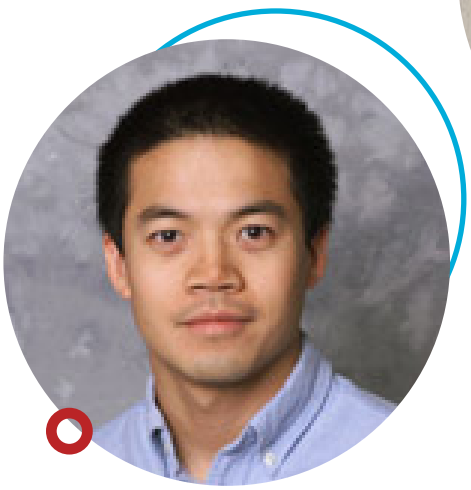
automation and supply chain systems by giving workers the tools they need. “This national consortium will not only share new information and technologies with manufacturers but will also address the need for education, training and workforce development. These are critical skills needed for advanced manufacturing and cybersecurity.”

CyManII will leverage up to $70 million in federal funding over five years, subject to appropriations, and the funding will be matched by over $40 million in private cost-share commitments. Sandia will use approximately $800 thousand in the first year to focus on developing a security/supply chain roadmap and finding vulnerabilities in industrial control systems. Sandia and Purdue will collaborate to address secure automation and supply chain. Sandia’s Abe Clements, in Systems Security Research, initially proposed the work along with David Carter, a cyber systems security researcher in San Antonio working under Mike Lopez, Cyber Systems Security manager. Afterward, they recruited other Sandia experts including Brian Gaines in Computer Systems Security Analysis and Brandon Eames in Cyber Mission Alliances to act as points of contact in the collaborative partnership with Purdue.

CyManII leverages Clements’ firmware emulation, HALucinator, which locates vulnerabilities in industrial control systems.

Pictured: *David M. Nicol, CyManII VP for Securing Automation at U of Illinois*

Pictured: *Abe Clements, Sandia systems security research and developer of HALucinator firmware*



Pictured: *Dongyan Xu, Purdue Director of the Center for Education and Research in Information Assurance and Security*

Pictured: *NSU President Dr. Javaune Adams-Gaston presented at a Sandia panel discussion to open Black History Month in 2021.*

Pictured: *Rahni Kellum, business development lead for the START HBCU Program, says, "START HBCU is more than recruiting. It's about relationships."*

STRATEGIC PARTNERSHIPS FORGED WITH FOUR RENOWNED HISTORICALLY BLACK COLLEGES AND UNIVERSITIES

It's the "START" of something great at Sandia! Four schools known for their academic excellence and scientific capabilities joined Sandia's Securing Top Academic Research & Talent with Historically Black Colleges and Universities (START HBCU) Program. Sandia Labs Director, James Peery, and Advanced Science & Technology Associate Labs Director and Chief Research Officer (CRO), Susan Seestrom, are both committed to the program's success. Seestrom signed MOUs with Florida A&M, Norfolk State, North Carolina A&T State, and Prairie View A&M in October 2020.

The START HBCU Program is focused on increasing Sandia's diversity pipeline through the creation of strategic partnerships and cultivation of strong research collaborations with distinguished universities. Each university brings expertise in areas that complement Sandia's expertise.

- Florida A&M (FAMU) provides exceptional research programs in numerous engineering fields and also has an environmental science institute.
- Norfolk State (NSU) possesses centers for materials research and cybersecurity, and a development institute in information assurance research.
- North Carolina A&T (NC A&T) has an institute in autonomous control and information technology, is focused on machine intelligence research, and has a lab dedicated to intelligent mobile information systems.
- Prairie View A&M (PAVMU) is known for its centers in radiation engineering, space exploration and big military data intelligence.
- Alabama A&M will join the START HBCU Program in the Fall of 2021. Its areas of expertise include materials science, nanotechnology, cybersecurity, hypersonics, energy, and bioscience.

Since the program's inception, Sandia has funded a total of ten LDRD projects with START HBCU schools in the areas of material science, biology, computing information systems, and engineering

sciences. In fiscal year 2021, six LDRD collaborations in materials science kicked off with three HBCUs. The synergistic projects connect Sandia mission needs with technical expertise at the universities. For example, Sandia principal investigator (PI) Wei Pan is collaborating with Professor Doyle Temple at NSU to grow quantum materials using a floating-zone technique. This collaboration will also help train the future workforce in the emergent quantum information science industry. Sandia PI Andrew Kustas is partnering with Professor Tarik Dickens and his team at FAMU to examine the feasibility of producing magnetic alloys using a novel dual-mode directed-energy deposition additive manufacture process.

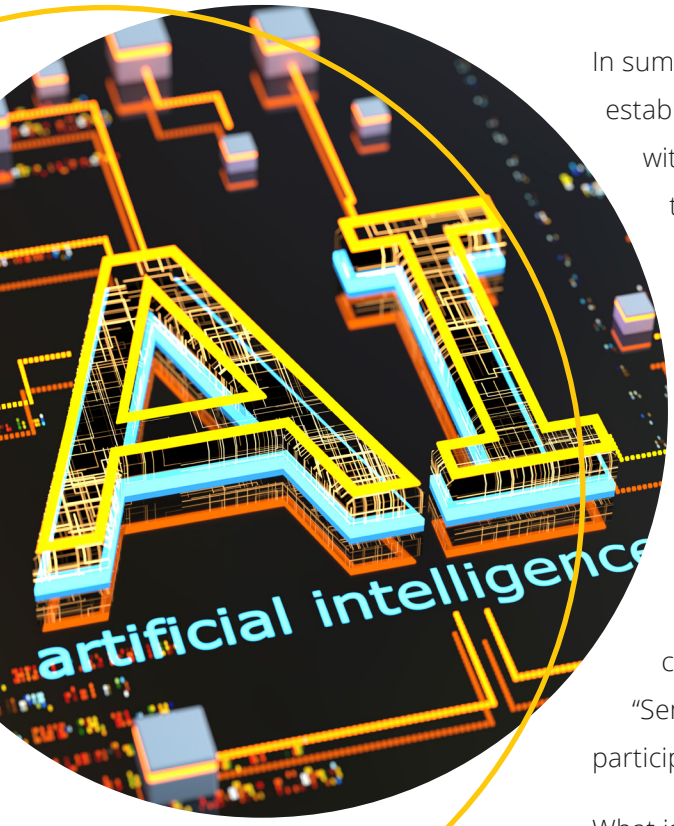
Other START HBCU events in late 2020 and into 2021 include:

November 2020: Five Sandians presented "Career Pathways at a National Laboratory: Industry and Academia—the Best of Both Worlds" to graduate students in NCA&T's "Accelerate to Industry Program."

February 2021: NSU President Dr. Javaune Adams-Gaston opened a Sandia panel discussion on the importance of HBCUs to kick off Black History Month.

April 2021: Sandia and FAMU collaborated on the first "Sandia National Labs Knowledge Exchange (SNAKE) Series" event. After Sandia's Dr. LaRico Treadwell discussed the mission application space for the materials science spectrum at the first monthly seminar, a discussion on developing fault-tolerant materials to support the Sandia mission led to a proposal by Treadwell and FAMU's Rebekah Sweat, which was ultimately funded by NNSA and now has five FAMU students, ranging from undergraduate to Ph.D., working alongside the FAMU professors.

SANDIA INTERNS RESEARCH HYPERSONIC AUTONOMY SOLUTIONS AT AutonomyNM BOOTCAMP



In summer 2020, the Autonomy for Hypersonics (A4H) Mission Campaign established an AutonomyNM Bootcamp lecture series in conjunction with ten university collaborators from across the country. With the support of Sandia CRO and SAA program champion Susan Seestrom, approximately 30 student interns and 12 Sandia technical staff participated in the series of eight virtual AutonomyNM Bootcamp lectures, spread over 10 weeks. The participants gained knowledge on building advanced autonomous systems from leading academic experts, including professors from Georgia Tech, U of Illinois, and UT Austin.

Interns applied lessons and concepts introduced by each professor in a simulation environment. The SAA team plans to continue to support the growth of this program and is exploring a "Semester-at-the-Labs" concept that would provide course credit for participation.

What is AutonomyNM? AutonomyNM fosters collaboration with external partners to enable innovative research that can be spun-in for national security and spun-out for commercialization. This is accomplished through three critical phases: (1) helping Sandia identify, explore, and spin-in novel ideas that provide transformative autonomy solutions, (2) creating paths that allow Sandia autonomy and AI researchers and their collaborators to take their innovative solutions outside of the Labs through spin-off ventures, and (3) developing a pipeline of autonomy and AI talent for the Labs.

A new AutonomyNM facility allows Sandia subject matter experts to work alongside external AI researchers to adapt breakthrough technologies for unique mission contexts. AutonomyNM also provides an R&D testbed for modeling and simulation and for live/virtual/constructive experimentation. By being co-located, Sandia employees will gain the know-how to leverage relevant AI and machine learning solutions and tailor them to fit Sandia's advanced systems and mission needs.

SANDIA, UNM, GEORGIA TECH AND PURDUE CONTINUE ACADEMIC ALLIANCE PARTNERSHIPS TO ENABLE GROUNDBREAKING RESEARCH

Sandia signed new MOUs with academic partners Georgia Tech, Purdue and UNM during 2020. Both Georgia Tech and UNM MOUs focus on (1) solving big problems, (2) sustaining and engaging human capital, and (3) accelerating technology adoption in Sandia's Research Challenge areas. The MOU at Purdue focuses on: (1) hypersonic flight systems, (2) cyber resiliency and resilience in complex systems, (3) trusted systems and communications, and (4) advanced data science.

Virtual ceremonies were held for each signing with Sandia CRO Susan Seestrom in attendance. Executive Vice President for Research Chaouki Abdallah signed for Georgia Tech. Provost and Executive Vice President for Academic Affairs James Holloway signed for UNM, and Executive Vice President for Research and Partnerships Theresa Mayer signed for Purdue. Mayer noted, "Sandia National Labs is a recognized world leader in technology research and implementation. This partnership will allow us to work together to solve significant national issues and problems that no one institution could address alone."

Pictured: *Susan Seestrom, Sandia Associate Labs Director for the Advanced Science and Technology Division and CRO*


GEORGIA TECH
ATLANTA, GA

ACCOMPLISHMENTS

KEY LEADERSHIP

Georgia Tech

Chaouki Abdallah
Executive Vice President for Research

Olof Westerstahl
Associate Director Strategic Industry Collaborations, Sandia Research Engagements

Remi Dingreville
Adjunct Assistant Professor, Mechanics of Materials (Based at Sandia National Labs)

Rob Butera
Vice President for Research Development and Operations

Sandia Labs

Rebecca Horton
Senior Manager in Center 1900, Campus Executive

Andre Claudet
Manager in Center 1900, Campus Partnership Manager

Scottie-Beth Fleming
Recruiting Lead

ADDRESSING SERIOUS COUNTERFEIT CONCERNS IN THE NATIONAL SECURITY SUPPLY CHAIN

An Advanced Persistent Threat (APT) actor is suspected to be responsible for the global cyber-attack via a U.S.-based software company, who disclosed late in 2020 that up to 18,000 customers including sectors of the federal government were running compromised software.

CONTRIBUTOR SPOTLGHT

Santiago Grijalva

Georgia Tech's Santiago Grijalva advises the U.S. electricity industry on smart grid interoperability standards and frameworks and grid modernization, and he is a pioneer in decentralized power system control and energy internet. Grijalva, with expertise in computer science and electric power systems, is a leading researcher on smart power systems and renewable energy integration.

Cybersecurity in the supply chain is not a problem affecting only IT. The broad risks touch sourcing, vendor management, supply chain continuity and quality, transportation security and many other enterprise-wide functions. The DOE Office of Cybersecurity, Energy Security, and Emergency Response (CESER) is focused on improving energy infrastructure security, supporting the national security mission, and funding research across the U.S. through awards.

Georgia Tech, named No. 1 in undergraduate cybersecurity education by *U.S. News and World Report*, in 2020 and 2021 respectively, received a two-year, $2 million award from DOE CESER to advance supply chain cybersecurity that includes a $200 thousand subcontract and collaborations between Santiago Grijalva and Sandia's Ali Pinar. Grijalva is a Georgia Power distinguished professor and director of the Georgia Tech Advanced Computational Electricity Systems (ACES) laboratory. Pinar is a principal member of Sandia's technical staff, distinguished member of the Association for Computing Machinery, and respected expert in network analysis and graph mining. Together, they are applying graph algorithms to real-world problems.

"The GridTrust: Electricity Grid Root-of-Trust Decentralized Supply Chain Cyber-Security" project will address counterfeit/cloned components or potentially altered devices. This collaboration is related to the Science and Engineering of Cybersecurity by Uncertainty Quantification and Rigorous Experimentation (SECURE) Grand Challenge at Sandia, which focuses on developing a foundation for cyber modeling and experimentation to catalyze the use of quantitative metrics and analytical evidence, to inform high-consequence national security decisions. This GridTrust project has its roots in a 2019 Sandia Day event held at Georgia Tech that helped to facilitate institutional connections.

HYPERSONIC RESEARCH IS AT THE CENTER OF MANY SANDIA-GEORGIA TECH COLLABORATIONS

***Pictured:** Sandia helps U.S. defense agencies understand the physics associated with aircraft flying more than five times the speed of sound through the use of its hypersonic wind tunnel.*

Hypersonic, which is defined as greater than five times the speed of sound, is generally considered to be the point at which aerodynamic heating could have a significant impact on vehicle performance. Vehicle shape changes in hypersonic flight, creating challenges for flight control. DOE's past investments into hypersonics have fueled the nation's current warfighter capability, and DOE is continuing to invest in the future of hypersonics technology development through Sandia's Autonomy for Hypersonics (A4H) Mission Campaign.

Ani Mazumdar, previously a postdoc with Sandia's High Consequence Automation and Robotics Group, is now a Georgia Tech assistant professor in the George W. Woodruff School of Mechanical Engineering and adjunct professor in the Daniel Guggenheim School of Aerospace Engineering. Mazumdar is a valuable contributor to the A4H Mission Campaign. His work in motion primitives has been instrumental in several of A4H's rapid trajectory generation projects and is currently being leveraged to develop a library of physics-constrained trajectories for in-flight path updates to accommodate changes in mission objectives. Some of his work was included in a recent joint Georgia Tech and Sandia publication for the American Institute of Aeronautics and Astronautics SCITECH 2021 conference. Mazumdar's support and

collaboration goes beyond A4H-funded research, however. He provided support for the AutonomyNM Bootcamp, which is designed to attract collaborative research in AI and autonomy, and he developed a talent pipeline in these critical fields for Sandia. Mazumdar referred several students to the program and is currently working with his Georgia Tech students through a Vertically Integrated Projects course that assists Sandia and the new AutonomyNM robotarium by providing a simulation environment and a fixed-wing platform for hardware implementation.

The 30 AutonomyNM Bootcamp interns in summer 2020 gained exposure to Sandia's unique national security mission and hypersonic research and development. They also gained valuable experience by working on the first two drone systems. Using the drones, the Labs will test new algorithms for autonomous navigation, guidance and control, and target recognition. The AutonomyNM drones will provide Sandia an agile platform to quickly evaluate algorithms and technologies for autonomous flight before incorporating them into larger flight systems and tests. These drones will fly in the new indoor high-bay robotarium, a facility that also provides collaborative office space for visiting AutonomyNM professors. Virtual field days for the AutonomyNM interns were held August 4-6, 2020. Mazumdar said, "The AutonomyNM program gave two of my students a unique opportunity to work directly with some of the world's leading experts in hypersonics and guidance/navigation/control. They gained knowledge in two critical areas: (1) understanding the unique challenges faced by algorithms intended for hypersonic flight, and (2) appreciating the multidisciplinary nature of hypersonics research that must combine understanding of high-speed aerodynamics, thermal effects, flight mechanics, feedback control, and artificial intelligence."

CONTRIBUTOR SPOTLGHT

Ani Mazumdar

Georgia Tech's Ani Mazumdar studies robot mobility with the goal of understanding and achieving agile, versatile, and efficient robot behaviors in unstructured environments. When he was a Sandia postdoc in Albuquerque, he and his team participated in the 2015 DARPA Robotics Challenge Finals. "Systems that can reconfigure have the potential to function effectively in unstructured environments by changing their gearing, shape, or control architecture to best match the changing conditions."

FACILITATING USE OF ARTIFICIAL INTELLIGENCE FOR MISSION PRIORITIES

A new AI co-design center, launched in 2020, will allow scientists at Georgia Tech, and Sandia and Pacific Northwest national laboratories to develop core technologies that are important for the application of AI to DOE mission priorities—such as cybersecurity, electric grid resilience, graph analytics, and scientific simulations. The Center for AI-focused Architectures and Algorithms (ARIAA), funded with $5.5 million from the DOE Office of Science, is centered around a concept known as "co-design," alluding to the need for researchers to weigh and balance capabilities of hardware and software. Not a physical facility, but a collaborative environment, the new center will allow researchers at their individual locations to simulate and evaluate AI hardware when employed on current or future supercomputers.

"A co-design center provides a wonderful opportunity for people with diverse backgrounds—hardware designers, theoretical computer scientists, mathematicians and domain scientists—to come together to develop solutions to a very challenging problem, the co-design of machine learning accelerators," said Sandia project lead Siva Rajamanickam, an expert in high-performance computing. As a collaborator in ARIAA,

Pictured: *Tushar Krishna's research at Georgia Tech focuses on building hardware platforms to run AI applications efficiently.*

Sandia will develop methods to effectively use emerging machine-learning devices and provide AI researchers with access to computer facilities and testbeds.

The Georgia Tech lead and ON Semiconductor Junior Professor in the School of Electrical and Computer Engineering (ECE) with an adjunct appointment in the School of Computer Science, Tushar Krishna works on custom hardware accelerators for AI. "Georgia Tech provides a great environment to carry out research in hardware-software co-design due to a rich collaborative environment across ECE and the College of Computing, and vibrant research centers such as Machine Learning at Georgia Tech and the Center for Research into Novel Computing Hierarchies that bring together researchers with experience in algorithms, compilers, architecture, circuits, and novel devices, fostering collaboration and innovation," said Krishna.

One focus for the center will be on sparse computations, a type of computation that examines many interactions, recognizing that only a few may affect the outcome to a problem. For example, there might be millions or even billions of users on a social media site, but a user cares about updates only from a few hundred friends. "Sparse computations will be a focus of the ARIAA center because the method greatly reduces the number of computations on problems with large amounts of data," noted Rajamanickam. "It is highly desirable to several computational areas of interest to DOE."

The center will collaborate closely with DOE's newly formed Artificial Intelligence and Technology Office, created by former Secretary of Energy Rick Perry to coordinate the department's AI work and accelerate the research, development, and adoption of AI to impact people's lives in a positive way.

CONTRIBUTOR SPOTLGHT

Siva Rajamanickam

Siva Rajamanickam, Sandia project lead for ARIAA, is designing architecture-aware algorithms for next-generation supercomputers. "Utilizing special-purpose computing devices to focus on machine-learning tasks should encourage rapid deployment of these technologies in several fields," Rajamanickam said. He believes designing such devices and influencing their design elsewhere is important to position the U.S. as a leader in this emerging field. "The [ARIAA] center will focus on the most challenging basic problems facing the young field, with the intention of speeding advances in cybersecurity, electric grid resilience, physics and chemistry simulations and other DOE priorities."

IDENTIFYING POTENTIAL CAPABILITIES OF MALWARE WITH A NEW MODELING PROTOTYPE

Identifying the potential capabilities and payloads of malware is critical to remediating and containing the threat to infrastructure.

Critical U.S. facilities, such as nuclear and electrical plants, are the constant targets of advanced adversaries delivering malicious software, which is designed to harm or exploit programmable devices, services or networks. Identifying the potential capabilities and payloads of malware is critical to remediating and containing the threat to infrastructure.

The malware threat extends to industrial control systems (ICS) and their graphical user interface systems known as SCADA (which stands for supervisory control and data acquisition), which are also vulnerable to exploits by attackers. A Department of Homeland Security ICS malware trends whitepaper pointed out that "the discovery of vulnerabilities in ICS devices is still a growing field and that the number of discoveries is likely to increase as researcher interest expands."

Enter Sandia's cybersecurity specialist Moses Ike and Georgia Tech's Brendan Saltaformaggio in the School of Electrical and Computer Engineering. Ike's cybersecurity research on protecting critical infrastructure from ICS malware, in collaboration with Saltaformaggio's work in hardware constraints estimation for ICS malware triage, resulted in Context-Aware Concolic Execution Engine (CACEE), an initial prototype for modeling unknown hardware features in ICS malware.

CACEE's new capability is essential to effectively reverse engineer malware in critical infrastructure systems because ICS malware targets SCADA networks and exploits connected physical components such as programmable logic controllers. Initial tests of CACEE on real-world ICS samples demonstrated success in locating malware code features with efficiency and accuracy and eliminates the "analyst-in-the-loop" limitation.

CONTRIBUTOR SPOTLGHT

Brendan Saltaformaggio

Brendan Saltaformaggio serves as the director of the Cyber Forensics Innovation (CyFI) Laboratory at Georgia Tech, which investigates advanced cybercrimes and the analysis/prevention of next-generation malware attacks. Saltaformaggio said, "CACEE will enable the U.S. government to generate emulation environments by leveraging automated analysis techniques, using only firmware images as released by the manufacturer, extracted from a device, etc." Saltaformaggio participated with Sandia in Tracer FIRE events to train students through competitive scenarios utilizing malware from real-world cyber campaigns.

CONTRIBUTOR SPOTLGHT

PROVIDING MORE RESEARCH OPPORTUNITIES FOR GRADUATE STUDENTS

Raheem Beyah (top)
Robert Butera (bottom)

Raheem Beyah, Georgia Tech's Dean of the College of Engineering, and Robert Butera, Georgia Tech's VP for Research Development and Operations, helped facilitate the LDRD agreements with Sandia.

In January 2020, Georgia Tech's Executive Vice President for Research (EVPR) Chaouki T. Abdallah signed an agreement stating that new sponsored-LDRD projects in fiscal year 2021 will receive a 1:1 match on Graduate Research Assistantships (GRA) up to one GRA per year (stipend, tuition, fringe). This program applies to new awards and annual funding increments to existing LDRD awards.

Rebecca Horton, Sandia senior manager of Academic Programs, said of the new agreement, "This 1:1 cost match is funding more real-world experience for graduate students who will work with Sandia on approved LDRD projects. It's a win-win."

UNDERGRADUATES PARTICIPATE IN STATE-OF-THE-ART PROGRAM AT NANOSCIENCE RESEARCH FACILITY

Eight undergraduate students from Georgia Tech were selected for a unique 2020 pilot initiative held at the Center for Integrated Nanotechnologies (CINT), a DOE-funded nanoscience research facility. The students, selected by Georgia Tech's Jud Ready, Institute for Materials (iMAT) deputy director and Georgia Tech Research Institute research engineer, conducted research for two months with a CINT scientist on an LDRD-related project in CINT's collaborative, multidisciplinary environment. They were also provided access to state-of-the-art expertise and instrumentation.

The 2020 pilot concluded with students presenting their work for Sandia researchers and Georgia Tech faculty. Three of the eight students continued through the fall with one remaining on site at CINT to continue his research with his mentor; the other two worked virtually from Georgia. The talent pipeline initiative, funded jointly through Sandia and Georgia Tech's 1:1 cost matching agreement, was led by CINT manager, Jeff Nelson, and continues into 2021 with four new Georgia Tech students who began work at CINT on June 1 along with seven other interns from SAA schools.

Pictured: *The Center for Integrated Nanotechnologies in Albuquerque, New Mexico*

CONTRIBUTOR SPOTLGHT

Thomas Marchese

Thomas Marchese, one of the undergraduate participants in the CINT User Group community, studied materials science and engineering at Georgia Tech. He was excited to expand his research on mechanical properties of solid-state battery materials at CINT. "The research I've conducted and skills I've learned at Sandia have properly prepared me for my long-term goals which include graduate school and a position at a national lab or in academia." He drafted a standard operating procedure for the Cryo Focus Ion Beam/Scanning Electron microscope and the associated transfer systems which will help train many users for years to come on the device.

U of ILLINOIS

CHAMPAIGN, IL

ACCOMPLISHMENTS

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LEVERAGING COGNITIVE SCIENCE RESEARCH PRINCIPLES TO STUDY THE HUMAN ELEMENT INVOLVED IN MISSION-CRITICAL DOMAINS

Pictured: *Sandia's Susan Adams wears a cap dotted with electrode sensors that are injected with gel for a research experiment on assessing language comprehension.*

Language is typically thought of in terms of spoken or written communication, but anytime a word is seen or heard, it is processed in the brain as electrical activity. Event-related potentials (ERPs) are the electrophysiological brain response resulting from a stimulus such as a specific sensory, cognitive or motor event. In two different collaborative LDRD projects with University of Illinois Urbana-Champaign (U of Illinois), novel methods are being developed to assess how individuals process language and computer code.

In one project, an individual's language proficiency is being evaluated using ERPs, which are known to be associated with language processing. The response can be time-locked to events of interest, such as the onset of a stimulus in a person's environment, providing detailed information about how that stimulus was processed by the brain. These ERPs are well-characterized and highly consistent across individuals.

While this project builds on existing ERP research to develop testing and data analysis methods that can assess bilingual or multilingual individuals' proficiency in each of the languages that they can comprehend, Sandia PI Laura Matzen said, "Assessing a person's linguistic abilities without advance knowledge of those abilities requires innovative research outside of the scope of any prior published work."

Sandia's academic partners at U of Illinois, including Professor Kara Federmeier in the Department of Psychology and Neuroscience Program, Professor John Willetts in the Aerospace Engineering Department, and graduate student Lin Khern Chia, designed a well-controlled stimulus set of English words to model the structure of knowledge in the semantic memory. Although all of the words presented to participants were in English, the team included individuals in the study with diverse language backgrounds and varying levels of English fluency.

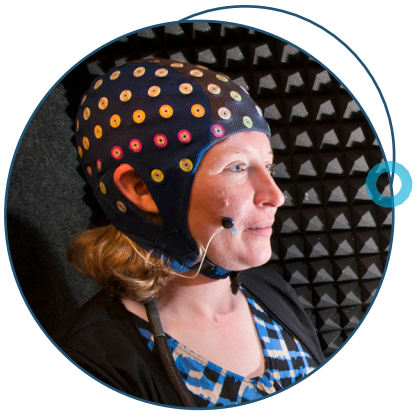
The plan to utilize electroencephalograms (EEG) to record each participant's brain electrical activity with millisecond-level resolution was

(Continued on next page)

CONTRIBUTOR SPOTLGHT

Laura Matzen

Laura Matzen is a distinguished member of Sandia's technical staff whose primary interest is using cognitive neuroscience methods to understand how humans process and encoded information in memory. Sandia originally funded Matzen as a graduate student at U of Illinois through the Excellence in Engineering Fellowship. After joining the Labs full time, she recruited three full-time staff and two interns to Sandia from U of Illinois. Speaking on the ERP study and the shift to integrate machine learning, she said, "By Sandia funding a project that is so interdisciplinary, our team could possibly change the way the field approaches this data in the future."



put on hold until the summer of 2021, after the pandemic. During the quarantine, the team pivoted to an online study allowing participants to respond to a word-length judgment task. Several unexpected positive outcomes resulted from the change. One, it provided them with a more diverse range of individuals who could be located anywhere in the world. Two, the relatively low cost allowed both teams to collect a much larger sample size (i.e., hundreds of participants instead of 20-30). Matzen also noted that the shift in the approach helped them realize the value of machine learning techniques for data analysis, saying. "Machine learning isn't traditionally used with EEG research, but by working with Christina Ting, a Sandia expert in machine learning, we saw a different way to approach the data, which is paying off in novel results."

Mallory Stites, a collaborator on Laura Matzen's project and fellow U of Illinois cognitive psychology Ph.D. graduate, has a separate collaborative LDRD with U of Illinois. In her project, they're using eye-tracking to understand the moment-to-moment processes involved in reading and understanding code. Due to in-person data collection restrictions imposed during the COVID-19 pandemic, the Sandia team developed a novel experimental paradigm called "artificial foveation" to collect eye-tracking-like data remotely by tracking mouse movements on a screen while a person reads code line-by-line. The U of Illinois and Sandia teams compared differences in viewing patterns between expert and novice programmers as they solve a range of problems in different programming languages and environments, with the goal of understanding the key features that drive how people make sense of code. Collaborators at U of Illinois include Dr. Kiel Christianson, professor and chair of the Educational Psychology Department and Dr. Nigel Bosch, assistant professor in the Educational Psychology Department and the School of Information Sciences. These two projects together demonstrate how Sandia is leveraging basic cognitive science research principles to rigorously study the human element involved in mission-critical domains.

DELIVERING PREDICTIVE, AGILE REENTRY TOOLS

If you watch any documentaries about space missions, it's frequently stated that the most dangerous times for the flight are the 10 minutes after launch and the time of reentry. With regard to reentry, there are critical requirements that must be balanced including deceleration, heating, and the accuracy of landing/impact. Model inputs for some of the nation's most advanced reentry code is based on a lower-fidelity predecessor from the 1960s. Experts believe the physics models and material properties were calibrated to flight-test data, compensating for model-form error in the legacy code. The validity of such calibrative models is limited in scope, and the mission is rapidly evolving beyond these confines.

An LDRD project led by Sandia PI Jeff Engerer and U of Illinois reclaims the technical basis for reentry materials and modeling, defines the process for characterizing and predicting performance of new materials, and will deliver a predictive model. While full-physics experiments are best for producing calibrative models, predictive models are better developed when the experimental conditions are well-known, and later validated in full-physics environments.

While the project focuses on the models and parameters required by reentry codes, the results will also improve the technical basis for a variety of harsh environments. The identified tasks leverage Sandia's models, infrastructure and expertise, benefit from collaborative experiments at Montana State University that characterize pyrolysis-gas chemistry, and are assisted in chemistry simulations by U of Illinois professor Kelly Stephani and student Mitchell Gosma, and in mesoscale imaging/modeling by U of Illinois professor Francesco Panerai and student Collin Foster.

These improvements better position the nation to meet the demands of rapid development cycles and technological challenges on the 20-year horizon.

USING ELECTRON DYNAMICS AT THE ATOMIC SCALE TO ADVANCE MODERN ELECTRONICS

Space-based microelectronics found on such things as satellites, or components used in medical nuclear physics therapy, ion-beam surface modification processes, or sensors in civilian nuclear reactors are examples of electronic components that can be subjected to radiation damage where electronic stopping is important, according to Sandia researcher Remi Dingreville. To advance silicon-based electronics, research is needed around projectile ions with high kinetic energies since the transition can damage material structures. In particular, defects created by fast incident projectiles modify a material's electrical and mechanical properties and, thus, operational performance. This has profound consequences. Understanding the many underlying fundamental questions creates an immense need for predictive modeling.

For the purpose of one LDRD project, researchers Cheng-Wei Lee and André Schleife from U of Illinois, and Sandia researchers James Stewart, Remi Dingreville and Matthew Foiles are striving to push silicon-based electronics to

the next level by achieving quantum bits through the introduction of dopants to highly precise spatial control. (Dopants change the electrical fields of silicon-based electronics.)

The researchers used ion irradiation because real devices require precise positioning of the dopants and their spacing. Through this commonly-used method, they accelerated an ion in an electric field and shot it into a silicon target. The projectile ion experienced a decelerating stopping force in the target due to its interaction with electrons and nuclei with the complicated multiscale interactions, ultimately determining the final position of the ion inside the target.

Taking the method a step further, the researchers combined accurate first-principle electronic-structure models with large-scale atomistic molecular dynamics simulations. This multiscale approach revealed real-time electron dynamics and captured the electron-ion interactions at the atomic scale. The simulations revealed an intricate relationship between electronic stopping forces and the charge equilibration as the projectile moved through the target material. Next, they incorporated the electronic-stopping data from these simulations into longer time and larger length scale molecular dynamics simulations to predict the outcome of ion irradiation. The coarse graining significantly surpassed existing empirical models that ignore the atomistic structure of the target entirely. It also demonstrated that damage formation in a target is significantly affected by electronic stopping.

Utilizing such multiscale approaches helps fine-tune experimental parameters and could potentially help achieve better spatial control over dopant positioning in silicon, which is critical for advancing modern electronics. A full article is available in A*merican Physical Society*.

CONTRIBUTOR SPOTLGHT

André Schleife

André Schleife directs research at U of Illinois as an associate professor in Materials Science & Engineering. His group's work revolves around excited electronic states and their real-time dynamics in various materials using accurate computational methods and making use of modern super computers. Speaking of the ion irradiation project, Schleife said, "My experience with first-principles simulations of electronic excited states in materials in general and, more specifically, of electronic stopping in metals and semiconductors prepared me for this work."

EXAMINING CICADA WINGS TO SPARK IDEAS FOR ARTIFICIAL STRUCTURE DESIGN

What unique features can be found in cicada wings, and how could those properties be used to design other structures? To answer these questions, Marianne Alleyne and Nenad Miljkovic from U of Illinois, Jessica Kustas from Sandia, and other researchers from the U.S. Army Corps of Engineers studied two cicada species, Neotibicen pruinosus and Magicicada casinnii. "We chose to work with wings of this species of cicada because our past work demonstrates how the complex nanostructures on their wings provide an outstanding ability to repel water. That is a highly desirable property which will be useful in many materials engineering applications, from aircraft wings to medical equipment," said Alleyne, an entomology professor. Kustas added, "Previous research had already shown that some species of cicada illustrated superhydrophobicity, antimicrobial, and self-cleaning properties on their wings. Our hope was to expose the differences in species to build an understanding as to the mechanisms by which these species possess these features, and for the species that do not, why they don't. The overall hope was/is to implement the mechanisms that create these features into man-made surfaces to create multi-functional surfaces."

Sandia first developed a method allowing for a gradual extraction of the compounds on the surface of the wing without damaging the structure, then they enclosed it in solvent and microwaved slowly. Through this process, they discovered that cicada wings are coated in hydrocarbons, fatty acids and oxygen-containing molecules such as sterols, alcohols and esters. The study also revealed that altering these surface chemicals changes the nanopillar structure which, in turn, changed the wings' wettability and antimicrobial characteristics.

These preliminary findings offer insight into the intersecting roles of structure, chemistry, and function. Understanding how the wings work together may help scientists to design artificial structures with similar surface traits that would benefit numerous applications. Read more about this study in Advanced Materials Interfaces.

This is a highly desirable property that will be useful in many materials engineering applications, from aircraft wings to medical equipment.

CONTRIBUTOR SPOTLGHT

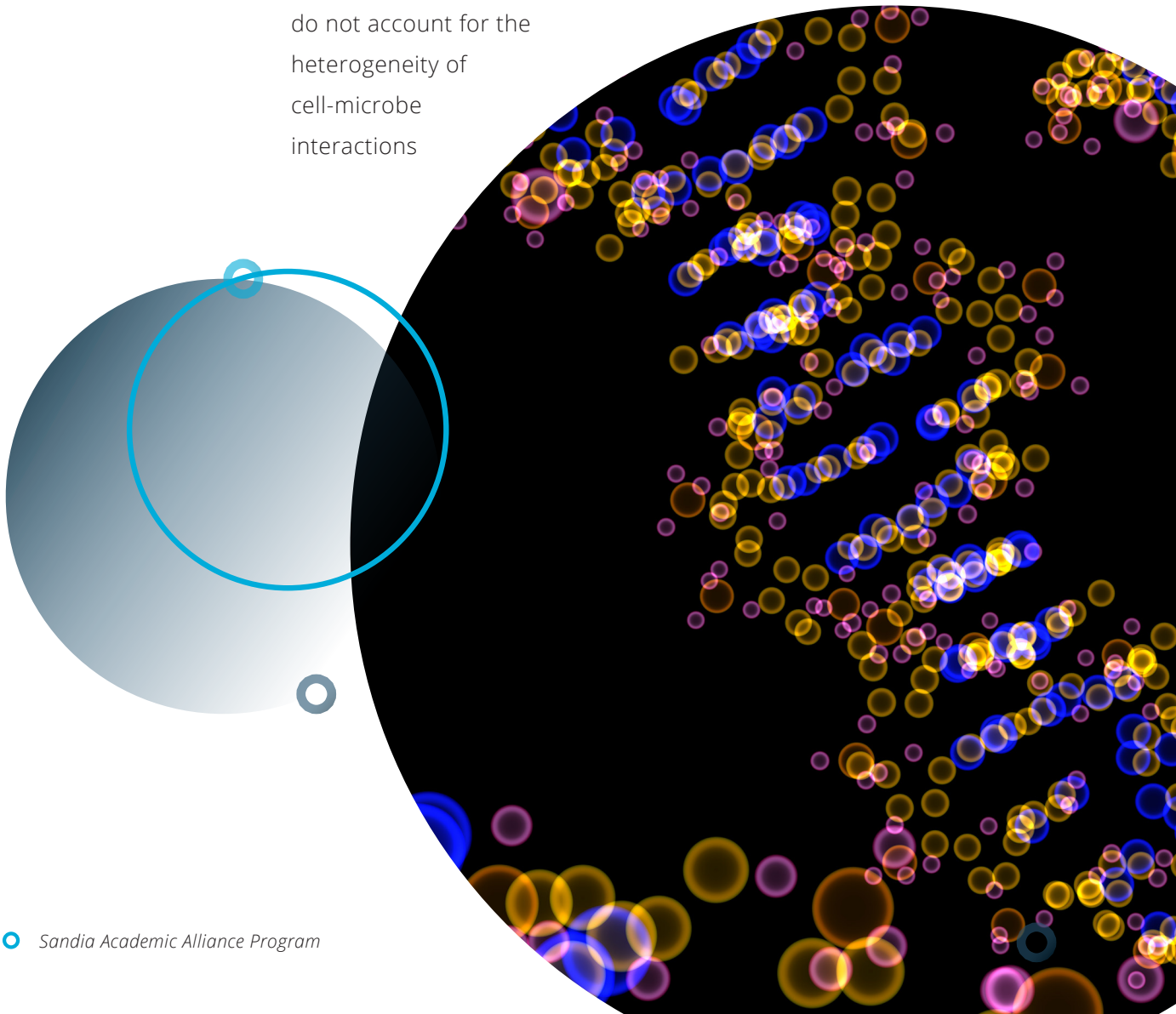
Nenad Miljkovic, Marianne Alleyne, and Dan Cropek

Nenad Miljkovic, left, Marianne Alleyne, center, and Don Cropek, right, are involved in biological research at U of Illinois. Alleyne, assistant professor in entomology, is interested in how biological systems can lead to innovative design in human society. "Insects can inspire innovation. For instance, the way insect cuticle is formed and how it is recycled can teach us a lot about the hierarchical organization of many resilient materials, about conservation of resources, and about adaptability."

EXAMINING INFECTIONS AT SINGLE-CELL RESOLUTION COULD BE A GAME CHANGER

The human microbiome is a community of trillions of microorganisms including bacteria, fungi and viruses that live on and inside the human body. Not all microbes are dangerous, but some are pathogens that could cause havoc if they increase exponentially or move to environments where they shouldn't exist. For example, with regard to COVID-19 virus, some recent lab studies suggest that a compromised gut microbiome with depleted levels of bacteria species may play a role in a patient's severity.

The current genetic sequencing methods employed when evaluating a complex microbiome collect RNA from bulk samples that contain large numbers of cells, and therefore do not account for the heterogeneity of cell-microbe interactions



CONTRIBUTOR SPOTLGHT

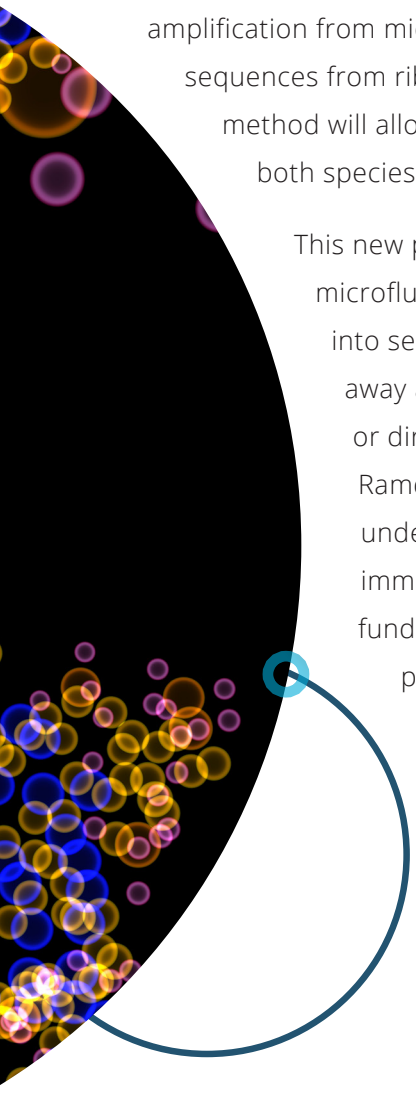
Ramdane Harouaka

Ramdane Harouaka, Sandia microfluidics engineer in biotechnology and bioengineering, has influenced pharmacology and personalized therapeutics for cancer patients through his work in biomedical engineering. His research interests include microfluidics/micro-electro-mechanical systems as enabling platform technologies, single cell resolution analysis, and biosensing.

that can occur within a complex microbiome. This type of collection is ineffective because it averages interactions between cells across time and organisms and obscures the information needed to understand stability or progression of signatures that would differentiate pathogenic activity from non-harmful interactions. More recent barcoding strategies have enabled high-throughput processing of single human cells for RNA sequencing, but they don't effectively capture RNA from bacteria and other microbes.

A team of researchers at Sandia Labs and U of Illinois are developing a versatile platform to allow for the examination of wide varieties of multiorganism pairings within microbiome systems at single-cell resolution. Their proposed innovation is to develop new biochemistries for RNA-sequencing library preparation that will allow simultaneous amplification from microbes and host cells, while avoiding undesirable sequences from ribosomal RNA. The team hypothesizes that this method will allow amplification of the entire transcriptomes from both species of a cell-microbe pair, which is unprecedented.

This new protocol is compatible with easily fabricated microfluidic platforms, which will segregate single cells into separate reaction chambers while also washing away any uninvolved microbes that are not internalized or directly attached. "Through this work," Sandia's Ramdane Harouaka said, "researchers will better understand the role of the microbiome in modulating immunity and susceptibility to infection and drive fundamental research relevant to national security, public health, and bioenergy applications."



LEADING INNOVATOR, TIAN MA, COLLABORATING WITH U OF ILLINOIS ON NUMEROUS REMOTE SENSING PROJECTS

Pictured: *Sandia computer scientist Tian Ma, who has earned numerous awards for his work in remote sensing systems, is involved with several collaborations with U of Illinois.*

Tian Ma, a distinguished R&D computer scientist, is a nationally recognized leader in research and engineering, particularly, remote sensing systems. With 17 years of experience at Sandia, he is known for his expertise in detection algorithms and as a pioneer in the field of tracking systems, especially in nuclear nonproliferation. His work on state-of-the-art algorithms for operational systems have solved U.S. government technical challenges and provided new, much needed mission-enabling capabilities.

In real-time remote sensing applications, data are continuously flowing into the system; Ma's research focuses on detecting objects of interest, tracking the motion, and classifying the types of object in near-real-time.

Currently, Ma is the PI for an LDRD project on "Robust Scalable Detection and Tracking for Wide Area Surveillance."

Ma collaborated with several U of Illinois science and engineering faculty including Ramavarapu Sreenivas from Industrial and Enterprise Systems Engineering, Minh Do from Electrical and Computer Engineering, Gul Agha from Computer Science, and Jagadeesh Yedetore and Heather Filippini with the U of Illinois Applied Research Institute. These partnerships have involved nine graduate and five undergraduate university students. In 2020, Ma expanded his collaboration with Professor Venugopal Veeravalli to investigate the theory of the quickest change detection on heterogenous sensor networks.

UNM

ALBUQUERQUE, NM

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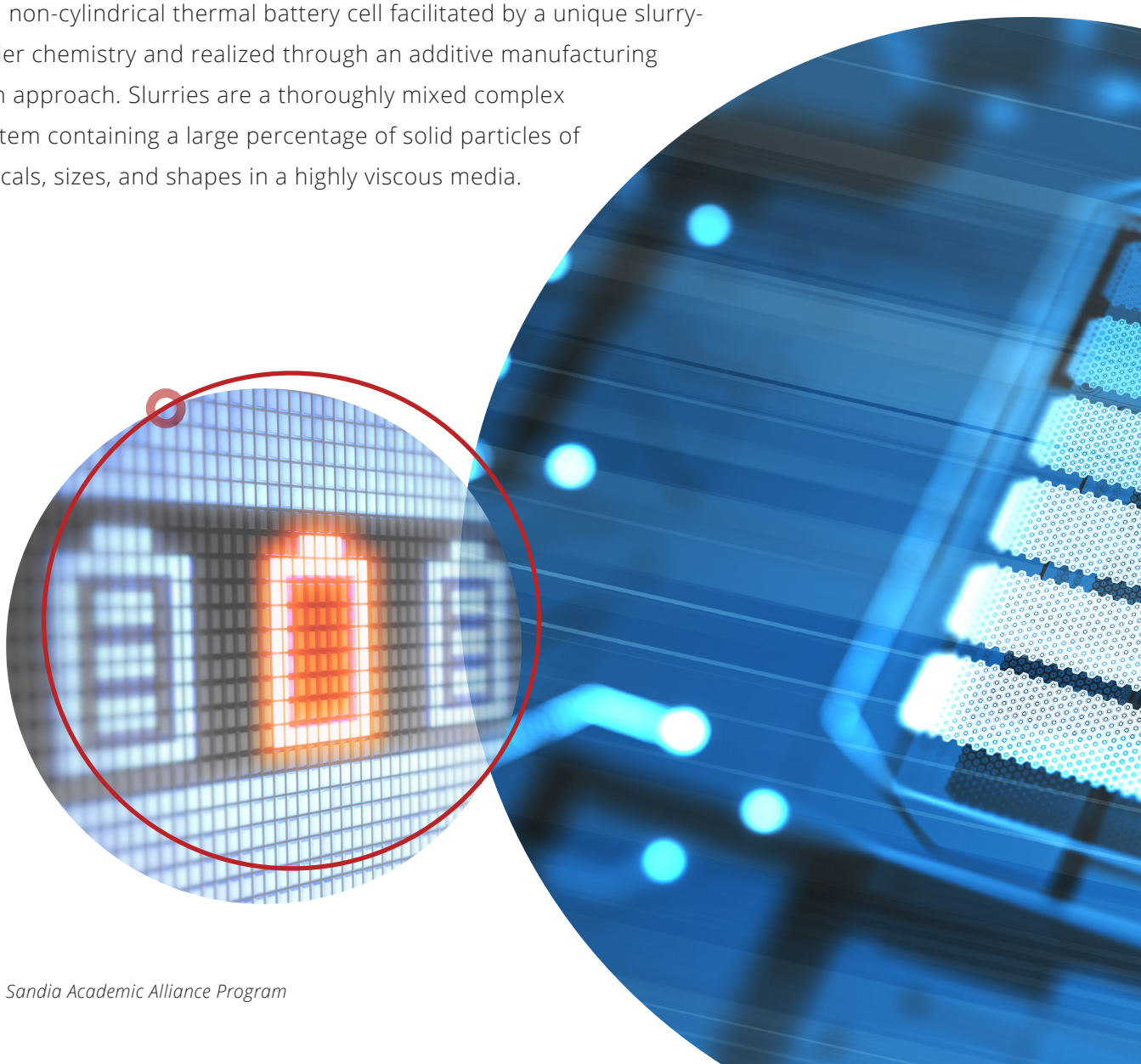
HIGH-POWER APPLICATIONS GET CHARGED UP WITH UNCONVENTIONAL BATTERIES

The basic principles involved in a thermal battery occur at the atomic level of matter, with energy being added to or taken from either a solid mass or a liquid volume that causes the substance's temperature to change. Some thermal batteries also involve causing a substance to transition thermally through a phase transition, which causes even more energy to be stored and released.

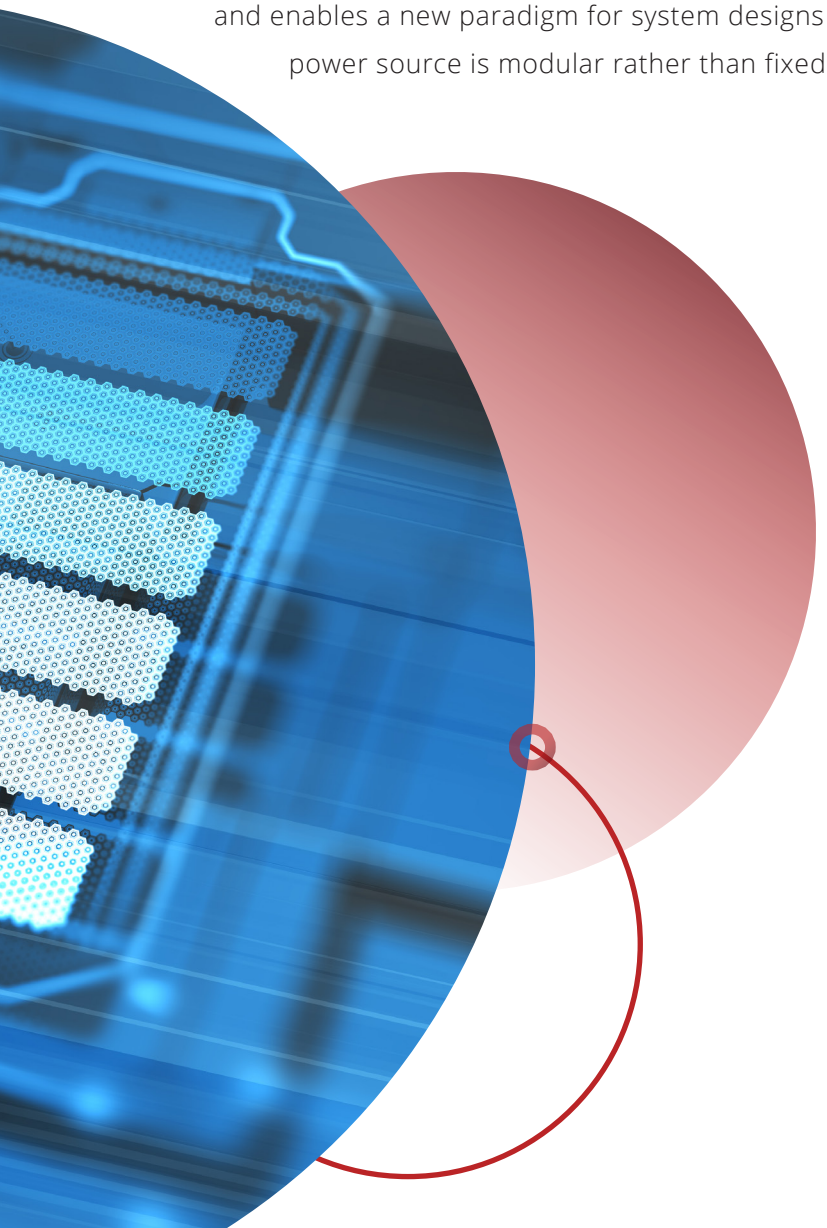
Thermal batteries have many benefits including being rugged, reliable, high power, able to withstand severe stresses such as acceleration, shock, vibration and spin, have a long shelf life, and can be designed and optimized for power or capacity. These batteries are essential power sources in a broad range of systems that restrict them to cylindrical form factors, small diameters, and excessive thickness.

An LDRD project done in collaboration with UNM is focused on the development of a large area, low profile, and non-cylindrical thermal battery cell facilitated by a unique slurry-processed binder chemistry and realized through an additive manufacturing (AM) fabrication approach. Slurries are a thoroughly mixed complex suspension system containing a large percentage of solid particles of different chemicals, sizes, and shapes in a highly viscous media.



AM offers an attractive and scalable approach to fabricating thermal battery films in large form factors. Gravure printing, a particularly attractive AM technology for this application, is capable of rapid and conformal deposition of large areas with small film thickness and precise overlay capabilities. Slurry formulations will address the rheological needs of the AM fabrication process while still meeting battery needs in terms of film adhesion, cohesion, and electrochemical performance.

The realization of this involved process would be a thin, conformal thermal battery cell produced via AM that retains high functionality and enables a new paradigm for system designs in which the power source is modular rather than fixed.



CONTRIBUTOR SPOTLGHT

Fernando Garzon

Fernando Garzon, a UNM professor in the Department of Chemical and Biological Engineering, was previously a faculty research scientist in Sandia's Advanced Materials Laboratory. He stated of his experiences, "The LDRD program definitely helped me grow collaborations with the Power Sources Technology Group (PSTG). I am advising three students within PSTG and collaborating on other projects. I have also met other Sandia staff who are engaged in energy research and submitted LDRD proposals in the battery research areas."

PROMINENT QUANTUM RESEARCH FUNDED AT UNM AND SANDIA

If we had to identify a theme for 2020, most of us would say "COVID-19," but for UNM and for many national labs including Sandia, the theme could also be quantum.

DOE is making significant investments in the nation's quantum computing capabilities through the creation of five Quantum Information System Centers. UNM will be involved with the Quantum Systems Accelerator (QSA) led by Lawrence Berkeley National Laboratory funded at $115 million over the next five years. The center's multidisciplinary expertise and network of world-class research facilities will enable the team to co-design the solutions needed to build working quantum systems that outperform today's computers. The goal is to deliver prototype quantum systems that are optimized for major advances in scientific computing, discoveries in fundamental physics, and breakthroughs

in materials and chemistry. In addition to furthering research that is critical to DOE's missions, this foundational work will give industry partners a toolset to expedite the development of commercial technologies.

The UNM Center for Quantum Information and Control (CQuIC) is instrumental in growing New Mexico's participation and helping the National Quantum Initiative to extend the reach of QIS in pioneering new practical advances in quantum systems. CQuIC continues to strengthen partnerships with adjunct faculty from Sandia and Los Alamos National Laboratory who provide a broader focus for CQuIC's quantum information science (QIS) research, as well as employment opportunities for CQuIC graduate students.

Ivan Deutsch, UNM Regents' Professor and CQuIC director said of the center, "The QSA will catalyze national leadership in QIS to co-design the algorithms, quantum devices, and engineering solutions needed to deliver certified quantum advantage in DOE scientific applications."

UNM is also a part of the Quantum Systems through Entangled Science and Engineering (Q-SEnSE) institute, funded by the National Science Foundation through its Quantum Leap Challenge Institute program. Q-SEnSE, led by University of Colorado Boulder, will promote collaboration among prominent researchers in quantum experiment and theory, science and engineering. Together, they will explore how advanced quantum sensing can enable new fundamental physics discoveries, develop and apply novel quantum technologies, provide tools for a national infrastructure in quantum sensing, and train a quantum-savvy workforce. The UNM portion of the award is $1.25 million over five years.

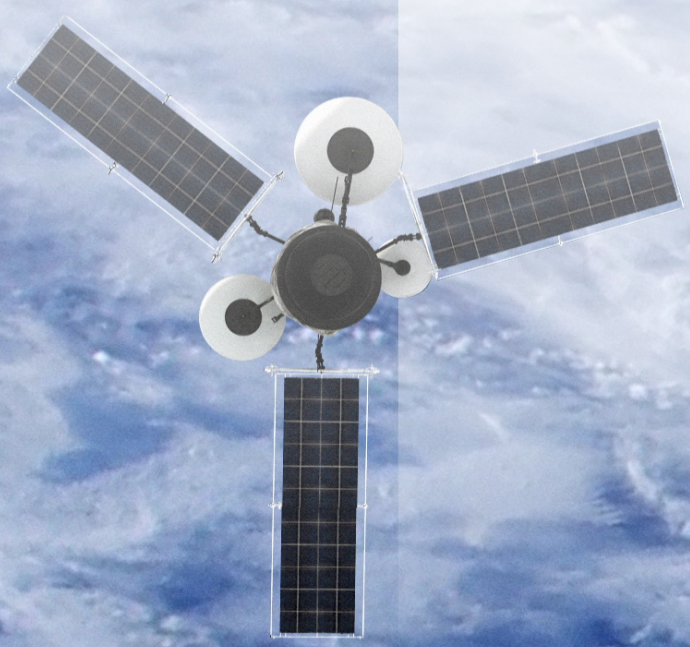
CONTRIBUTOR SPOTLGHT

Ivan Deutsch

Ivan Deutsch, UNM CQuIC Director, stated, "Curiosity-driven research has led to radical new technologies, and new knowledge and understanding drove the development of new experimental tools and rigorous theory, which defined the road map for second-wave quantum technologies. As technology has matured, the race to develop and commercialize near-term applications has accelerated." Deutsch notes that as the QIS industry ramps up, continuous feedback between basic science and technology will be essential in helping to answer questions about how much quantum complexity can be generated with a NISQ device and what conditions are needed for a true quantum advantage.

BUILDING THE WORLD'S FIRST LASER REFRIGERATED SENSOR

Remote sensing allows the physical characteristics of an area to be imaged and monitored by measuring its reflected and emitted radiation at a distance. Remote sensing instruments on research aircraft or satellites provide global measurements of data for civil, research and military purposes such as taking pictures of temperature changes in the ocean or monitoring oil spills. To operate with low noise (reduce dark current), the detectors must be cooled to a very low cryogenic temperature (~150 K – 77 K). Currently, optical refrigeration is the only cryogenic solid-state refrigeration process in the world.



During long deployments, bulky, expensive, and inefficient mechanical refrigerators are used to keep the sensors cool, but their moving parts and gasses cause vibration resulting in blurred images and reduced lifetimes through mechanical wear. Even utilizing significant progress in vibration suppression, microphonic noise becomes a limiting factor in image resolution. In some cases, mechanical refrigerators are switched off to acquire images, an action that carries significant risk of startup failure, and long cool-down times that can approach several days.

In this collaborative research project, scientists Seth Melgaard at Sandia and Mansoor Sheik-Bahae at UNM, among others, are working to take the optical refrigeration (OR) technology from academia and build the world's first optically cooled sensor. OR uses absorption of a laser to generate strong anti-Stokes fluorescence in specific materials and is currently the only cryogenic solid-state cooling technology. It has the ability to achieve the needed temperatures, is vibration free, and could provide low mass, scalable local (i.e., pixel level) cooling.

To extend OR beyond the current state-of-the-art, several engineering improvements are needed. By improving size, weight and power through the development of lightweight, compact, efficiently cooled sensors, more missions can accommodate sensor packages. Currently, no solid-state refrigeration is deployed for remote sensing applications. If successful, this technology will benefit a variety of domestic and defense applications.

While continuing work on the sensor demo, the team is searching for sponsor follow-on funding with the hopes of realizing a demo in space, perhaps on a small cube satellite. Another LDRD proposal in development is focused on demonstrating a unique aspect of photon recycling, which will further enhance efficiency.

CONTRIBUTOR SPOTLGHT

Mansoor Sheik-Bahae

UNM's Mansoor Sheik-Bahae and other researchers from UNM and Los Alamos National Laboratory used an all-optical refrigeration scheme to successfully cool a photodetector to cryogenic temperatures for the first time. Sheik-Bahae, who performed pioneering work on the physics, measurement, and applications of the cascaded second-order nonlinearities, has made key theoretical and experimental contributions to the field of solid state laser cooling and is working on ultrashort laser pulse characterization, extreme wavelength generation/detection, and semiconductor plasmonics. He is also involved with Sandia's microelectronics thrust area.

NUCLEAR ENGINEERING AND PROJECT MANAGEMENT PROGRAMS RESULT FROM UNM-SANDIA PARTNERSHIP

Pictured: *UNM's Nuclear Engineering Building*

Nuclear Security Program

Talent pipeline development is always in focus for UNM and Sandia, who partner together to educate students so they are equipped to contribute effectively and quickly to Sandia's national security mission work. It started with the signing of a strategic MOU in 2018 to advance project management and create a pipeline of project management professionals from UNM who would be qualified to work at the Labs. In September 2020, the Nuclear Security Program, embedded within the UNM Nuclear Engineering Department, was established through an MOU to provide students with the theoretical foundations, advanced methodologies, and practical skills required to secure and protect nuclear materials and facilities.

Subject matter experts from Sandia, Los Alamos National Laboratory (LANL), and UNM developed an accredited Nuclear Security Program launching in summer 2021, which is supported by the National Nuclear Security Administration's Office of International National Security. This effort, led by Sandia PI Alan Evans, who is also a UNM graduate, will prepare the next generation of experts to apply advanced engineering capabilities to the challenges faced in protecting the nuclear industry of the future. It will also enable Nuclear Security Program students to have access to renowned international nuclear security experts and the unique, real-world training facilities at both Sandia and LANL.

Hyoung K. Lee, professor and chair of the UNM Department of Nuclear Engineering, said he hopes the new agreement creates more robust opportunities for current and future UNM nuclear engineering students.

"UNM has such a phenomenal resource right in its backyard

with Sandia, so it makes sense to maximize that proximity by creating a partnership that will truly enhance students' education," he said. "We are very excited to be developing this program that we feel, with Sandia's collaboration, will offer UNM students an incredible advantage in the nuclear security field."

UNM Master of Science (MS) Project Management Program

In mid-December, the New Mexico Higher Education Department provided final approval of the UNM MS Project Management Program, fulfilling a major goal of the two-year-old agreement between UNM and Sandia that outlined their joint plans for collaboration on project management education and professional development. UNM will become one of only a handful of U.S. universities to offer the project management master's degree. The UNM MS Project Management Program will provide students with an education in project controls, project management, and leadership.

Sandia relies on project managers to deliver on national security activities in a timely and cost-effective manner and currently employs approximately 500 project management professionals, and 58% of those are UNM graduates. There is an anticipated increase for at least the next 15 years. Tristan Walters, Sandia Corporate Project Management Office manager, said, "Many factors are driving an increased and continued demand for rigorous project management, from several complex nuclear weapon modernization programs in planning and execution stages to large capital construction projects being planned to maintain and advance Sandia's capabilities... All these drivers, combined with industry expectations and trends, factor into Sandia's growing need for project management expertise."

The new program will provide Sandia with a great recruiting pipeline and save Sandia significant costs because the Labs will need only to provide program-specific training.

CONTRIBUTOR SPOTLGHT

Adam Hecht

UNM's Adam Hecht conducts research on radiation detection and simulations in service of nuclear nonproliferation. He believes that detailed knowledge of nuclear fission is important for building new concept nuclear reactors, figuring out how to detect and identify smuggled nuclear materials, or for nuclear forensics to understand where nuclear materials may have come from. Speaking on his team's research, "We're working to do very delicate measurements, atom by atom, to measure the particles coming out of fission," Hecht said. "It's basic scientific research at the moment, but it is likely to be useful when weapons inspectors try to detect nuclear material."

CONTRIBUTOR SPOTLGHT

Natalie Pitcher

Sandia University Programs technical lead Natalie Pitcher worked with Diane Peebles, NM Partnerships manager, to initiate the Research Spotlight Forum. Pitcher said, "Participation in the forum has grown steadily since the program's inception, and UNM's contributions have been vital. Forums provide an avenue for university scientists and Sandia staff to discuss ongoing research in the field followed by conversations that highlight possible avenues for collaboration."

PUTTING HOT RESEARCH TOPICS IN THE SPOTLIGHT

Sandia and UNM launched the Research Spotlight Forum to foster research collaborations between Sandia, UNM and other academic partners. Since implementation, 11 spotlight forums have been held with the first event focused on autonomy for hypersonics and machine learning. Other hot topics included engineering mechanics, resilience for space systems, quantum computing, cybersecurity, resilient infrastructure, advanced manufacturing, social science and diagnostics, biosensors, bioengineering and bioinformatics, and women in science, technology, engineering and mathematics (STEM).

The series has seeded new collaborative relationships with universities by increasing faculty's knowledge of Sandia program areas and providing Sandia staff with the opportunity to learn more about each university's capabilities, faculty expertise, and their involvement in related programs.

At the advanced manufacturing forum, researchers from Sandia, UNM, UT Austin, Georgia Tech, and NMSU presented on design optimization, in situ metrology and control, and understanding how processes and defects impact properties and performance. Discussion also included additive manufacturing at all scales—from nanotweezers for precise atomic manipulation to full component production—and addressed applications such as advanced microelectronics and energetic materials. Sandia materials science researcher and UNM National Laboratory Professor Randy Schunk presented on the thin-film coating and consumer products industries. Schunk is focused on growing a modeling and simulation community of practice at all scales, from sub-molecular to continuum to system, at Sandia's Advanced Manufacturing Laboratory. At the forum, he discussed an LDRD project on the development and application of high-end simulation tools. This collaborative work is being done by the Schunk Research Group at UNM, which is an academic partner in NASCENT, a National Science Foundation Nanosystems Engineering Research Center.

THE HOLY GRAIL OF DETECTOR DEVELOPMENT

High-resolution, room-temperature radiation detection is the holy grail of detector development in national security, medical, and research applications. High-resolution detectors based on germanium require cryogenic temperatures because room-temperature detectors such as sodium iodide have very poor resolution. Cadmium zinc telluride-based detectors can operate at room temperature with reasonable resolution, but experience issues with purity, cost, and handling.

UNM scientists Adam Hecht and Ganesh Balakrishnan are collaborating with Sandia researchers Anthony Rice and Paul Sharps to improve aluminum antimonide-based gamma detectors by reducing leakage currents and device lifetime with chemical passivation. The end result—with growth on silicon, reduced leakage current, and improved material—will be an extremely deployable, low power, and rugged radiation detection capability that can be manufactured in large quantities at low cost.

CONTRIBUTOR SPOTLGHT

Gunny Balakrishnan

UNM's Ganesh (Gunny) Balakrishnan, associate professor in the Department of Electrical and Computer Engineering and associate director in the Center for High Technology Materials, has partnered with Sandia for many years, providing great insight into microelectronics. His primary research focus for the past decade has been the growth and characterization of highly mismatched III-Sb compound semiconductors on GaAs and silicon substrates.

FUNDING GREAT RESEARCH TWO DIFFERENT WAYS

ACORN awards seed new collaborations for early career researchers

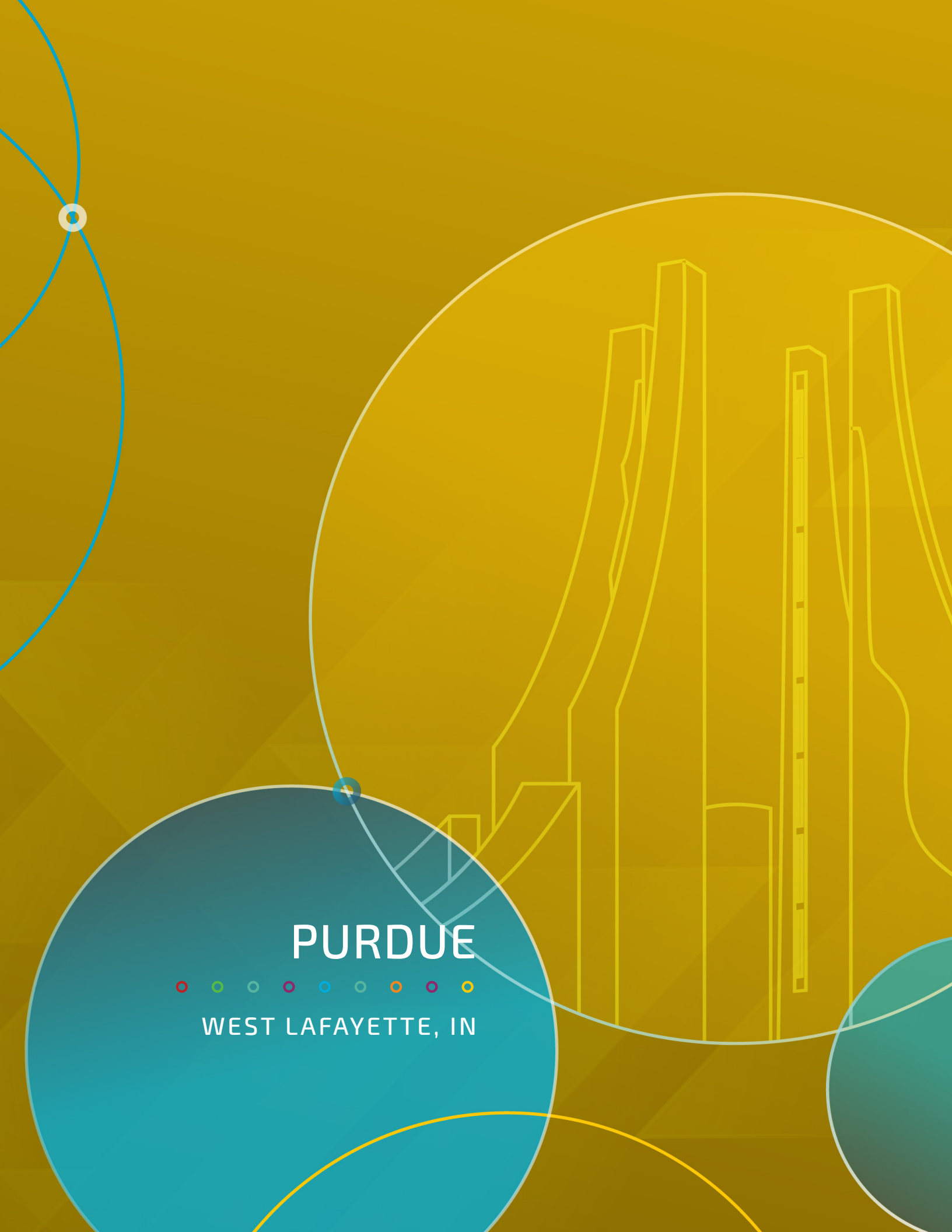
Accelerated Collaborative Research Nucleus (ACORN) is a new Sandia strategic initiative designed to fund LDRD project collaborations with NM universities. This program focuses on providing early career researchers with cross-institutional engagement. Each early career Sandia staff member (<5 years at Sandia) is connected with a new university faculty member (<5 years at the university) to initiative collaborative work. Typical projects run for 2-3 years with funding up to $100 thousand per year. One new project is typically started each year.

LDRD and UNM's Office of the Vice President of Research (OVPR) supplements working together

One of the OVPR projects focuses on controlling nonlinear dynamical structures under extreme normal environments and required the OVPR-funded purchase of a large shaker and a data acquisition system required for operation.

Graduate student Eric Robbins is working toward a Ph.D. as he makes advancements in his research project, partnering with structural dynamics expert Ben Pacini from Sandia. The OVPR-funded shaker and data acquisition system are not only enabling this project but will advance UNM's research in the area of structural dynamics and controls for years. The new equipment will also be made available to teams participating in the Nonlinear Dynamics (NOMAD) summer research institute, co-led by Sandia's Rob Kuether and UNM's Tariq Khraishi from the Department of Mechanical Engineering.

Pictured: *Preliminary data from an experiment on the shaker provides information on the damage to a structure.*


PURDUE
WEST LAFAYETTE, IN

ACCOMPLISHMENTS

KEY LEADERSHIP

Purdue

Theresa Mayer
Executive Vice President for Research and Partnerships

Dan DeLaurentis
Professor and President's Fellow for Defense Initiatives

Timothée L. Pourpoint
Professor, School of Aeronautics and Astronautics

Sandia Labs

Marcy Hoover
Director of Center 8100, Campus Executive

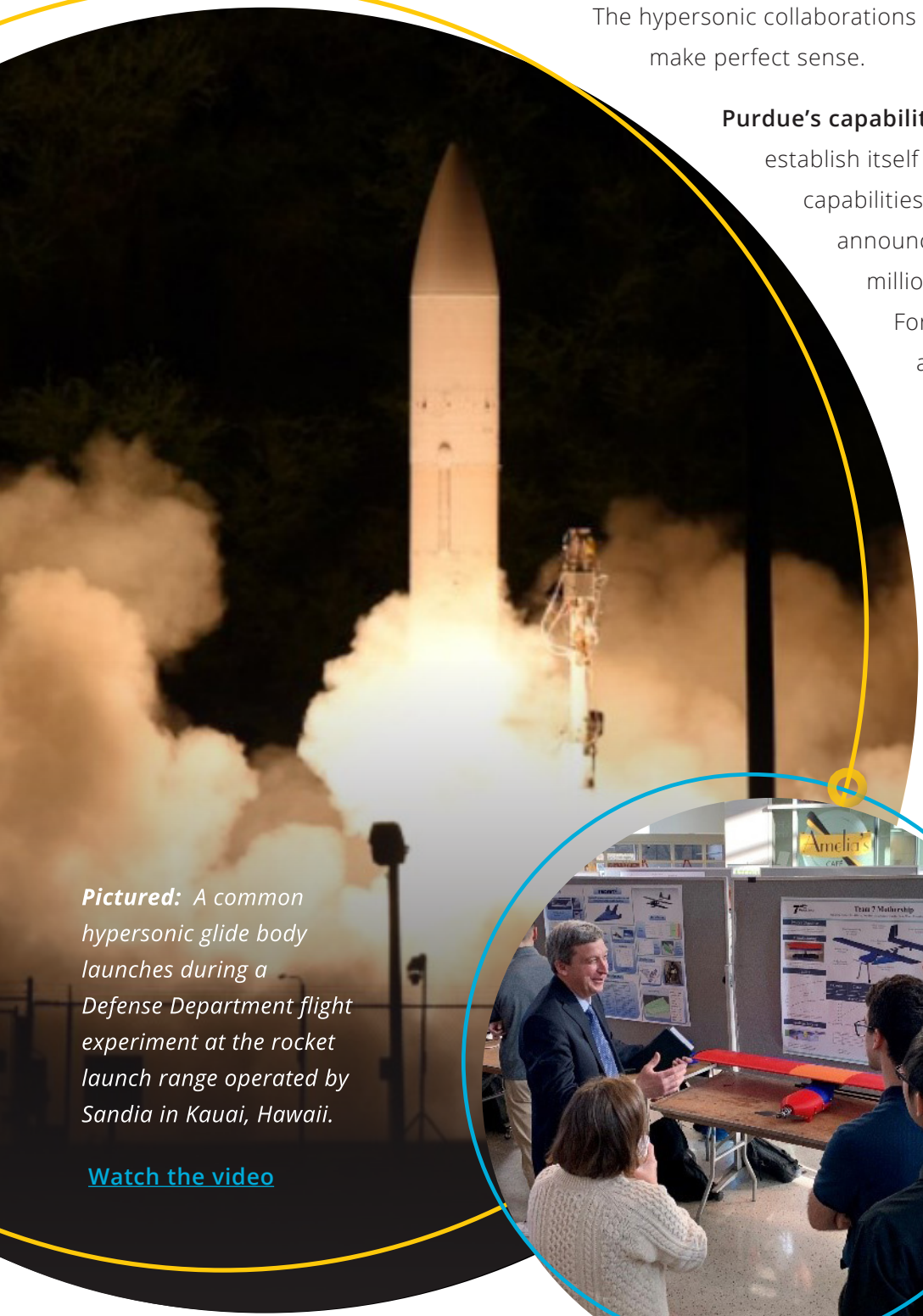
Kamlesh Patel
Manager in Center 1900, Campus Partnership Manager

Kim Welch
Manager in Center 2800, Recruiting Lead

GOING HYPERSONIC WITH PURDUE COLLABORATIONS

The hypersonic collaborations between Purdue and Sandia make perfect sense.

Purdue's capabilities: Purdue continues to establish itself as a hub of hypersonic capabilities research. They recently announced the receipt of a $5.9 million contract from the Air Force Research Lab to develop a multipurpose hypersonics R&D facility featuring the first-ever Mach 8 quiet flow wind tunnel that can flow air at eight times the speed of sound, or more



Pictured: *A common hypersonic glide body launches during a Defense Department flight experiment at the rocket launch range operated by Sandia in Kauai, Hawaii.*

Watch the video

Pictured: *Sandia manager, Dennis Helmich, speaks to a group at the Purdue Capstone poster session.*

than 6,000 mph. Purdue has one of the nation's deepest hypersonic teams with nearly 40 world-renowned researchers with capabilities in navigation, aerodynamics, aerothermal effects, propulsion, autonomy, system engineering, high-temperature materials and manufacturing. Jonathan Poggie, a Purdue professor of aeronautics and astronautics, leads the hypersonics program. "The Mach 6 quiet wind tunnel was the seed that got things started. All around the university there are many leading experts interested in the field of hypersonics," Poggie said. "We were able to put together a really great team because we have such talent and interest."

Sandia's capabilities: Sandia has conducted hypersonic flight research for the last 40 years, including conducting the first successful flight test of a non-ballistic hypersonic glide vehicle in 1985. A memorandum signed by multiple DOD agencies established a Sandia-developed design as the common hypersonic glide body being further developed and produced by industry contractors. Since 2018, Sandia committed $40 million of its LDRD funds to explore autonomy and machine learning technology for hypersonic flight vehicles and has test capabilities in its own hypersonic wind tunnel. In addition, Sandia leads an academic research coalition focused on creating artificially intelligent aerospace systems by integrating expertise from throughout the country with its own knowledge in high-performance flight vehicles. "Sandia is continuing its legacy of excellence in the national interest by providing advanced technology to ensure the protection of our nation and its warfighters," said Associate Labs Director Mike Burns, who oversees national security programs at Sandia. "I'm very proud of the contributions made by our team and thank the DOD and the NNSA for the opportunity to contribute to the national hypersonic systems team."

CONTRIBUTOR SPOTLGHT

A4H Team, Ken Patel, John Sullivan

Sandia's Autonomy for Hypersonics (A4H) team leaders Jay Brown and Meg Davidson collaborated with Campus Partnership Manager Ken Patel and Purdue Professor John Sullivan to develop glider specifications/parameters and design reference missions (DRMs) for the AA451 senior design class. The DRMs mimic some of the challenges experienced when adapting autonomous systems technologies to hypersonic glide vehicles.

The 60 graduating seniors were divided into eight teams and challenged to design, build, and fly hypersonic-like gliders. Sandia leaders including Dennis Helmich, Ed Cole, and Ben Cook stopped at the AA451 Senior Design Class poster session at the end of the last in-person fall semester to view the Sandia-sponsored Capstone project work. In addition to the final poster session, there was also an on-campus flight demonstration.

TACKLING NATIONAL SECURITY PROJECTS IN DATA SCIENCE AT DATA MINE SYMPOSIUM

Identifying insights from enormous datasets and using data as a fuel for artificial intelligence and automated systems are areas of strategic importance to U.S. security, so Sandia joined forces with Purdue to design two national security projects in data science that integrate with undergraduate coursework. Twenty students worked on Sandia projects related to flight pattern analysis and multi-agent adversarial game theory in the Data Mine, a living and learning community on the Purdue campus.

Purdue's Integrative Data Science Initiative boasts many world-leading efforts in research and education. The Data Mine provides upwards of 800 students with coursework opportunities in 20 different learning communities to prepare them for the data-driven workforce of the 21st century. Originally planned as an in-person presentation, the alternate virtual Data Mine Symposium took place on April 13, 2020. Ten students presented on two Sandia projects at the e-symposium. Jason Reinhardt from Sandia's Systems Research and Analysis department also met with eight students to discuss using the game theory approach to detect strategy deviation in game play. There was a second semester of activity in spring 2021, culminating in a virtual presentation this past April.

"The presentations demonstrated the great progress made by the students in understanding key national security related problems leveraging data science," said Ken Patel, Sandia's campus partnerships manager at Purdue University. He added, "Purdue provided Sandia with collaborative space in the heart of campus to engage with Purdue students on national security-related projects. The agreement provides a framework for streamlining our future partnership."

Pictured: *Sandia's Danny Rintoul (shown in turquoise on the right) presents the "Flight Tracker" concept to Data Mine students in one of the first meetings with the group.*

CONTRIBUTOR SPOTLGHT

Jason Reinhardt

Jason Reinhardt is a national security systems analyst at Sandia whose work is focused on probabilistic analysis methods, quantitative and non-quantitative approaches for risk analysis and management, as well as the modeling and analysis of strategic interaction in conflict escalation, asymmetric deterrence, and stability. He's been involved with Data Mine's unique live-learn community and is currently working on developing new risk analysis tools for managing cyber threats to critical infrastructure and using games as data generating processes to understand interstate conflict.

CONTRIBUTOR SPOTLGHT

Kat Ward

Katrina "Kat" Ward is a senior R&D scientist who works with the Data Science and Applications department. She's very active in contributing to educational events and assisted with the Purdue Data Mine Symposium, noting that the students in the Data Mine show a deep desire to understand our nation's top security challenges. "Their solutions have impressed several Sandians and given us much to think about when approaching problems ourselves. I strongly believe that working closely with them is providing a gateway for top talent to understand what Sandia does and provides a step in the door for them to come intern and work with us."

WANTED: NEXT GENERATION OF RADIATION-HARDENED AND ADVANCED PACKAGING ENGINEERS

Sandia National Labs is a recognized world leader in technology research and implementation.

Pictured: *The Microsystems and Engineering Sciences Applications (MESA) complex produces electronic circuits and computer chips designed to withstand high levels of radiation.*

Devices used in national security and defense must remain secure and operate in extreme environments, and this extends to the area of microelectronics. A multi-university public-private-academic partnership called Scalable Asymmetric Lifecycle Engagement Microelectronics Workforce Development program (SCALE) led by Purdue and sponsored by the Office of the Secretary of Defense is poised to meet this need. SCALE, composed of many schools and industrial partners including Sandia, will be led by Peter Bermel, Purdue Associate Professor of Electrical and Computer Engineering. The $19.2 million funding will be used to develop the microelectronics workforce of the future across the nation's engineering universities.

SCALE is developing curricula, internships, and targeted messaging to attract and retain a larger cohort of U.S. citizen students to complete the program in the DOD-prioritized microelectronic focus areas. The model will include both formal academic and continuing education elements through internships, fellowships, and experiential learning.

Theresa Mayer, Purdue University executive vice president for research and partnerships, said secure and resilient microelectronic systems "underpin advanced technologies critical to national security, including artificial intelligence, hypersonics, advanced communications networks, autonomous systems and others. Cutting-edge education and research are at the heart of meeting these national security needs."

In a virtual meeting on April 17, 2020, Sandia and Purdue signed a new MOU that extends the research partnership until 2030. "Sandia National Labs is a recognized world leader in technology research and implementation," Mayer said. "This partnership will allow us to work together to solve significant national issues and problems that no one institution could address alone."

Ken Patel is helping to shape the partnership through internships at Sandia. "Internships are essential ingredients when it comes to training the workforce of the future. By giving students meaningful mission work, they learn how to truly apply their knowledge."

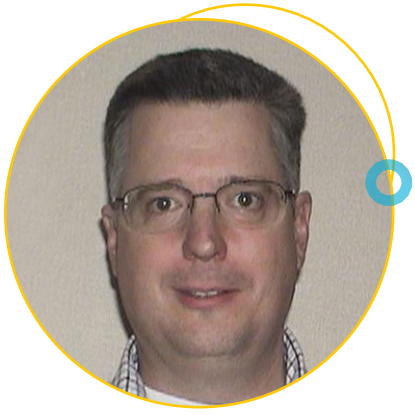
One area of focus for the partnerships will, of course, be microelectronics. Purdue has deep expertise in developing trusted microelectronics through efforts such as the National Science Foundation-supported Network for Computational Nanotechnology and the Purdue Quantum Science and Engineering Institute.

Sandia and Purdue are partnering on programs for the Defense Advanced Research Projects Agency (DARPA) through the Semiconductor Research Program, including the Joint University Microelectronics Program (JUMP), the Center for Heterogenous Integration Research on Packaging, and the nanoelectronics Computing Research Program (nCORE).

CONTRIBUTOR SPOTLGHT

Nathan Nowlin

Nathan Nowlin has 25 years' experience in advanced microelectronics and radiation effects research and is leading Sandia's efforts to advance collaboration and talent development in radiation-hardened microelectronics. At Sandia, Nowlin led R&D efforts for radiation hardening by design, advanced circuit modeling of radiation effects, and product engineering for high-reliability, high-consequence systems. His efforts in Application Specific Integrated Circuit (ASIC) design enabled Sandia to successfully begin its largest ASIC production mission in its history at the MESA complex.



AT THE SPEED OF LIGHT...SANDIA AND PURDUE'S ENERGETICS RESEARCH CENTER ADDRESSES THREATS

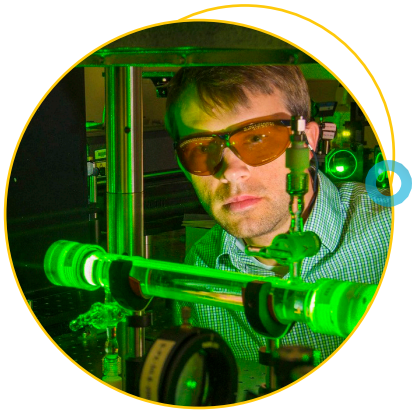
Over the last seven years, Sandia focused effort on a handful of bold, ambitious, and large projects with the potential for enormous impact to the security of the nation. These projects, or Grand Challenges (GC), span three years and advance the frontiers of science and engineering. One new GC LDRD project is Light Speed: Accelerating Fundamental Predictions of Explosive Optical Emissions. This challenge is tied to the acceleration and addition of critical physics to explosive fireball simulations while quantifying uncertainty, or remote sensing of explosive fireballs on the horizon.

Pictured: *One of a series of tests studying fragmenting explosives in ways that haven't been possible in the past. The project observes explosively driven fragments with flash X-ray and high-speed cameras.*

CONTRIBUTOR SPOTLGHT

Daniel Guildenbecher

Sandia's Daniel Guildenbecher emphasizes experimental diagnostics of multiphase flows, particularly those involving particle transport, liquid fragmentation, combustion, and energy conversions. He received his Ph.D. in Mechanical Engineering from Purdue in 2009 and was a visiting professor there after he graduated. Guildenbecher helped to facilitate the partnership between Purdue and Sandia on the Light Speed GC.

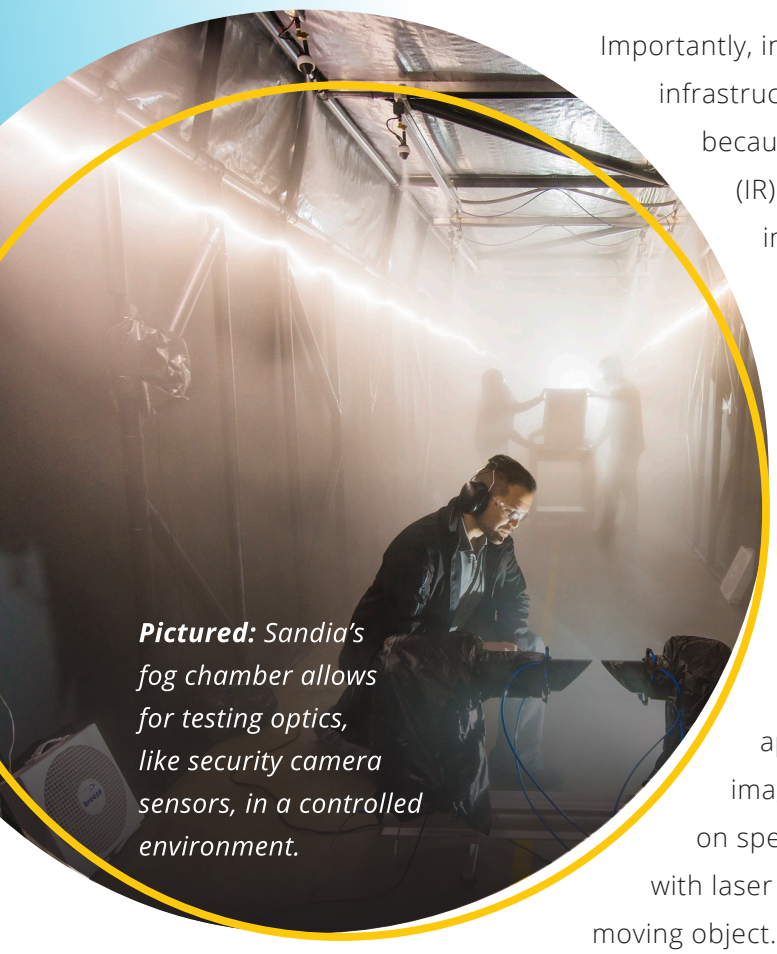


Purdue and the U of Illinois are both partnering with Sandia on the Light Speed Grand Challenge. Purdue's Energetics Research Center (PERC), an interdisciplinary team focused on research that addresses existing and emerging explosives-based threats to civilian and military infrastructure, commerce, and aviation, will support multiple students at Zucrow Labs, who are also assisting on the work. Professor Nick Glumac at U of Illinois said, "This research funding allows us to continue work in explosive signatures that we've been doing for DOE and DOD for a long time now. This work has led to a continuous stream of progress in identifying and cataloging optical signatures of explosives throughout the electromagnetic spectrum. In addition, this GC provides the students with access to interactions with Sandia and Purdue, which is relevant for future job prospects. I currently have five former graduate students from my group working at Sandia, and this collaboration allows my current students to make similar connections and be exposed to DOE laboratory environments for potential future careers."

If the collaborative teams are successful, the Light Speed GC will result in faster and higher fidelity explosive signature predictions that advance the nation's ability to provide actionable information on accelerated timelines and respond to rapidly evolving and unpredictable nuclear threats. Light Speed actually had roots in a collaborative LDRD project between Sandia and Purdue, "Revolutionizing Spatial and Temporal Blast Characterization." The insight and data gained during the effort, led by Sandia PI Dan Guildenbecher and Purdue's Tim Pourpoint and Steve Son, contributed to Light Speed's genesis.

HIGHLY SCATTERED LIGHT ALLOWS VISIBILITY IN DEGRADED VISUAL ENVIRONMENTS

Seeing through naturally occurring aerosols such as fog or man-made aerosols can create degraded visual environments that severely impact transportation, aviation, astronomy, remote sensing, security, surveillance, and more. Fog is particularly concerning because it occurs in all climates and at certain locations with high frequency. Current methods that provide a mechanism for seeing through aerosols are costly and limited to only a few meters. In response, one LDRD led by Brian Bentz in Sandia's Applied Science and Technology Maturation department is addressing this problem by developing a computational imaging and optimization approach that combines the information from many light detectors to potentially image 10 times deeper into aerosols than current imaging methods.



Pictured: *Sandia's fog chamber allows for testing optics, like security camera sensors, in a controlled environment.*

Importantly, integration of this new capability into existing infrastructure would only require software modifications because data from conventional detectors, such as infrared (IR) cameras, can be used. Applications include improving image/visual quality for site and asset protection, early warning systems, harbor security, maritime navigation, locating adversarial targets and systems, and guidance for aviation and unmanned vehicles.

Purdue professor Kevin Webb and his electrical and computer engineering students in the Webb Group pursue fundamental research at the interface of physics, mathematics, and various application domains. They've explored approaches to imaging using laser light in scattering media, touching applications in diverse environmental sensing and in vivo imaging. The group discovered a means to image based on speckle pattern changes, a phenomenon that occurs with laser light in a scattering medium, such as fog, that hides a moving object. Building on the work of the group, Purdue partnered

with Sandia to explore a means to image and localize objects through fog.

"Purdue's alliance with Sandia provides unique opportunities, facilities, and exposure, and the results of each project have broad applications," says Kevin Webb.

Sandia's Ken Patel facilitated the LDRD by connecting the Webb Group with Brian Bentz, one of their former students who now leverages Sandia's fog chamber, one of the largest fog chambers in the world, for his research on back-calculating an image moving through a fog. The facility provides a fully characterized degraded visual environment that can be generated reliably and consistently, removing the variability of environmental conditions that affect real-world outdoor testing. Brian Bentz and the Webb Group have been working on a localization method that uses incoherent optical information to estimate an object's location, and pairs this with coherent speckle for imaging. To aid in this work, Sandia has designed a table-top fog chamber to conduct experiments that will be built at Purdue. The facility will assist researchers, particularly the Webb Group, in conducting more broad-based research, in addition to the current focus with Sandia.

Ryan Hastings, Ph.D. student, has championed the award-winning research at Purdue with contributions from another Ph.D. student, Justin Patel. Undergraduate student Emi Mondragon from Trinity College (Texas) contributed to the project during her Purdue summer undergraduate research fellowship in 2020. Mondragon authored a report on the work she did with Bentz and presented their results at a virtual symposium.

Successful completion of this LDRD project will result in new fundamental understanding related to seeing through aerosols with light, and the establishment of an advanced capability that provides tactical information in adverse conditions.

CONTRIBUTOR SPOTLGHT

Emi Mondragon

Emi Mondragon started working as an electrical engineering undergraduate Sandia intern in 2017, and she continued for four summers. She conducted research on projects ranging from electromagnetic systems to computationally modeling light in a fog-like environment. In addition to her course work and internship, Emi is also a Pathways Scholar at Purdue where she collaborates with faculty and Sandia researchers on other co-op projects that challenge and motivate her to solve complex problems by integrating difficult mathematical concepts.

GETTING CERIAS ABOUT CYBER THROUGH SOL4CE LAB ON THE PURDUE CAMPUS

On November 8, 2019, Purdue CERIAS partnered with Sandia to develop SOL4CE (Scalable Open Lab for Cyber Experimentation), a cyber range providing Purdue faculty, students, and collaborators with a safe and relevant place to explore the cyber world via experimentation. SOL4CE will be a broad area of cybersecurity research that will make use of Purdue's digital nuclear reactor, the only such facility in the United States. Zach Benz and Bei Bei Chen from Sandia Emulytics leadership were critical in bringing this laboratory to fruition.

The new laboratory is a mirror of the facilities already within Sandia that served as the platform for joint CERIAS and DOE research since 2017. Theresa Mayer, executive vice president for research and partnerships at Purdue said, "The opening of SOL4CE at Purdue allows us to increase both the speed and impact of our national security research collaboration with Sandia."

The term 'emulytics' was coined to represent the new lab's capability in providing high-fidelity emulation and large-scale analysis in a safeguarded virtual environment. SOL4CE leverages minimega, an open-source toolset developed by Sandia for various cybersecurity research and education needs.

Joel Rasmus, CERAIS managing director, noted, "SOL4CE brings cyber emulation and analysis capabilities to Purdue that until now were only available in a handful of classified laboratories around the world, and only came about after a long history of delivering impactful research to the DOE. We're grateful for their [Sandia's] long collaborative support, for placing this asset at Purdue, and for allowing other industry and commercial partners to collaborate with our faculty in the new SOL4CE

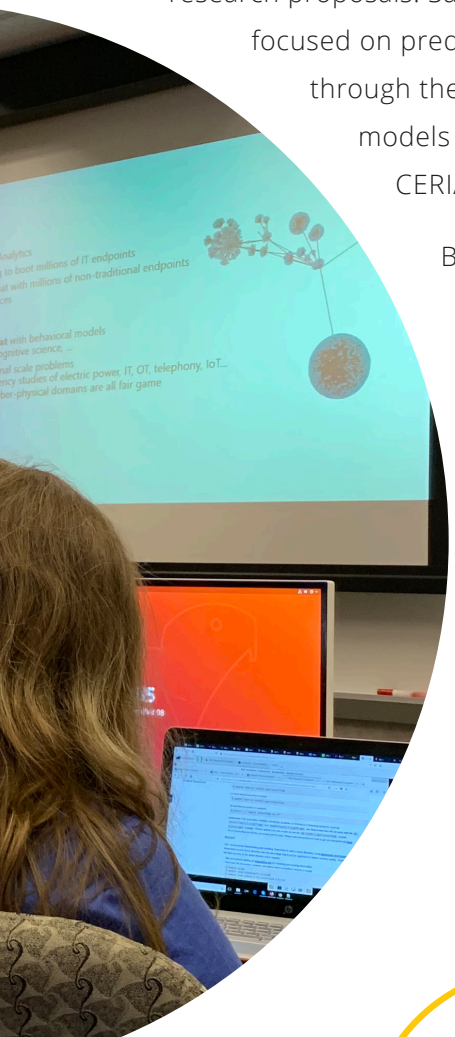
Pictured: *Sandia's Vince Urias gives a tutorial on SOL4CE at the Purdue campus.*

lab." SOL4CE will provide curriculum development, training, test and evaluation, and systems design.

The first project deployed on the SOL4CE laboratory is research being conducted by Dongyan Xu, director of CERIAS, and researchers at Sandia. "SOL4CE is serving as a platform for our emerging research and education in cybersecurity for cyber-physical systems, including advanced manufacturing and autonomous vehicles."

Sandia cybersecurity expert, Vince Urias, gave a workshop at Purdue that featured a Sandia-supported mini-LDRD call for ideas to expand the objectives of his supplemental LDRD with Dongyan Xu. He wanted to partner with a researcher on a relevant cyber project to be tested in the SOL4CE laboratory. Six project ideas were submitted, and in the down-selection process, there were two finalists with strong research proposals. Sandia funded the one with Urias as the PI focused on predictive threat modeling and cybersecurity through the design of a traffic generation capability that models unique benign and malicious actors at scale. CERIAS funded the other LDRD finalist.

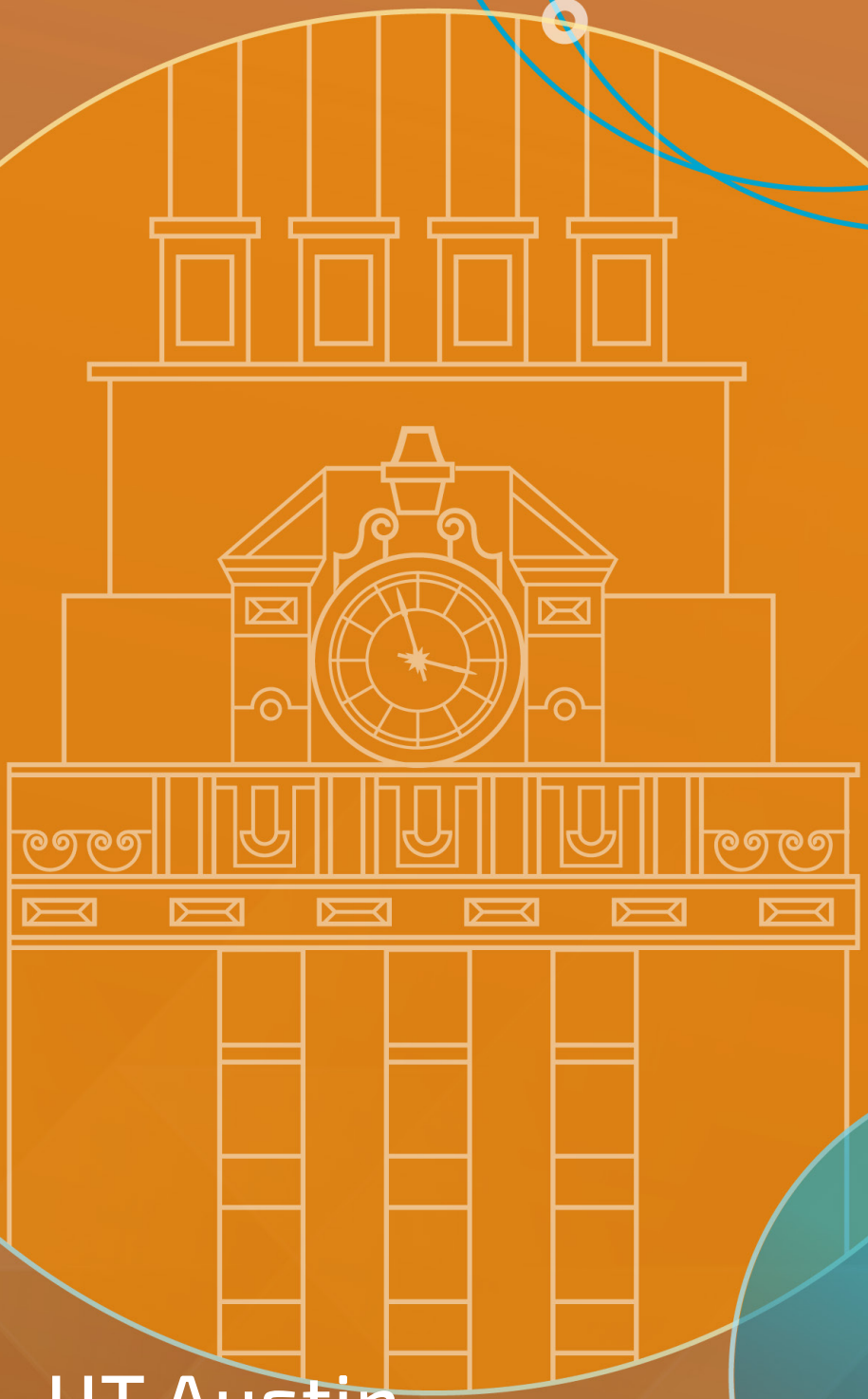
By virtually connecting CERIAS's faculty and students from 20+ departments with next-gen cyber experimentation technology, SOL4CE is helping to bring about a step-change in the way institutions address the research and educational needs of the cybersecurity market.



CONTRIBUTOR SPOTLGHT

Dr. Yung-Hsiang Lu

Dr. Yung-Hsiang Lu, Purdue Professor of Electrical and Computer Engineering, and Purdue student Haobo Wang leveraged the SOL4CE platform for their mini-LDRD research project in which they were analyzing the immense data feed from over 100 network cameras. Their application programming interface allowed for optimization, so they could successfully use Sandia's virtualization tool.



UT Austin

AUSTIN, TX

ACCOMPLISHMENTS

KEY LEADERSHIP

UT Austin

Dan Jaffe
Vice President of Research

Jennifer Lyon Gardner
Associate Vice President of Research

John Ekerdt
Associate Dean of Research, Cockrell School of Engineering

Sandia Labs

Justine Johannes
Director of Center 6600, Campus Executive

Alex Roesler
Deputy Director in Center 5400 Deputy Campus Executive

Nadine Miner
Manager in Center 1900, Campus Partnership Manager

Michelle Pang
UT Recruiting Lead (20+ person recruiting team)

BIO-INSPIRED COMPUTING OPENS UP PATHWAYS FOR COLLABORATION

Bio-inspired computing is related to artificial intelligence (AI) and machine learning (ML) but is distinct from traditional AI in its approach to computer learning. In traditional AI, intelligence is often viewed as being created by a programmer who imparts "intelligence." Bio-inspired computing begins with simple organisms that adhere to a set of simple rules. Then over time, within simple constraints, these organisms evolve. Advances in DNA sequencing, various biotechnology manipulations, and the intersection of biology with engineering and mathematics continue to empower the influential field. Plus, bioengineering and bio-inspired research are useful to both society at large and to national security.

Numerous applications benefit from brain-inspired (neuromorphic) computing because it responds more quickly to world circumstances than other techniques. Sandia PI Brad Aimone is focused on computational neuroscience modeling and research. Aimone said, "While AI is traditionally expensive, bio-inspired approaches (lower algorithms and hardware) are both more efficient and useful in more systems due to their low size, weight, and power requirements. It's also quite robust." He added, "National labs, generally speaking, don't have this type of neuromorphic computing background or deep expertise. UT Austin has an excellent base for neural science research in its strong computer science program and novel devices

(materials and components), which couple well with Sandia's applied microelectronics research."

UT Austin's EJ Lee-Furman was instrumental in helping to organize the bio-inspired computing colloquium with Aimone who discussed the next generation of brain-inspired AI at the first event.

Aimone noted that the current neural networks revolution was fed by significant advances in computing power and the abundance of training data. However, the expanding scale of neural network models and costs of data collection/management have increased both the energy and monetary costs associated with AI research. Increasingly, researchers need novel, data-efficient AI solutions that achieve cognitive capabilities while leveraging low-power hardware, such as neuromorphic systems. As Aimone explained, Sandia's research in brain-inspired algorithms enables current AI methods to be deployed on low-power spiking neuromorphic hardware, and also help reach toward novel cognitive capabilities that have eluded the current generation of AI methods. He also described two Sandia-developed tools for porting algorithms to neuromorphic hardware and illustrated how seemingly non-cognitive algorithms can be represented in a spiking framework. Sandia's recent progress in formalizing neuroscience knowledge of hippocampus subregions into algorithms, he concluded, are suitable for a brain-like memory formation.

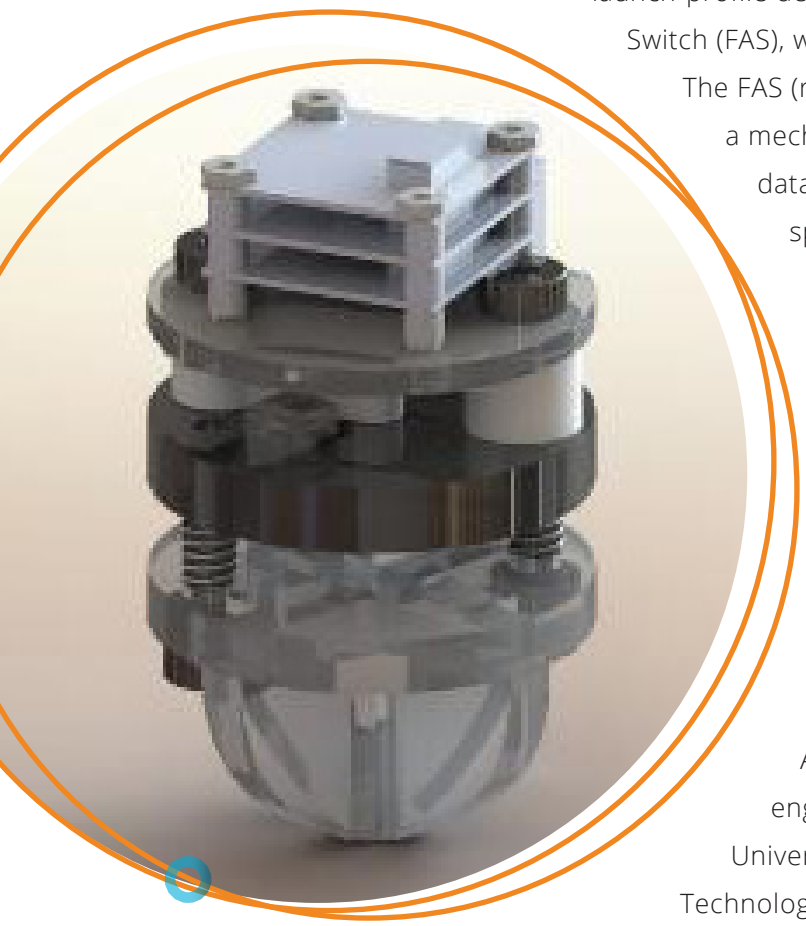
The technical exchange resulted in a set of working groups in bio-inspired computing and neuromorphic hardware. Currently, each group is developing white papers to help crystallize ideas for future funding opportunities.

CONTRIBUTOR SPOTLGHT

Brad Aimone

Brad Aimone is a computational neuroscience modeling researcher, who also helps lead Sandia's Neural Exploration Research Laboratory (NERL). NERL enables researchers to explore the boundaries of neural computation and provides a testbed facility for comparative benchmarking and new architecture exploration through use of a variety of neuromorphic hardware and neural algorithms.

READY, SET... DESIGN A FLIGHT ACCELEROMETER SWITCH!



Pictured:
Flight accelerometer switch: A mechanically actuated switch that records flight data upon experiencing a specified acceleration.

On April 16, 2020, participants in the Third Annual Senior Design Bonanza were challenged to design, prototype, test, and produce a launch-profile detection system. The system, a Flight Accelerometer Switch (FAS), was to act as the payload of an EggTosser rocket. The FAS (roughly the size of a chicken egg) had to operate as a mechanically actuated switch that would record flight data onto an on-board SD card after it experienced a specified acceleration.

Each academic year, Sandia employees create a mechanical design challenge for student teams to solve. Student teams are then matched with a Sandia mentor who provides technical feedback and expertise throughout the year. This collaboration engages students with Sandia in a relevant challenge while they earn academic credit, plus it fosters research collaborations and opens the door for future hires.

At the conclusion of the 2020 Bonanza, mechanical engineering students from six universities (UT Austin, University of Georgia (UGA), Rochester Institute of Technology, North Carolina Agricultural and Technical State University (N.C. A&T), Howard University, and University of Colorado Boulder) showed off their final FAS results in a virtual design review where Sandia staff and university faculty offered feedback. "Every year, I'm impressed with the out-of-the-box thinking that the students

bring to the design challenge," says Michelle Pang, co-lead and mentor for the 2020 Senior Design Bonanza. "I enjoy witnessing how they utilize their resources to refine ideas based on analysis and experimentation, and to produce their final physical or conceptual prototype." Co-lead and mentor, Karl Walczak, was similarly impressed with the students' final projects. "It's been interesting to see how teams approach the problem and develop designs throughout the year despite build-and-test limitations due to the global pandemic. The students adapted to the situation and finished strong."

The change to a virtual final event didn't alter the quality of the student presentations, which were top notch. "We were really impressed with the students' projects and how they overcame many obstacles due to COVID-19," says Pang. "They all showed resilience and delivered great results." While all teams excelled, Team Aggie Switch (N.C. A&T) won the Most Innovative Design Award; Team Texas Launch Horns (UT Austin) won Best Use of (Computational) Modeling and Simulation; and Team Sandia Dawgs (UGA) won Most Scalable and Adaptable Design.

For the 2021 academic year, the Sandia Bonanza team is creating a more multidisciplinary design challenge that represents real-world engineering applications and allows more universities to participate. "I'm optimistic about how we can grow the program," Pang concluded. "The Bonanza benefits the universities and students who participate, and Sandia benefits by providing a future workforce with experience on the types of R&D problems that are relevant to our missions."

CONTRIBUTOR SPOTLGHT

Michelle Pang and Karl Walczak

Michelle Pang and Karl Walczak from Sandia helped guide the Third Annual Senior Design Bonanza at UT Austin. They are both big proponents of helping to provide educational experiences for university students and invest significant time in leading events such as these.

INVESTIGATING CLIMATE CHANGE AND EVALUATING THE IMPACT

Jennifer Frederick, a computational geoscientist at Sandia, and UT Austin Professor Hugh Daigle are modeling what impact climate change is having on the Arctic. Their results demonstrate increased wave activity along with other physical and chemical changes; their work is supported by other scientists who also presented during a poster session entitled "Understanding the Marine Geological Record Through 50 Years of Ocean Drilling." Frederick and Daigle presented at the 2019 and 2020 Fall Meeting of the American Geophysical Union. Together, they provided new insights gained from synthesizing scientific ocean drilling data from both soft and hard rocks and how to generate robust paleo-interpretations from marine sediment drifts, which provide some of the highest resolution marine geological records.

In 2020, Frederick, Daigle and their team presented their work at the Gordon Research Conference on Natural Gas Hydrate Systems. (One of the team members, Michael Nole, a Sandia early career staff member who graduated from UT Austin, was recently named chair of the next Gordon Research Symposium for the conference. This great honor signifies Nole as an early career shining star in the field of gas hydrate research and will allow him to interact closely with senior members of the research field.) Continuing their partnership into 2021, Frederick and Daigle connected with Professor Steven Constable from Scripps Institute of Oceanography EM Laboratory. With Daigle as PI and Constable as co-PI, the team submitted a proposal to the National Science Foundation for a project focused on conducting electromagnetic surveys of the North Atlantic coast seafloor

Pictured: *A core sample of thermokarst-cave ice with vertical frost cracks indicates multi-day thawing-degree temperatures occurred in this Arctic area.*

to detect and better characterize gas hydrate reservoirs and methane gas seafloor seepage.

Another extensive Sandia-UT Austin team developed the predictive Arctic Coastal Erosion (ACE) model. Sandia expert Diana Bull presented their work at the 2019 AGU (American Geophysical Union) Advancing Earth and Space Science Conference. The ACE Model consists of oceanographic and atmospheric boundary conditions that force a coastal terrestrial permafrost environment (a multi-physics based finite element model). Emily Bristol, Craig Connolly and James McClelland from the Marine Science Institute at UT Austin performed integral permafrost material analyses, which led to accurate representations of the terrestrial bluffs. The model and data will inform scientific understanding of coastal erosion, contribute to estimates of geochemical and sediment land-to-ocean fluxes, and facilitate infrastructure susceptibility assessments. The ACE model is currently being applied in DOE's InteRFACE (Interdisciplinary Research for Arctic Coastal Environments) project. InteRFACE, led by Los Alamos National Laboratory, aims to quantify and reduce uncertainties in our fundamental understanding of the magnitude, rates, and patterns of change along the Arctic coast.

Susan Seestrom, Sandia Associate Labs Director and Chief Research Officer said, "Our current efforts in the Arctic leverage Sandia's deep experience in computing, from verification and uncertainty quantification to multiphysics applications to increasingly complex numerical models, and decades of experience in unique and quantitative Earth sciences research."

CONTRIBUTOR SPOTLGHT

Hugh Daigle

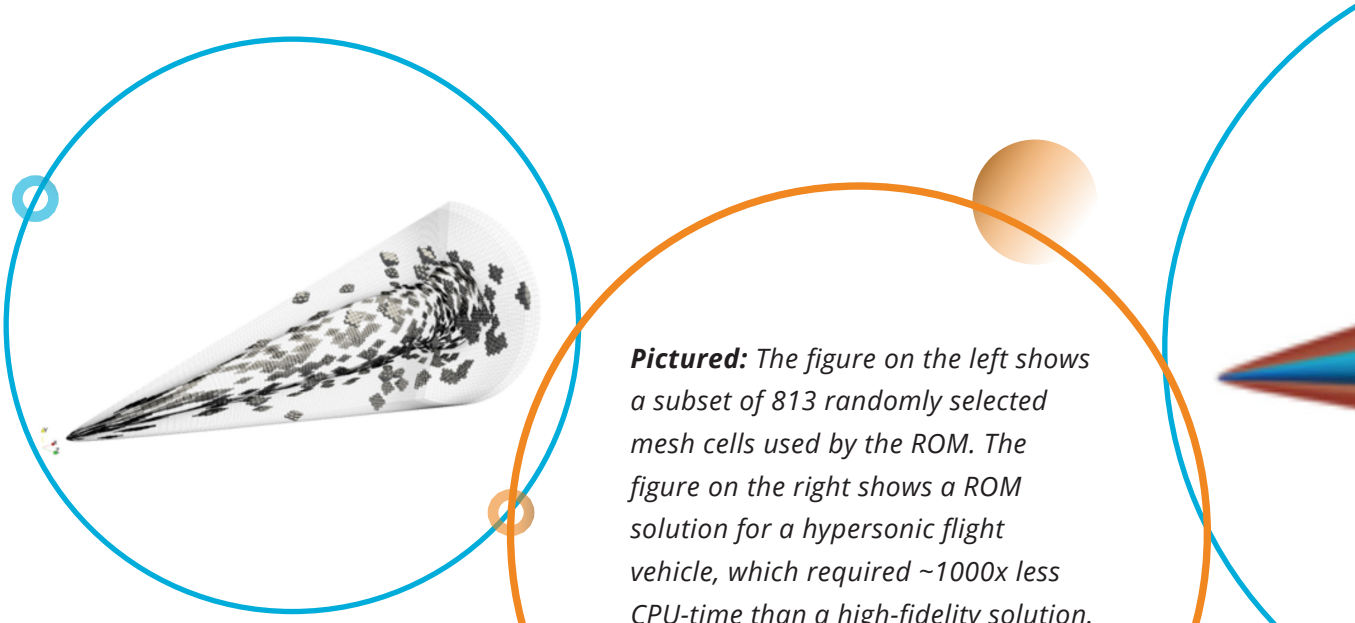
UT Austin's Hugh Daigle focuses on characterizing physical and transport properties of rocks using a combination of laboratory experiments and numerical simulation. His current research topics are methane hydrate accumulation in marine sediments, understanding multiphase flow during production from hydrate reservoirs, applications of nanoparticles and nanotechnology in various aspects of oil and gas exploration and production, and transport processes and geohazards in shallow marine sediments.

SANDIA AND UT AUSTIN COLLABORATIONS MOVE INTO HYPERSPEED

The figure on the left shows a subset of 813 randomly selected mesh cells used by the reduced order model (ROM). The figure on the right shows a ROM solution for a hypersonic flight vehicle, which required ~1000x less CPU-time than the high-fidelity solution in the center.

Sandia and UT Austin are joining together on hypersonic opportunities. Sandia, who invested $40 million in LDRD funds to explore autonomy and machine learning technology for hypersonic flight vehicles, provides large-scale environmental testing facilities, high-performance computing, high-energy physics laboratories, special prototyping, and limited production capabilities. UT Austin offers the tools for early stage R&D for missile components and is committed to working with the U.S. military and the Army Futures Command (headquartered in a UT Austin building) to identify and prioritize research that can be quickly adapted to help protect and defend the nation's interest.

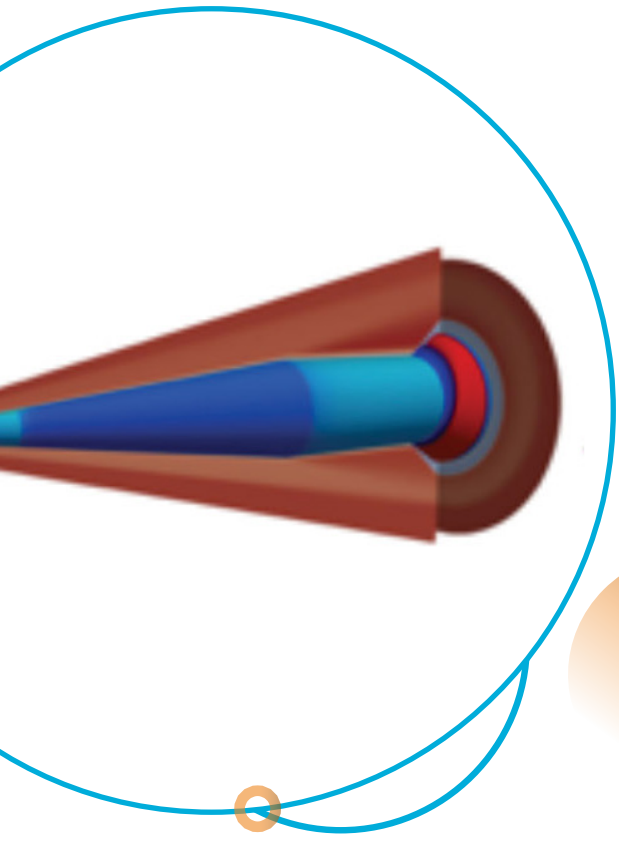
In 2019, the entities began collaborating on a three-year project to enable high-fidelity aerothermal simulations of hypersonic vehicles with Sandia's Patrick Blonigan as PI and Dr. Karen Willcox, director of



Pictured: *The figure on the left shows a subset of 813 randomly selected mesh cells used by the ROM. The figure on the right shows a ROM solution for a hypersonic flight vehicle, which required ~1000x less CPU-time than a high-fidelity solution.*

the Oden Institute for Computational Engineering and Sciences at UT Austin, providing expertise on ROM. The work was also supported by Samuel Majors, a UT Austin graduate student who set up interfaces with OpenFOAM, an open-source Computational Fluid Dynamics (CFD) solver with hypersonic capabilities.

Because of that project, a major collaboration opportunity emerged in 2020 when UT Austin was selected by NASA and the Air Force Office of Scientific Research to lead three other universities in a project to redefine sensing and analysis of hypersonic vehicles. The goal of the three-year, $3.3 million Full Airframe Sensing Technology (FAST) project is to create a new paradigm in sensing for hypersonic vehicles, which could also be applied to lower-speed craft. They are evaluating vehicles for aerodynamic changes during flight tests and using that information to infer where force is being applied so they can better protect and control them during flight. Sandia will be providing expertise in the area of air flow simulations around the hypersonic vehicles.



CONTRIBUTOR SPOTLGHT

Karen Willcox

Karen E. Willcox is Director of the Oden Institute and a professor of aerospace engineering and engineering mechanics at UT Austin. Her research has produced scalable computational methods for the design of next-generation engineered systems, with a particular focus on model reduction as a way to learn principled approximations from data. These methods are widely applied in aircraft system design and environmental policy decision-making. Willcox is on the committee for Rising Stars in Computational and Data Sciences, an intensive academic and research career workshop series for women graduate students and postdocs co-organized by Sandia and UT Austin's Oden Institute.

CONTRIBUTOR SPOTLGHT

DEVELOPING NANOSCIENCE IN THE LAB AND TAKING IT TO THE MARKETPLACE

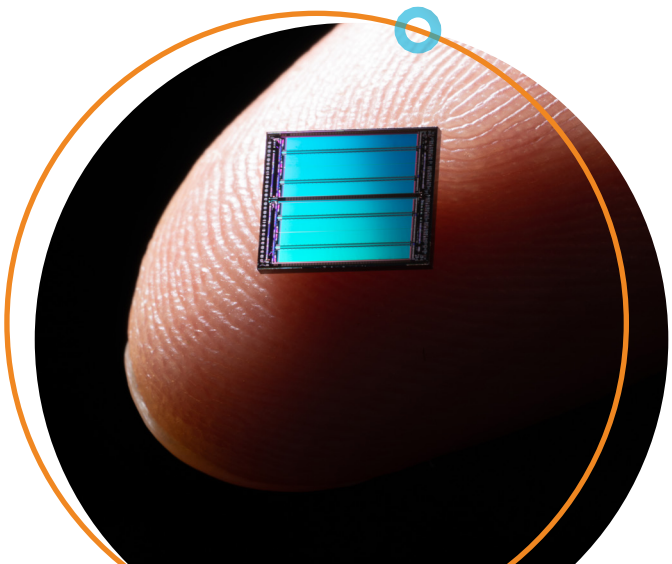
Matt Weldon

UT Austin's Matthew Weldon learned the semiconductor industry as an employee for manufacturers of semiconductor process equipment and metrology tools, plus he enjoys technology startups, which makes him the perfect NASCENT Assistant Director and Industrial Program Coordinator. He currently works at the UT Austin Pickle Research Campus and is focused on nanomanufacturing systems development.

NASCENT (Nanomanufacturing Systems for Mobile Computing and Energy Technologies), a NSF Nanosystems Engineering Research Center, is headquartered in Austin. NASCENT, led by UT Austin, develops high-throughput, high-yield and versatile nanomanufacturing systems to take nano-science discoveries from the lab to the marketplace, and is composed of faculty and graduate researchers from partner universities (UNM, UC Berkeley and University of Houston), industrial partners, and associated research institutions.

Throughout the year, NASCENT offers a variety of workshops, seminars, and full courses to help educate future research and technology leaders with technical depth, broad understanding of real market demands, skills for innovation, and the creativity needed to bring the benefits of nanomanufacturing in computing, electronics, energy, healthcare, and sensing.

In the NSF Innovation Corps Experience, NASCENT researchers, Juan Faria-Briceno and Steve Brueck, UNM professor, and their business mentor, Palladian Chief Technical Officer Scot Moye, recently participated in a Corps Experience designed to help scientific researchers become entrepreneurs. Briceno and Brueck's project centered on commercialization of the In-Line Scatterometry technology, which is targeted for application in nanoscale-featured web manufacturing. The team and their project received with the Cohort Award for highest level of achievement.



TEACHING LAB STEPPED IN AS TEST FACILITY WHEN SANDIA'S RESEARCH REACTOR SCHEDULE BACKED UP

Everyone has encountered scheduling problems, but the Nuclear Engineering Teaching Laboratory (NETL) at UT Austin helped Sandia work around a significant one in the fall. NETL functioned as a supplemental test facility to alleviate scheduling issues at the Annular Core Research Reactor. Over five days, more than 21 test items were irradiated in a total of 40 weapons survivability experiments. This work supported several mission campaigns, including nuclear deterrence, satellites, and High-G accelerometer tests. In addition, Sandia is exploring enhancements to allow for more tailored spectrums at NETL.

NATIONAL ENERGY TECHNOLOGY LABORATORY

Pictured: *Researcher John Hall stands near Sandia National Laboratories' Annular Core Research Reactor where scientists discovered a way to make medical isotopes.*

FIRST-OF-ITS KIND SOFTWARE CREATES ACCURATE DIGITAL REPRESENTATIONS OF COMPLEX OBJECTS

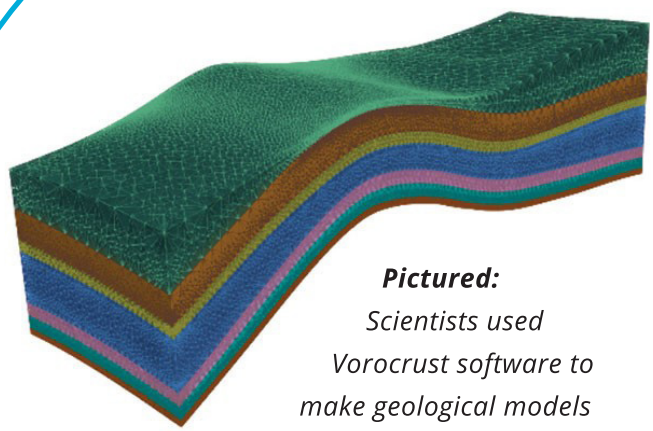
A first-of-its-kind software, Vorocrust, allows scientists in many disciplines to create accurate digital representations of complex objects, or meshes, of all kinds of parts, from rotors to wheels to protective equipment.

Complex meshes often have curves, sharp edges, or holes. Once created, they look like 3D images used in computer simulations that incorporate algorithms to determine when parts might fail in extreme conditions. This helpful — and often essential — aspect of design precedes the creation of prototypes and parts for testing.

"VoroCrust incorporates a special type of 3D polyhedral cells, called Voronoi cells, to create the meshes," said Sandia computer scientist and project lead Mohamed Ebeida. "Most other mesh-generation methods use 3D tetrahedral or hexahedral cells that can have low quality or are difficult to automate," he said.

"Existing methods for Voronoi meshing don't always conform to all corners and angles of complex objects. This can be fixed with manual labor, but it is a tedious process that can take a significant number of work hours," Mohamed said. VoroCrust is the first software to generate Voronoi-cell meshes that conform to complex models without needing to be fixed manually.

"Sandia identified meshing as the single biggest bottleneck in these analyses. Current practices require human intervention, and VoroCrust provides us with a path toward automating this process to relieve tech staff by reducing the time spent on fixing computer-generated errors in modeling," he said.



Pictured: *Scientists used Vorocrust software to make geological models as part of their research related to the geological disposal of spent nuclear fuel and high-level nuclear waste.*

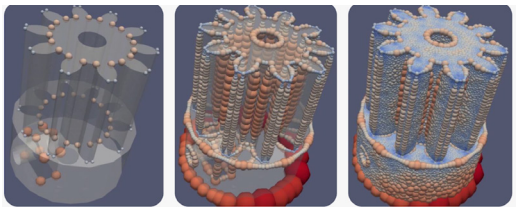
"The Voronoi magic will happen once you decompose the object into these

well-shaped pieces — these cells — you can mesh any model you want with confidence about the quality of the resulting mesh without any post-processing," Mohamed said.

Sandia manager Emily Stein and research engineer Tara LaForce used VoroCrust to make geological models for deep disposal of nuclear waste as part of DOE's spent fuel and waste science and technology campaign, which Sandia leads. The VoroCrust project receives funding from this DOE campaign and also from Sandia's LDRD program.

Sandia manager Joe Bishop, who has been interested in VoroCrust for years, said modeling and simulation engineers on his team could benefit from the software for simulations if current software packages can leverage the polyhedral elements. "We need to know if we can run our simulations on these objects and compare it to tetrahedral and hexahedral methods," he said. "VoroCrust is a promising tool. It could provide the geometry, and we would do the physics."

VoroCrust software was developed in collaboration with UT Austin, University of Maryland, College Park; and the University of California, Davis.



Scientists wanted to create a meshing software robust enough that it could model any object needed for simulation. Watch a video *of model examples and statements on the work by Sandia computer scientist Mohamed Ebeida.*

CONTRIBUTOR SPOTLGHT

Mohamed Ebeida

Sandia researcher Mohamed Ebeida works with the Discrete Math and Optimization team. His research interests span computational geometry (sampling methods and Voronoi tessellations) and uncertainty quantification and optimization. He collaborated with a team to develop VoroCrust, a software program that creates meshes using polyhedral cells rather than tetrahedral and hexahedral cells.

New Mexico Partnerships

ACCOMPLISHMENTS

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Associate Dean for Research and Innovation, UNM School of Engineering, Special Assistant to the Provost for Laboratory Relations

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Jim and Ellen King Endowed Dean of Research and Innovation, UNM School of Engineering and Computing

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New Mexico Institute of Mining and Technology (NM Tech)

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Linnea Sands
Partnership Development

Stephanie Gallegos
Administrative Support

Tracie Durbin
Faculty Loan Program

Jazmine Price
Communications Support

NM UNIVERSITY TEAMS TACKLE MULTIDISCIPLINARY ENGINEERING DESIGN CHALLENGE

Epic engineering battles took place in 2020 and 2021 between three university teams who competed in senior design competitions known as the NM Capstone Challenge. The students and their faculty sponsor from UNM, NMSU, and NM Tech represented multiple critical skills disciplines, including computer science, computer engineering, electrical engineering, and mechanical engineering because those are key skills needed to tackle national security projects at Sandia.

NM Capstone Challenge 2020: Develop an integrated sensing device capable of monitoring multiple environmental conditions during ground transportation of an asset or payload. In addition to measuring vibration, acceleration and temperature, and determining signal processing approaches, the students needed to develop a communications app and innovatively incorporate proximity sensors to

identify any nearby objects. Everything had to fit in a box no larger than 600 cubic centimeters (about half the size of a Girl Scout cookie box).

Throughout the project, the experimental mechanics and dynamics group provided technical support and guidance. A Sandia road test was scheduled but preempted by the pandemic. Two of the teams, however, were able to take their devices out on their own. Sandia mechanical engineer Abby Carnali, who works in vibrations and acoustics, said, "It's wonderful that the students took it upon themselves to do their own road tests. This just demonstrates how engaged they were."

Right before the state's stay-at-home order, a student from each team brought their device to Sandia's Environmental Test Facility to gather data and inform them of needed modifications before their final presentation. Due to the logistical hardships of COVID-19, no official winner was declared for the 2020 Challenge.

(Continued on next page)

Pictured: *Students participating in the 2020 (left photo) and 2021 (right) NM Capstone Challenge tested their devices at Sandia's Environmental Test Facility.*

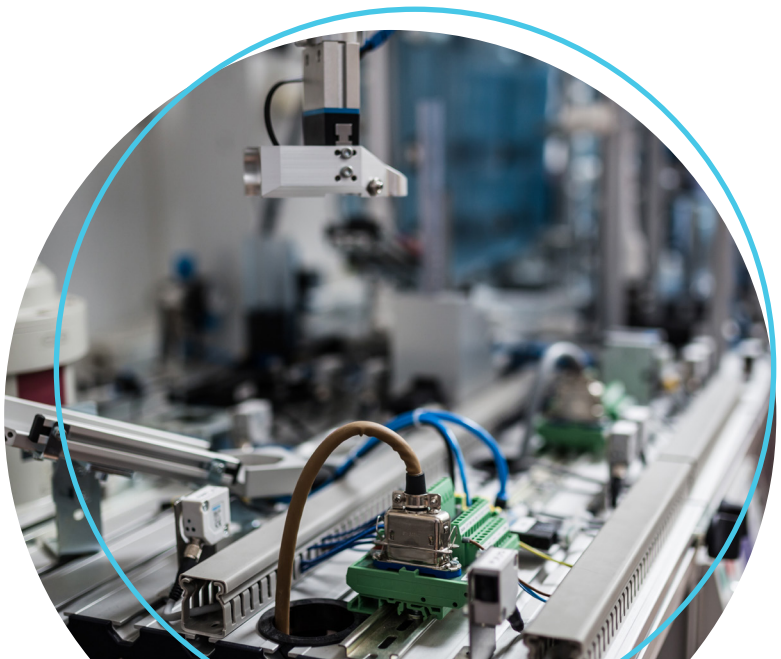
CONTRIBUTOR SPOTLGHT

Ramiro Jordan

UNM's Ramiro Jordan creates and leads STEM education, R&D, and entrepreneurial organizations around the world. With 25 years of experience in international engineering education research, he understands the value of educational activities such as the NM Capstone Challenge and encourages his students to participate. "Both the competition aspect and the multidisciplinary challenge helped my students increase their project management and teaming skills, in addition to demonstrating their engineering capabilities," said Jordan.

NM Capstone Challenge 2021: Design a fully integrated acceleration switch with the ability to accurately sense and report listed environments such as random vibration, acceleration, and temperature. The teams were also judged on their switch's design, volumetric footprint, power usage, weight-to-capability ratio, cost, effective integration of the hardware and software, data rate, robustness, and creative use of novel components. Due to COVID-19 safety guidelines, only one vaccinated student per school was allowed to come into Sandia with their devices for testing. After the final modifications, the university teams gathered via Zoom and presented an overview of their project design, engineering approach, hurdles they encountered, and final results. In the end, NM Tech was declared the winner of the 2021 NM Capstone Challenge. NM Tech student Meghan Cephus said, "We put functionality first, and it ultimately gave us the win."

In both years, the NM Capstone Challenge illustrated to students how their engineering education could be put to use and helped them gain other skills critical to job success. Tyler Mobraten, a NM Tech student, echoed this sentiment. "We are very grateful to Sandia for the opportunity to gain real world engineering experience. This was an invaluable experience as a student first entering the job market."



EARLY CAREER FACULTY MEMBERS AND EARLY CAREER PIS AT SANDIA AWARDED JOINT PROJECTS

Sandia's Accelerated Collaborative Research Nucleus (ACORN) program connects early career faculty members at New Mexico universities with early career LDRD principal investigators at Sandia. The program sponsors one new project per year at each of the New Mexico schools, with each project eligible for three-year funding.

The ACORN LDRD plus-up, "Sensitivity Methods for Monte Carlo Photon/Electron Radiation Transport," led by UNM professor Christopher Perfetti and Sandia PI Aaron Olson, enhances Olson's FY20 base LDRD "Next Generation Uncertainty Quantification and Stochastic Media Monte Carlo Transport Methods."

The base LDRD and plus-up are each in their second of three years. The plus-up work is enabling adaptation of local sensitivity methods previously developed by Professor Perfetti for neutron radiation transport to photon/electron radiation transport. These methods enable computation of local sensitivity information for multiple inputs from only one Monte Carlo radiation transport calculation and complement the base LDRD goal of developing the first-ever approach to construction of a full surrogate model from only one Monte Carlo radiation transport calculation. The base LDRD's other goal is to develop the first-ever Monte Carlo radiation transport in stochastic media model capable of accurately characterizing the effects of real-world random material mixing. These methods represent an innovative approach at utilizing machine learning and highly embedded uncertainty quantification methods for scientific computing on new computing platforms; they also have the potential to inform emerging computing trends.

The tools will provide a new level of fidelity for analyzing current nuclear weapons systems and enable design and analysis insights for new nuclear weapons system concepts.

CONTRIBUTOR SPOTLGHT

Chris Perfetti

Prior to his appointment at UNM, Chris Perfetti was an R&D scientist in the Reactor and Nuclear Systems Division at Oak Ridge National Laboratory, where he developed the CE TSUNAMI-3D code for sensitivity and uncertainty analysis and served as the Sensitivity/Uncertainty Analysis Method Team Lead for the SCALE Code Package.

Pictured: *Sandia PI Aaron Olson*

CULTIVATING EXPERTS IN HIGH-ENERGY DENSITY SCIENCE AND PULSED POWER

The SUPER Center provides an excellent platform to expand into the realm of high-pressure shock chemistry and physics.

Pictured: *Graduate researchers participating in the SUPER Center are utilizing Sandia facilities such as Thor, an accelerator that generates pressures allowing for the study of materials under extreme conditions.*

The collaboration between Sandia's Pulsed Power Sciences area and UNM's Earth & Planetary Sciences and Electrical & Computer Engineering departments has only continued to expand. Since signing an MOU in 2019, the focus of the Sandia/UNM Pulsed Power Extreme-condition Research (SUPER) Center has been on accelerating technical progress broadly in fields relevant to DOE/NNSA, cultivating a pipeline of experts in the fields of high-energy density science and pulsed power, and attracting new graduate researchers to propel the work forward.

Two of the graduate researchers are Wade Mans and Stacie Hernandez. Wade Mans is a current SUPER Center Ph.D. Fellow who is joined by Ph.D. student Stacie Hernandez. Hernandez was selected by UNM for a prestigious five-year research fellowship as the graduate SUPER Center Fellow for Electrical & Computing Engineering, with full financial support from the SUPER Center. The fellowship will focus on research in areas related to high-energy density science applied to understanding material properties in planetary interiors and will take advantage of the unique pulsed power experimental facilities at Sandia such as the Z machine and Thor, as well as the STAR gas gun facility.

This type of research connects tightly to Sandia's Radiation Effects and High-Energy Density Science Research Foundation, which addresses issues key to nuclear security and maintaining a safe, secure, and effective nuclear stockpile. Radiation effects science ensures that engineered systems are able to operate as intended in the radiation environments they encounter. In addition, high-energy density science validates models used to certify the performance of the stockpile, while pulsed power science enables terawatt to petawatt pulsed-power systems. Such systems efficiently deliver electrical energy — in pulses that are flexible in shape and duration — to a variety of loads.

CONTRIBUTOR SPOTLGHT

Wade Mans

Wade Mans is a SUPER Center Ph.D. Fellow in the Institute of Meteoritics Personnel at UNM. His work with the Dynamic Material Properties team at Sandia utilizes the experimental, theoretical, and computational capabilities of the Pulse Power Sciences Center to meet national security and fundamental science needs. In the SUPER Center, Mans is working on a research plan that uses UNM and Sandia facilities to examine the effect of shock on mineral compositions representative of those found within meteorites. The plan includes the development of new capabilities for facilities such as Thor at Sandia's Dynamic Integrated Compression Experimental Facility.

BRINGING SCHOLARS FROM AROUND THE U.S. TO TACKLE MECHANICAL ENGINEERING CHALLENGES

Pictured: *A group of NOMAD students gather on the UNM campus prior to the pandemic.*

The Nonlinear Mechanics and Dynamics (NOMAD) Research Institute brings together diverse teams of undergraduates, graduates, Ph.D. students, and early career researchers to work on computational and experimental projects germane to nonlinear mechanics and dynamics with Sandia's mission space. NOMAD, held on the UNM campus each summer, focuses on making significant progress toward solving major challenges in mechanical engineering.

Students are matched each year with research projects and mentors based on their interests and qualifications. They get to do meaningful work in cutting-edge R&D, collaborate with other researchers, and experience a short-term commitment that doesn't conflict with existing fellowships or assistantships.

In 2020, the NOMAD Institute explored ways to improve the way experiments and modeling are done in the engineering sciences. Often, they are performed in isolation from each other, but the processes can be better integrated, improving the outcomes of each, said Rob Kuether, the engineer at Sandia who organized the Institute this past year. Tariq Khraishi, professor of mechanical engineering, was the main UNM partner in the 2020 Institute.

Typically, there are 20 mostly graduate-level students from around the U.S. working on seven technical projects with 30 mentors from mid-June through July. In 2020, the scope was reduced due to COVID-19 and the 7th annual Institute was held virtually. All 11 students worked from home or their university, if allowed, and focused on four

computations and analytical modeling projects.

Participants published the results from their projects.

- Nonlinear Analysis of Mechanical Joints in Finger-Like Mechanism-Based Morphing Wing Devices
- Neural Network Informed Uncertainty Quantification for Structural Dynamics Reduced Order Models
- Nonlinear Normal Mode Force Appropriation Techniques to Investigate Wing-Pylon Assembly
- Correlation of Reduced-Order Model of Threaded Fastener

The NOMAD Institute program was started in 2014 by Sandia's Diane Peebles and Matt Brake. For more information, contact NOMAD@sandia.gov.

CONTRIBUTOR SPOTLGHT

Tariq Khraishi

Tariq Khraishi is a UNM professor in mechanical engineering and assistant dean for internships at the School of Engineering. His work has been funded by numerous government agencies and several corporations, making him a perfect collaborator on the NOMAD Institute. When discussing the benefits of NOMAD, he said, "It's a definite win-win situation. NOMAD connects UNM researchers (faculty and students) with Sandia researchers (staff and managers), which facilitates more collaborative opportunities." Khraishi is a solid advocate of NOMAD and hopes it continues to grow in stature, attracts applications from national students, and increases the competitive nature of the program.

CONTRIBUTOR SPOTLGHT

Rob Kuether

Rob Kuether, Sandia mechanical engineer with expertise in computational structural dynamics, led the 2020 NOMAD Research Institute. He's seen numerous benefits from the NOMAD program during the seven years of its existence, and he highlighted its criticality as a student pipeline. "NOMAD engages students in computational and experimental mechanics/dynamics research. In the future, we hope to attract top tier researchers and influence the research trajectories of students throughout the U.S." Kuether also noted that there have been quantifiable impacts to the Sandia's national security mission as a direct result of NOMAD research projects.

UNM BY THE NUMBERS

UNM and Sandia have enjoyed a close partnership for many years, collaborating on numerous research projects, sharing expertise and knowledge through joint academic appointments, and hiring many UNM graduates as interns or regular employees.

To further strengthen that partnership, UNM and Sandia signed a 10-year MOU for a strategic alliance. The 2020 agreement focuses largely on how the two can collaborate to solve challenges relating to national security, said Diane Peebles, Sandia's New Mexico Campus Partnership Manager.

NEW HIRES AT SANDIA FROM UNM

160 Alumni
137 Students

ON-ROLL AT SANDIA AS MEMBERS OF THE WORKFORCE

3,135 Alumni
352 Students

*Laboratory Directed Research and Development (LDRD)
† Including adjunct faculty, research faculty, lecturers, and advisors.
‡ New Mexico Small Business Association (NMSBA)

$1.4M

INVESTED AT UNM BY SANDIA IN 30 LDRD* PROJECTS

$2.2M

INVESTED AT UNM BY SANDIA IN 51 PROGRAM-FUNDED PROJECTS

4
PROJECTS

PROJECTS DONE IN PARTNERSHIP WITH NMSBA‡ AND THE UNM SCHOOL OF ENGINEERING

PROJECTS DONE IN PARTNERSHIP WITH NMSBA‡ AND THE UNM MANAGEMENT OF TECHNOLOGY PROGRAM

4
PROJECTS

HOLD SOME FORM OF SANDIA/UNM AFFILIATED ROLE AT UNM†

50
SANDIANS

SERVE ON A VARIETY OF UNM EXTERNAL ADVISORY BOARDS

61
SANDIANS

RELEASED AS JOINT SANDIA/UNM EFFORTS OR AS SANDIA REPORTS

16
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