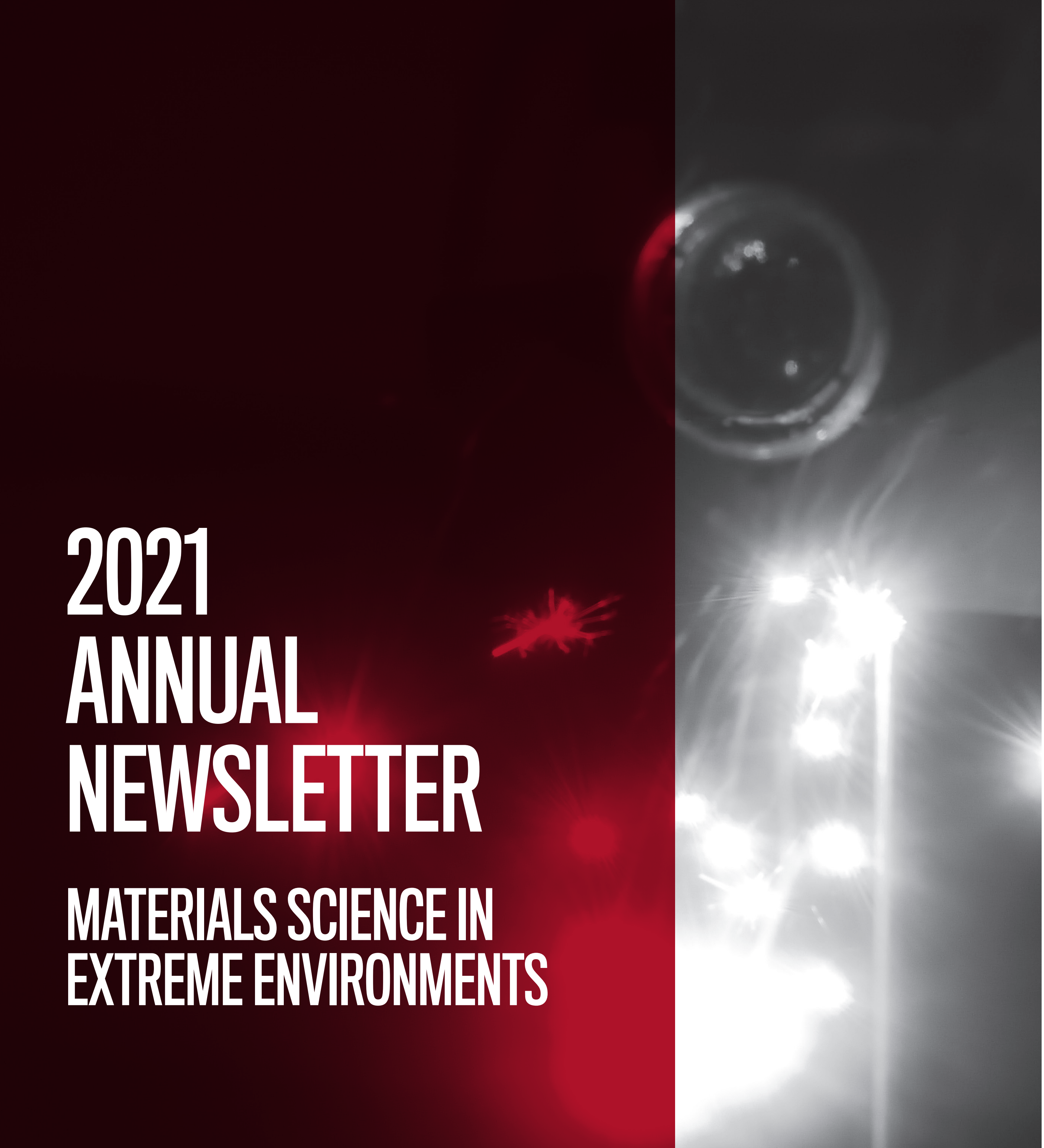

2021 ANNUAL NEWSLETTER

MATERIALS SCIENCE IN EXTREME ENVIRONMENTS

MSEE

MATERIALS SCIENCE IN
EXTREME ENVIRONMENTS
UNIVERSITY RESEARCH ALLIANCE

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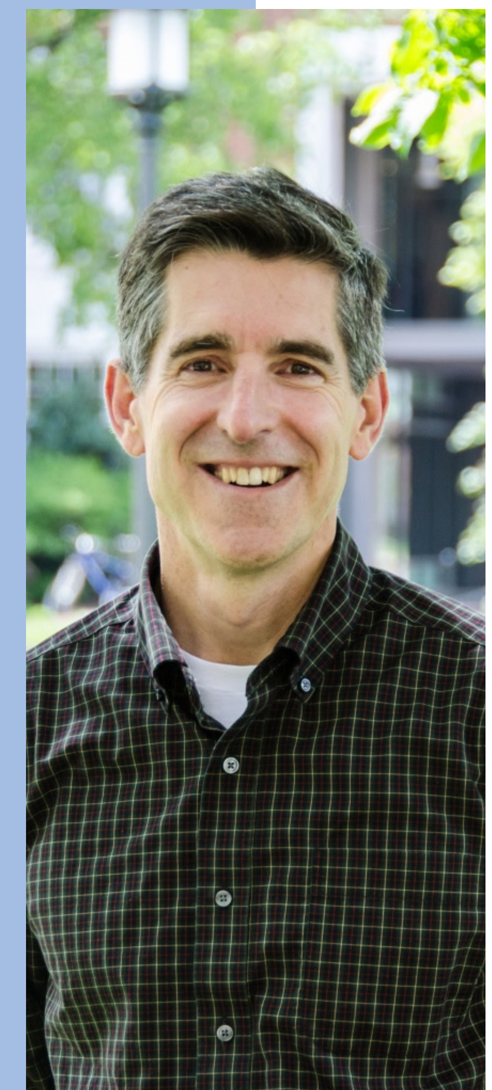
FROM THE DIRECTOR



TIM WEIHS
Director, MSEE URA
Professor, Department of Materials
Science and Engineering, JHU

As director of the Materials Science in Extreme Environments (MSEE) University Research Alliance (URA), I want to thank the many people who have been instrumental in successfully launching and running this alliance. These include the dedicated staff at Johns Hopkins University who provide incredible support, the principal investigators (PIs) across the country who collaborate so effectively, our partners at the Defense Threat Reduction Agency (DTRA) who offer guidance and feedback, our government and corporate affiliates who have shared insights regarding the applications we pursue, and lastly, our Science Advisory Board that offers sound recommendations. Together, as a cohesive consortium, we will support DTRA's mission to defend our country against weapons of mass destruction and provide reach-back technical support to the warfighter.

MSEE was established on May 14, 2020 with a 5.5-year, $35 million award from DTRA. The URA comprises four lead research area organizations: Johns Hopkins University, University of Illinois Urbana-Champaign, University of California Riverside, and University of California San Diego, as well as 12 other academic, federal, and industry partners across the United States. Our research is focused on two major topics: defense against nuclear blasts and defeat of chemical and biological agents. Our alliance is organized into four main research areas, each with multiple focus areas, and a cross-cutting research initiative.

Though limited by COVID-19 public health restrictions, we successfully held a two-day virtual kickoff meeting in July 2020. This event was attended by our 40 MSEE PIs, DTRA executive leadership, and more than 150 additional federal, industry, and academic stakeholders. Since then, we have leveraged the virtual environment and fostered collaborations through bi-weekly focus area meetings, monthly seminars, and workshops. We also have provided a range of workforce development activities that include bootcamps, short courses, Undergraduate Research Awards, and Extreme Science Internships hosted by Morgan State University.

In June of this year, we held MSEE's first Annual Technical Review, a three-day virtual event followed by meetings of the Government and Corporate Affiliates Program (GCAP) and our Science Advisory Board (SAB). Given the feedback we received from DTRA and our SAB, MSEE's impressive collaborative culture, our successful workforce development activities, and GCAP participation, MSEE URA's future is bright. I look forward to working with many of you in the coming year as we pursue fundamental science to support DTRA and develop the future MSEE workforce.

PROGRAM GOALS

Advance the fundamental understanding of materials and chemistries under extreme conditions of pressure, temperature, and radiation

Create state-of-the-art diagnostics tools, high-fidelity models, and advanced materials while facilitating their transition to DTRA applied research programs

Manage and foster a comprehensive, collaborative research environment

Train, mentor, and inspire the next-generation workforce

To achieve these goals, the MSEE URA has four distinct research areas and a cross-cutting research initiative. Research is focused on understanding, predicting, and controlling the behavior of materials in extreme conditions caused by weapons of mass destruction. The URA is expected to understand fundamental aspects associated with conventional weapon behavior, to develop advanced materials that can be applied to the destruction of chemical and biological agents, and to advance the understanding of nuclear explosion behavior and the material response to nuclear weapon generated and simulated environments.

RESEARCH AREAS AND LEADS

1: Material Properties and Failure;

2: Materials and Manufacturing for Synergistic Effects;

3: Chemistry in Extreme Environments;

4: Photon-Material Interactions;

5: Cross Cutting Research Initiatives.

TODD HUFNAGEL
Research Area 1 (RA1) and Associate Director of MSEE URA

MICHAEL ZACHARIAH
Research Area 2 (RA2)

NICK GLUMAC
Research Area 3 (RA3)

FARHAT BEG
Research Area 4 (RA4)

MARK FOSTER
Cross Cutting Research Initiatives Coordinator

STAFF

ANDREW PROULX
Program Manager

RACHEL WISE
Administrative Coordinator

DEFENSE THREAT REDUCTION AGENCY (DTRA)

MIKE ROBINSON
Collaborative Alliance Manager (CAM)

JACOB CALKINS
Technical Point of Contact (TPOC) for RA1 , RA4

JEFF DAVIS
Technical Point of Contact (TPOC) for RA1, RA2, RA3

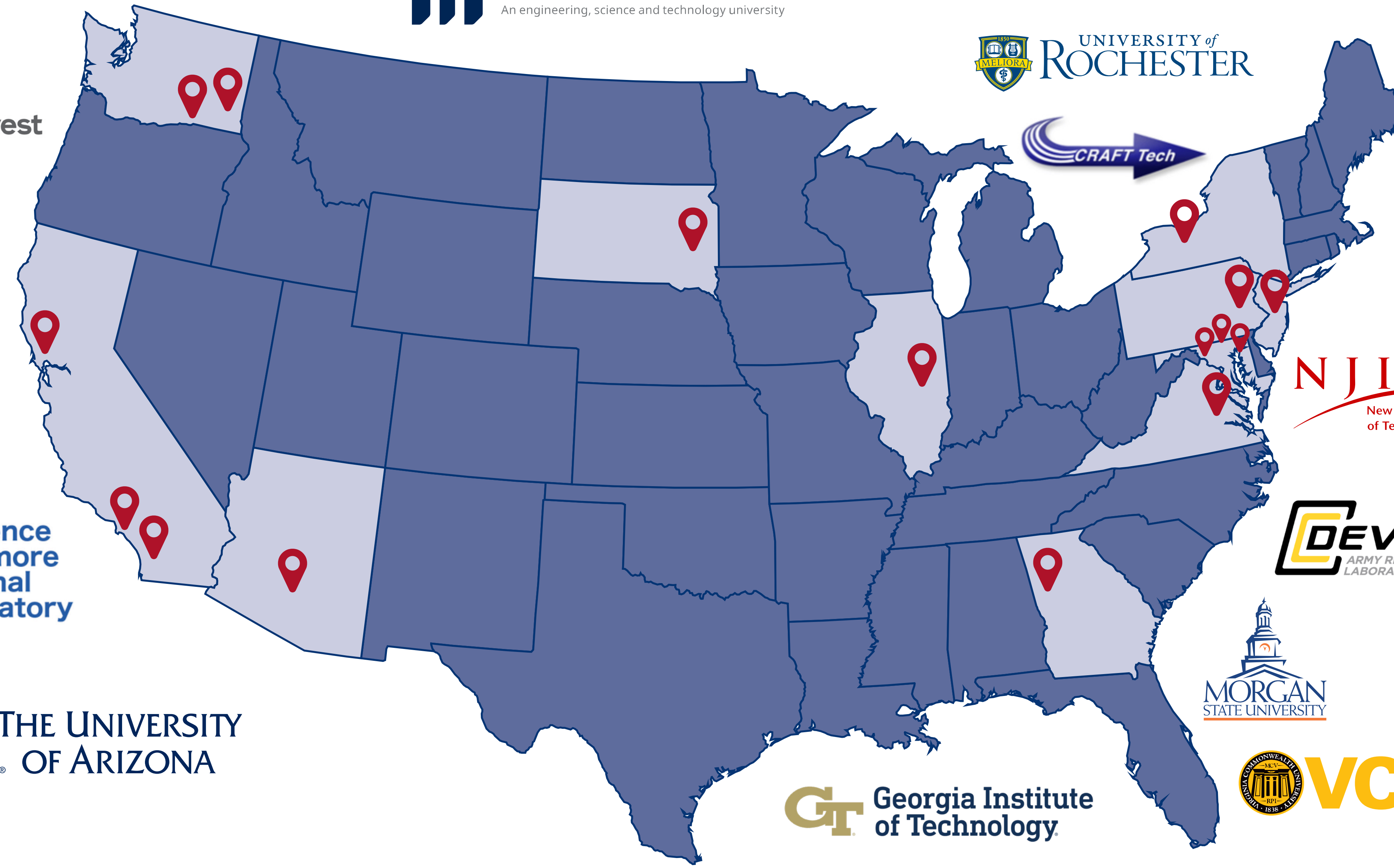
JULI-ANNA JOHNSON
Technical Point of Contact (TPOC) for RA2, RA3

DAVE PETERSEN
Technical Point of Contact (TPOC) for RA3

MSEE URA INSTITUTIONS

Johns Hopkins University · UC Riverside · UC San Diego · University of Illinois Urbana-Champaign

Washington State University · South Dakota Mines (An engineering, science and technology university) · University of Rochester · Pacific Northwest National Laboratory · CRAFT Tech · NJIT New Jersey Institute of Technology · Lawrence Livermore National Laboratory · DEVCOM Army Research Laboratory · Morgan State University · The University of Arizona · Georgia Institute of Technology · VCU



MSEE NUMBERS

INDIVIDUAL PARTICIPANTS

32
PRINCIPAL INVESTIGATORS

4
RESEARCH AREA LEADS

41
GRADUATE STUDENTS

2
ACTIVE DUTY MILITARY

10
FROM MSI INSTITUTIONS

15
POSTDOCS

3
FROM MSI INSTITUTIONS

9
FOCUS AREA COORDINATORS (INCLUDES CCRI COORDINATOR)

21
UNDERGRADUATES

4
FROM HBCU

6
ENGINEERS/TECHNICIANS

2
ADMIN STAFF AT JHU DIRECTLY SUPPORTING URA

PROFESSIONAL DEVELOPMENT OPPORTUNITIES

371
PARTICIPANTS IN EIGHT SEMINARS

136
PARTICIPANTS IN SIX WORKSHOPS

61
PARTICIPANTS IN TWO SHORT COURSES

25
INTERNSHIPS AND APPRENTICESHIPS AWARDED ACROSS FOUR PROGRAMS

Our seminars are held on the first Tuesday of each month at 3–4 PM ET. For more information about MSEE's upcoming seminars and other professional development opportunities, please visit our website: **hemi.jhu.edu/mseeura**.

PUBLICATIONS AND PROCEEDINGS

20
PEER REVIEWED JOURNAL ARTICLES

2
CONFERENCE PAPERS

9
EXTERNAL PRESENTATIONS

1
PATENT APPLICATIONS

PERSONNEL SPOTLIGHT

KERRI-LEE A. CHINTERSINGH, PhD

Assistant Professor, Chemical and Materials Engineering, NJIT
Former Postdoctoral Researcher, Hopkins Extreme Materials Institute (HEMI), Johns Hopkins University

MSEE TASKS

Cross Cutting Research Initiatives
Research Area 2, Focus Area 2: Tailoring Chemistry via Materials (RA2-FA2)
Research Area 3, Focus Area 2: High Temperature Properties and Chemistry of Agents and Simulants (RA3-FA2)

"The MSEE program affords me the opportunity to gain exposure to a broad range of topics and un-matched expertise for both experimental and computational cutting-edge research. It encourages a collaborative environment by creating a concrete network with more than 18 organizations, while enabling creativity and strengthening future research relationships for greater funding and scientific opportunities. With weekly/bi-weekly progress meetings, I can present findings to stimulate thought-provoking discussions, achieve efficient problem solving, and receive direct feedback from experts. The atmosphere allows ideas to be debated and for answers to bigger and more complex scientific questions to be sought. There is also more technical learning and greater skill/knowledge transfer of a wide array of interesting techniques that can be applied to other areas of research. Finally, I have the opportunity to showcase my research, strengthen my presentation skills, and interact with other young researchers. These are all tremendous benefits that will aid in preparing and building the foundation for a successful research career within and beyond this field, especially for an early-career faculty member like me."

SOPHIE PARSONS

PhD candidate, University of California San Diego/Lawrence Livermore National Laboratory

MSEE TASKS

Direct Laser Impulse (RA4-FA2)

"Being a part of the MSEE URA has been hugely beneficial for my research and development as a scientist. As a part of this program, I have had the opportunity to conduct my PhD work at a national lab as part of an interdisciplinary team of lab and university scientists. The ability to work with scientists across disciplines, universities, and research areas means that I have had the opportunity to learn from and collaborate with faculty and students with diverse subject matter expertise. This, coupled with access to equipment across the MSEE URA, has made my PhD work possible. Furthermore, the URA has provided me with access to wonderful mentors, both at my university and at the national lab."

MAXIMILIAN GARCIA

Undergraduate Research Intern at Hopkins Extreme Materials Institute (HEMI), Johns Hopkins University

MSEE TASKS

Strain Rate Effects on Granular Compaction (RA1-FA2)

"The MSEE program has provided me with a great opportunity for professional development by exposing me to many different scientific data collection instruments as well as improvement in professional skills such as coding, data analysis, and communication. It has also given me insight into the lives and careers of researchers, PhDs, and post-doctorates, as I have communicated and worked closely with each throughout the summer here. I thank MSEE for the time I've had this summer, and I highly recommend the program to any undergraduates looking to gain hands-on experience or explore other career options."

LORI J. GROVEN, PhD

Associate Professor, South Dakota Mines, Chemical and Biological Engineering Department

MSEE TASKS

Tailoring Chemistry Via Materials (RA2-FA2)

"The MSEE has provided to me and my students the opportunity to study materials that have broad reaching applicability, from combatting chemical warfare agents to high throughput catalysts. Most importantly, with our studies, we are helping secure our nation's security."

MSEE FACILITIES SPOTLIGHT

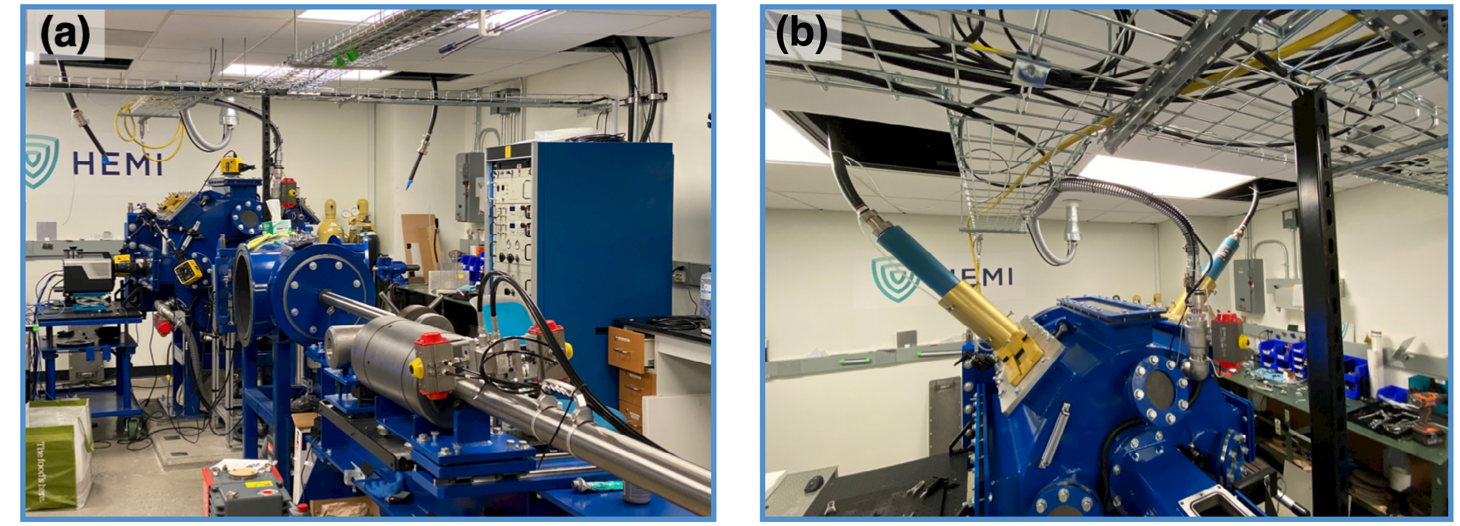
HYPERVELOCITY FACILITY FOR IMPACT RESEARCH EXPERIMENTS

The Hypervelocity Facility for Impact Research Experiments (HyFIRE) at the Johns Hopkins University (JHU) enables examination of the physics and mechanics of impact and penetration into materials at timescales ranging from nanoseconds to milliseconds, and length scales ranging from microns to meters. HyFIRE features a two-stage light gas gun capable of launching projectiles at velocities up to 7 km/s toward material targets. HyFIRE also features diagnostics, including multi-angle flash X-ray tubes and high-speed cameras for imaging, a photon doppler velocimetry system for measuring wave speeds through materials, ejecta tracking and catching systems, and a spectroscopy system for studying chemical reactions (Fig. 1).

Researchers from MSEE's RA1-FA2 (Material Properties and Failure—Materials Constitutive Models) use HyFIRE to study the response of dry and saturated Ottawa sand when impacted by 3 mm spherical projectiles traveling at 1.5 km/s. The goal of these experiments is to test HyFIRE's multiple diagnostics, particularly flash X-ray, PDV, and ejecta catching systems, for the first time. In addition, these experiments provide insight into a variety of geologic material behaviors, including sand fragmentation statistics and flow fields around penetrators.

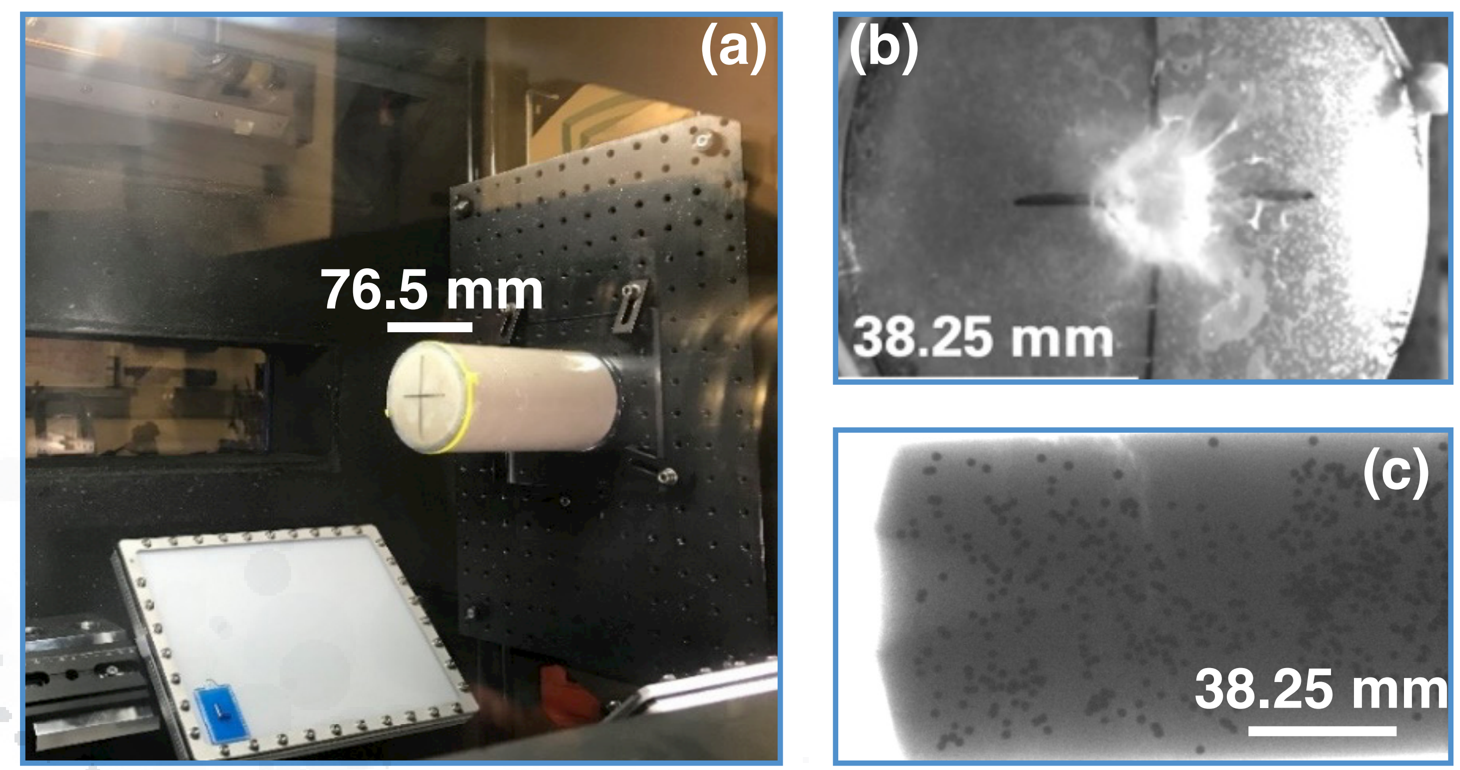
RA1-FA2 researcher Brett Kuwik (PhD candidate in the Department of Mechanical Engineering at JHU, advised by MSEE URA PI Ryan Hurley) designed and executed experiments in May 2021 with the help of JHU staff Matt Shaeffer and Justin Moreno (both of the Hopkins Extreme Materials Institute), and fellow Department of Mechanical Engineering PhD student Gary Simpson. Feedback from other RA1-FA2 researchers, including MSEE URA PIs KT Ramesh (professor, JHU Department of Mechanical Engineering), Todd Hufnagel (professor, JHU Department of Materials Science and Engineering), and Michael Shields (professor, JHU Department of Civil and Systems Engineering), were critical before and after experiments. The experiments provided the first through-thickness in-situ flash X-ray images of projectiles penetrating targets, confirmed that projectiles penetrate to deeper depths in saturated sands than in dry sands, and elucidated the sand fragmentation behavior expected along the penetration path (Fig. 2). This data will help shape the design and execution of future experiments and models within RA1-FA2 and is the first step for the URA in developing robust, mechanism-based constitutive models for predicting the mechanical penetration response of geomaterials.

FIGURE 1



HyFIRE facility at JHU (a) The two-stage light gas gun barrel and impact chamber. (b) A close-up of the impact chamber with two flash X-ray tubes attached in gold-colored mounts for imaging through materials as they are impacted by projectiles.

FIGURE 2



(a) Impact chamber of HyFIRE before impact experiment with Ottawa sand. The sand sample is mounted horizontally to the back of the chamber. The white plate is one of two flash X-ray detectors used to image through samples during impact. (b) A still-frame of 5 million frames per second high-speed video, showing the fluid and sand ejected about 8 microseconds after impact. (c) A flash X-ray image obtained from one of two detectors, showing the through-thickness material behavior at about 450 microseconds after impact. The grey region of the image is sand and the dark circles are lead particles used as flow-field tracers. A small crater is visible on the left side of the image. Changing the contrast in the image also reveals a stream of ejected particles.

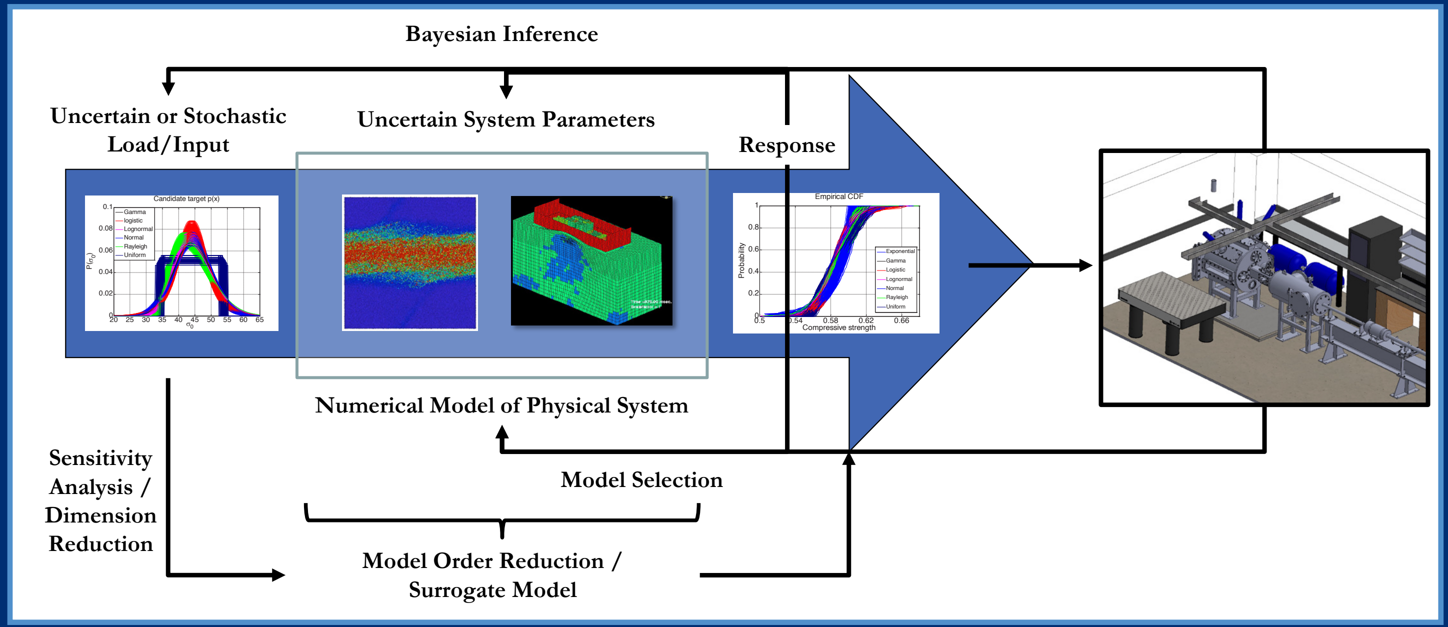
MSEE RESEARCH SPOTLIGHT

UNCERTAINTY QUANTIFICATION EFFORTS SPAN MSEE

A major component of the MSEE Cross-Cutting Research Initiative (CCRI) is uncertainty quantification (UQ). Michael Shields, associate professor of civil and systems engineering at Johns Hopkins University, and his team are working with research groups throughout MSEE to understand the important role that uncertainties play in understanding the complex behaviors of materials under extreme conditions. Shields and his team have developed a unified framework for UQ (see Figure) that is being applied across the URA through their open-source software package UQpy (Uncertainty Quantification with Python). To ensure the success of this effort, a UQ Subgroup with representatives from each focus area has been assembled and is meeting regularly to strategize and discuss UQ efforts throughout the program.

Shields and his team are specifically overseeing efforts to understand the influence of uncertainties in multiphase material equations of state and constitutive models under conditions ranging from very high-rate impact loading to the extreme temperatures and pressures that create warm dense plasmas. Bigger picture: the UQ Subgroup is beginning to contemplate the role of uncertainties in a wider range of efforts. Along with Bryan Wong, professor at the University of California, Riverside, the team is investigating stochastic methods for quantum control to efficiently decompose chemical warfare agents. Meanwhile, in collaboration with Davide Curelli, associate professor at the University of Illinois, Suresh Menon, professor at Georgia Tech, and Raj Sinha and Andrea Zambon from CRAFT Tech, the team is beginning to explore uncertainty in chemical reaction networks and transport. Collectively, these efforts are bringing researchers from across the URA together to tackle exciting and challenging problems.

To launch these UQ efforts, Shields and Dimitris Giovanis (assistant research professor at JHU) hosted two UQ short courses on June 2–4 and June 9–11, 2021. The first short course was offered to researchers in the MSEE URA and was primarily attended by graduate students, postdocs, and faculty. The second short course was offered to DTRA researchers. In total, the short courses were attended by more than 60 researchers and offered an introduction to the fundamentals of UQ, as well as their implementation in UQpy.



MSEE RESEARCH SPOTLIGHT

PLASMA ABLATION AND SHOCK GENERATION USING OMEGA LASER FACILITY

Thermo-mechanical shock (TMS) due to nuclear blasts in the upper atmosphere is a major threat for objects orbiting in space such as satellites. This type of shock becomes a major vulnerability at high X-ray intensities and at particular X-ray spectra and needs to be understood to design strategies for safeguarding our satellite systems. However, our ability to conduct experiments with high flux X-rays is limited, so instead, we turn to high laser fluxes and fluences to generate and study thermo-mechanical shock at multi-Mbar levels. However, to enable these studies we must first learn how to efficiently couple laser energy to a given target and to do so we must understand the underlying physics of laser-material interactions. In particular, we must characterize and understand the process of plasma blow-off as a function of the laser pulse length. In pursuit of this goal, RA4-FA2 researchers Tanner Cordova (PhD student in the Department of Mechanical and Aerospace Engineering, UC San Diego) and postdoctoral scholar (Dr. Kazuki Matsuo, Center for Energy Research, UC San Diego) carried out extensive radiation hydrodynamics modeling to understand the role of laser pulse length on the ablation and TMS propagation. Their modeling, guided by Professor Beg at UC San Diego, facilitated a design of the experiment. To then study their predicted laser-material interactions, this team secured a shot day on the Omega EP through the LaserNetUS program. The execution of the experiment and the subsequent data analysis was a team effort between UC San Diego and the Laboratory for Laser Energetics and included Tanner Cordova (graduate student), Drs. Mathieu Bailly-Grandvaux (Research Scientist) and Eric Hahn (post-doctoral fellow), who were advised by Professor Beg, and Dr. Tirtha Joshi (Research Scientist at LLE), who was advised by Dr. Spielman of University of Rochester and LLE. The schematic of the experiment and the data from various diagnostics are shown in Figure 1. Each experimental configuration maintained a constant laser intensity of 6×10^{14} W/cm^2. From analytical scaling, the ablation pressure should be proportional to the instantaneous intensity to the power 2/3 and independent of the pulse length, motivating a study of laser pulse length (100 ps, 500 ps, 1 ns, 10 ns) on the physics of plasma blow off and strong shock generation. In these experiments, the measured ablation front temperature is ~500 eV, regardless of pulse duration. Yet, the investigation of ablation temperature from the sole effect of pulse duration will require an experiment at constant laser fluence rather than constant intensity, which is planned next year. Interestingly, the measured shock velocity for a 10 ns pulse duration is on the order of 35 km/s compared to 3 km/s for 100 ps – marking a significant decrease in the shock pressure for sub-ns pulses, from ~22 Mbar to <1 Mbar, respectively. In fact, this trend is observed to be proportional to the pulse duration, indicating a significant contribution of rarefaction on the supported shock pressure and enabling a direct measurement of the decay rate thereof. Evidence of such multi-wave features can be identified in the 10 ns pulse data (Fig. 1d, e), marking distinct shock and release waves as they traverse the sample. These results clearly demonstrate that the laser pulse length plays a pivotal role in plasma ablation and strong shock generation and will help us build a deeper understanding of thermos-mechanical shocks that are due to nuclear blasts.

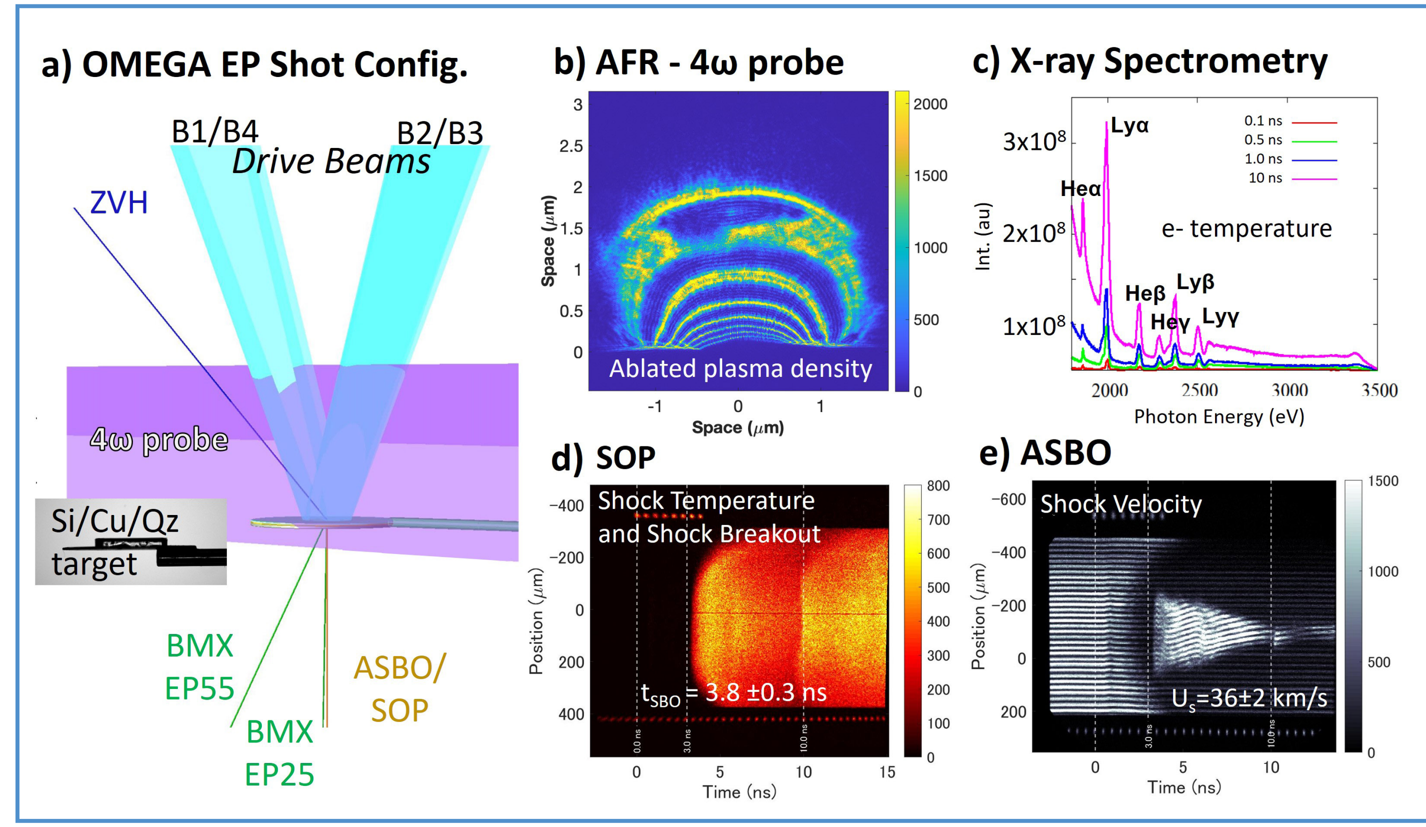


Fig. 1: a) DTRA OMEGA-EP experimental configuration. Systematic investigation of ablation physics and thermomechanical shock propagation at an intensity of 10^{15} W/cm^2 as a function of the laser pulse length. Target consists of 3 layers: Si/Cu/Qz. b) Angular Filter Refractometry (AFR) diagnostic using the 4ω probe to measure the density of the ablated plasma. c) Time-integrated X-ray spectrometry can provide an inferred electron temperature using the K-shell line ratio of *Lyγ* to *Heγ*. d) Streaked Optical Pyrometry (SOP) can measure shock breakout times and internal temperature of the Quartz. e) The Active Shock Breakout (ASBO) diagnostic measures the timing and thus velocity of the decaying shock wave.

GOVERNMENT CORPORATE AFFILIATES PROGRAM

To facilitate government and industry collaborations, the Materials Science in Extreme Environments University Research Alliance (MSEE URA) established the Government and Corporate Affiliates Program (GCAP).

The GCAP goals include:

» Facilitate the transfer of scientific and technological advances to partners

» Provide a network to enhance collaboration between academia, industry, and government organizations

» Assist members in recruiting and workforce development

The proposed GCAP benefits could include:

» First look at **science and technological** advances supported by DTRA through MSEE URA network and events

» **Annual symposium** to network, provide visibility of your organization, and recruit students

» Opportunities to host **graduate and undergraduate students for internships** to facilitate recruiting and workforce development initiatives

» **Recognition of your organization** with placement of your logo on the MSEE URA website, promotional materials, and annual reports to DTRA

» Ability to **advertise job openings** on MSEE URA website

» Access to **facilities and equipment** at MSEE URA consortium locations

» Early notification for **MSEE URA special events**: short courses, workshops and seminars

MSEE hosted its first GCAP meeting on June 25, 2021. Due to COVID-19 restrictions, this year's GCAP meeting was completed virtually. This meeting introduced the GCAP and described ways in which GCAP members can collaborate with the MSEE URA. Additionally, suggested research areas for collaboration were described by each research area lead. MSEE looks forward to hosting in-person meetings and collaboration in 2022.

GCAP MEMBER INSTITUTIONS

AFRL Eglin
AMG
Applied Research Assoc
Craft-Tech
DEVCOM ARL
DEVCOM Chem Bio Ctr
Draper
DSTL
DTRA
Energetics Technology Ctr
Fluid Gravity
Innovative Sci Sol Inc
JHU Applied Physics Lab
Lawrence Livermore NL
Lawrence Berkeley NL
Los Alamos NL
NAWS China Lake
NIST
NNSS Special Tech Lab
NRL
NSWC Dahlgren
NSWC Indian Head
Sandia NL
Savannah River NL
US Air Force Academy
US Military Academy
US Naval Academy

WORKFORCE DEVELOPMENT

Hallmarks of the MSEE URA is the program's commitment to workforce development and a strong belief that diversity is integral to the success of the program. A comprehensive approach that starts at the high school level and carries through to professionals and faculty will provide an enduring workforce that will impact future generations. MSEE offers a number of professional development programs in coordination with other STEM programs for individuals ranging from high school level to professionals and faculty.

CATHERINE BODINGER

UNDERGRADUATE RESEARCH AWARDS

MSEE provides opportunities for undergraduate students to participate in research through these awards. Students work under the mentorship of a MSEE principal investigator within the technical areas of nuclear blast and chemical and biological agent defeat. These are conducted during the semester and the summer, and the students earn a stipend. Through this program, undergraduates develop research skills and gain professional experience to prepare them for the next steps in their career development.

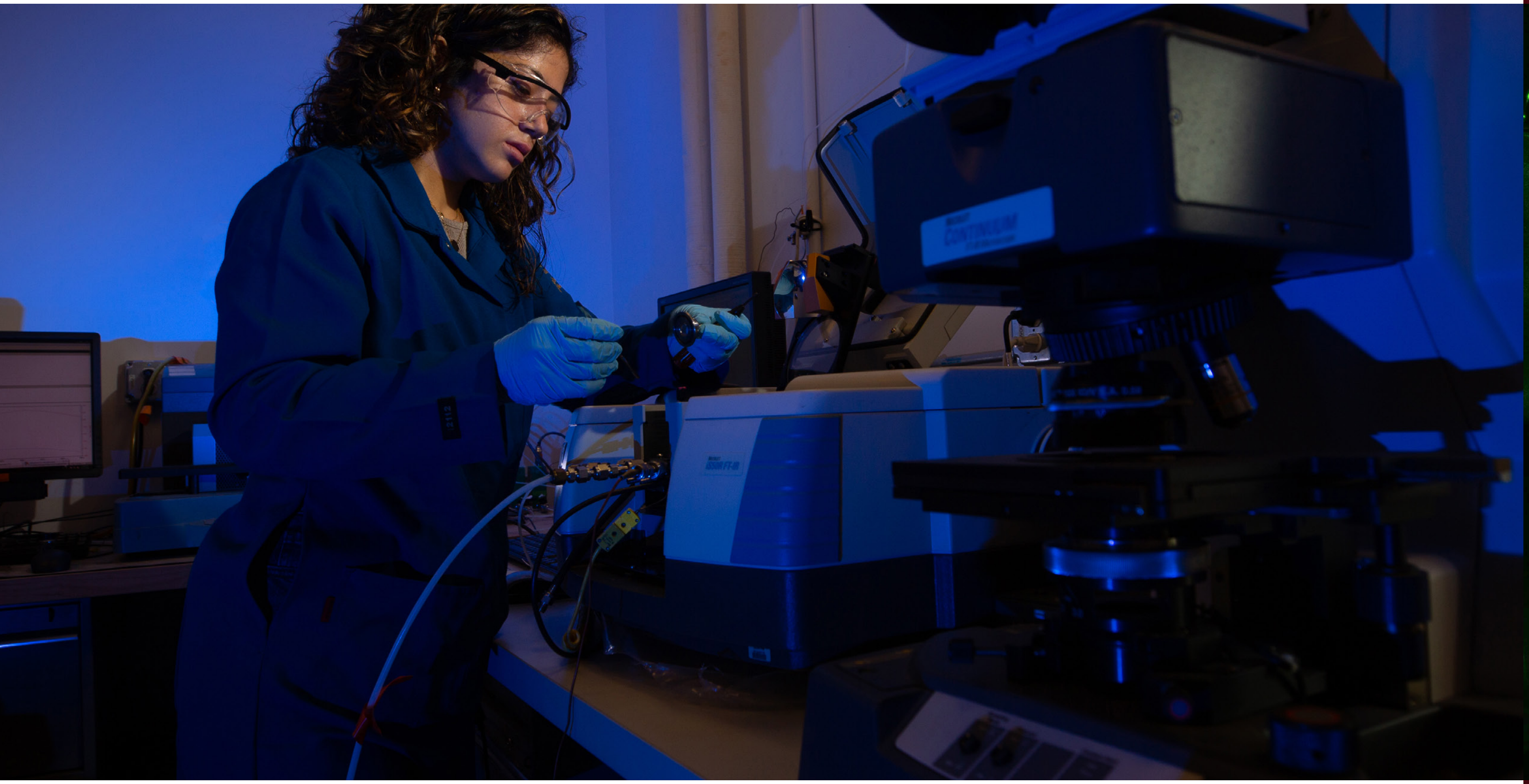
Name	University Attending
Catherine Bodinger	Western Washington University
Rodrigo De Leon	Virginia Commonwealth University
Maximilian Garcia	Johns Hopkins University
Colin Goodman	Eastern Michigan University
Lauren Gotshall	Gonzaga University
Omar Khan	Johns Hopkins University
Brynn Scheckenbach	Gonzaga University
Rostyslav Shkromiuk	New Jersey Institute of Technology
Agata Skura	New Jersey Institute of Technology
Dhylan Worster	Whitworth University

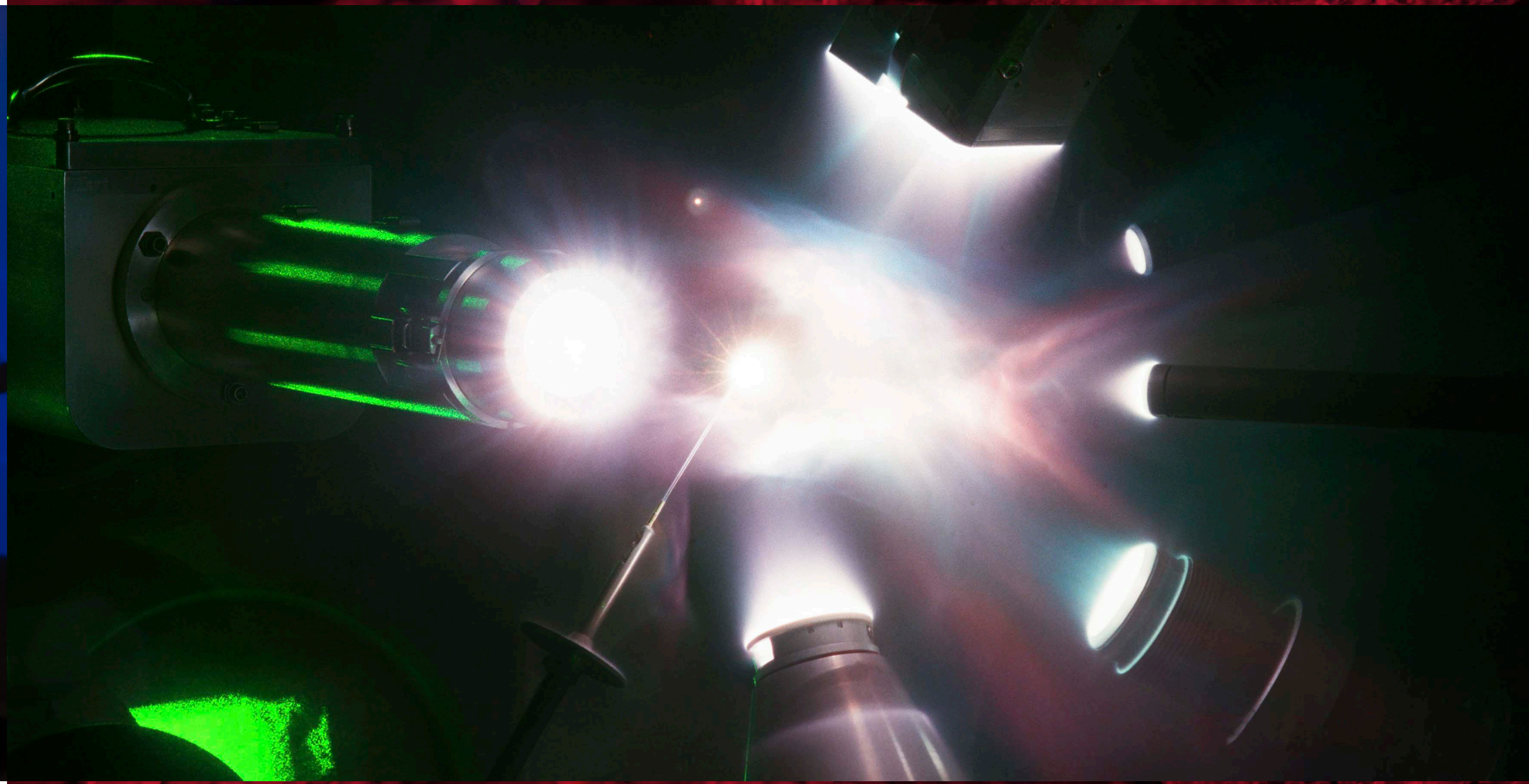
TRAVEL RESEARCH FELLOWSHIPS FOR GRADUATE STUDENTS AND POSTDOCTORAL SCHOLARS

In order to foster collaboration between university researchers and our partners at national and defense laboratories, MSEE awards Travel Research Fellowships. These fellowships provide funds for graduate students and post-doctoral scholars to make extended visits of one month or more to work with collaborators at national (DOE/NNSA) and defense (DOD) laboratories. Fellowship funds can be used to cover travel, housing, and incidental expenses associated with these visits.

AWARDEE

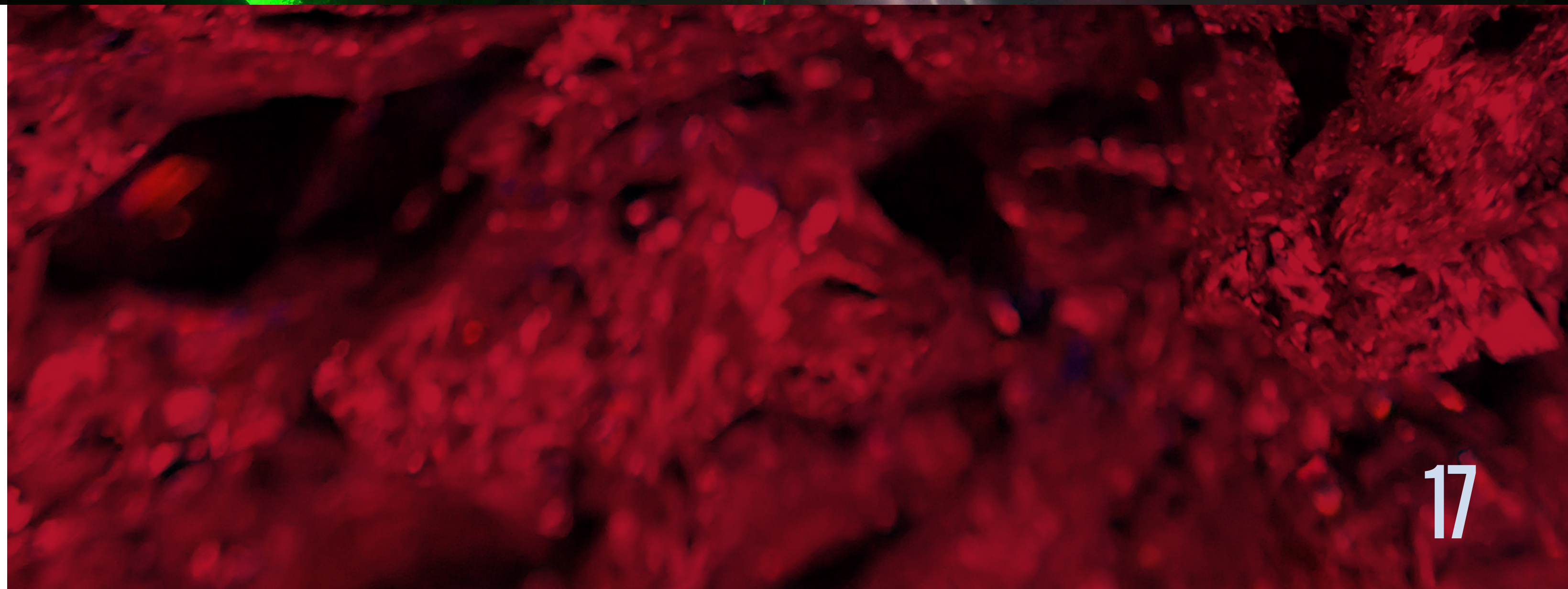
YOUSSEF ABOUHUSSIEN
Graduate Student Research Fellow
Virginia Commonwealth University
Delayed due to COVID-19

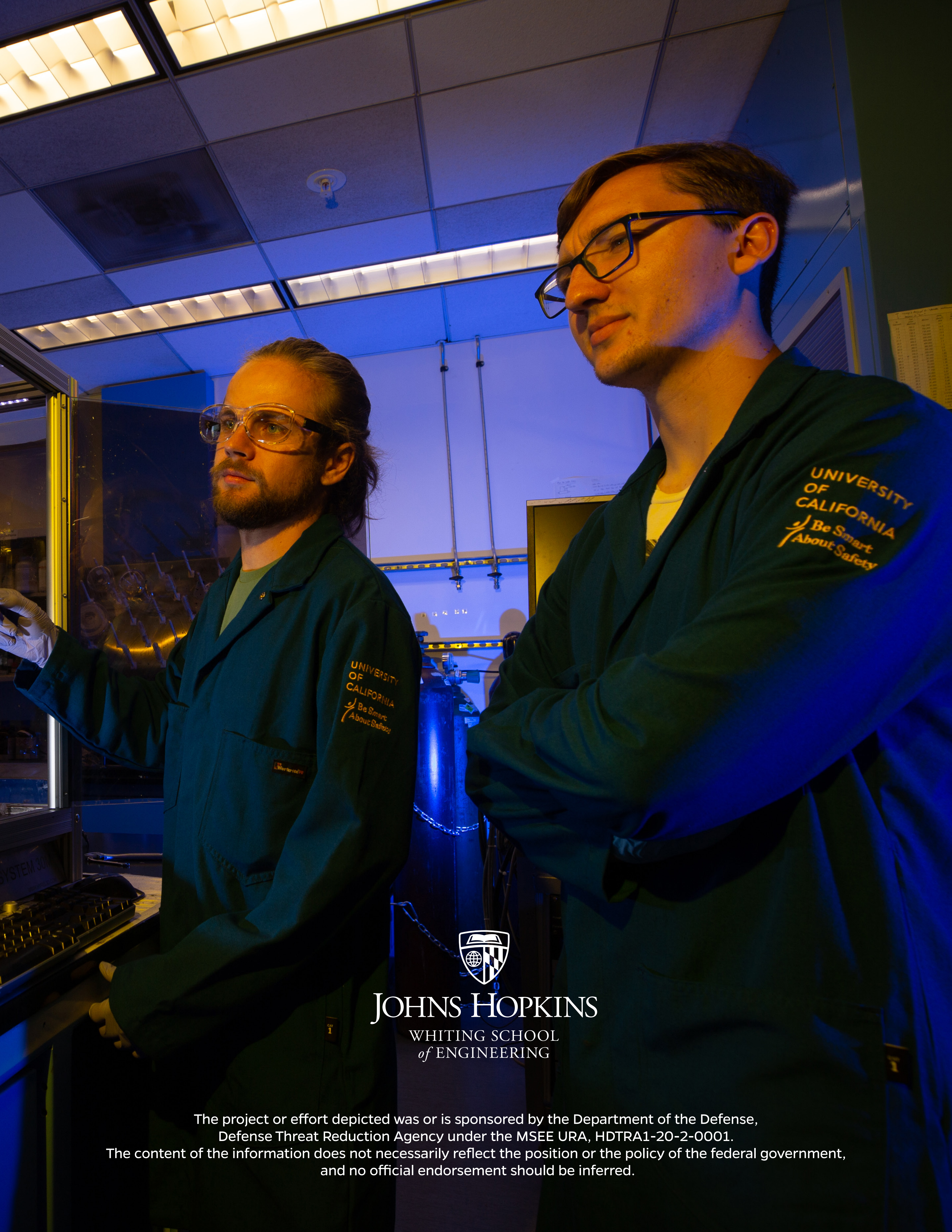




EXTREME SCIENCE INTERNSHIP WITH MORGAN STATE UNIVERSITY

The Extreme Science Internship program enables Morgan State University (MSU) students to participate in research internships associated with the MSEE URA. Students conduct internal internships during the academic year at MSU. During the summer, these students participate in an external internship at one of the many universities within the URA. ESI is focused on developing the student's research skills and providing a broadening experience. Graduates of the ESI program have pursued doctorates and positions in industry. The program is administered by Provost Hongtao Yu and Prof. Birol Ozturk at Morgan State.





JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

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