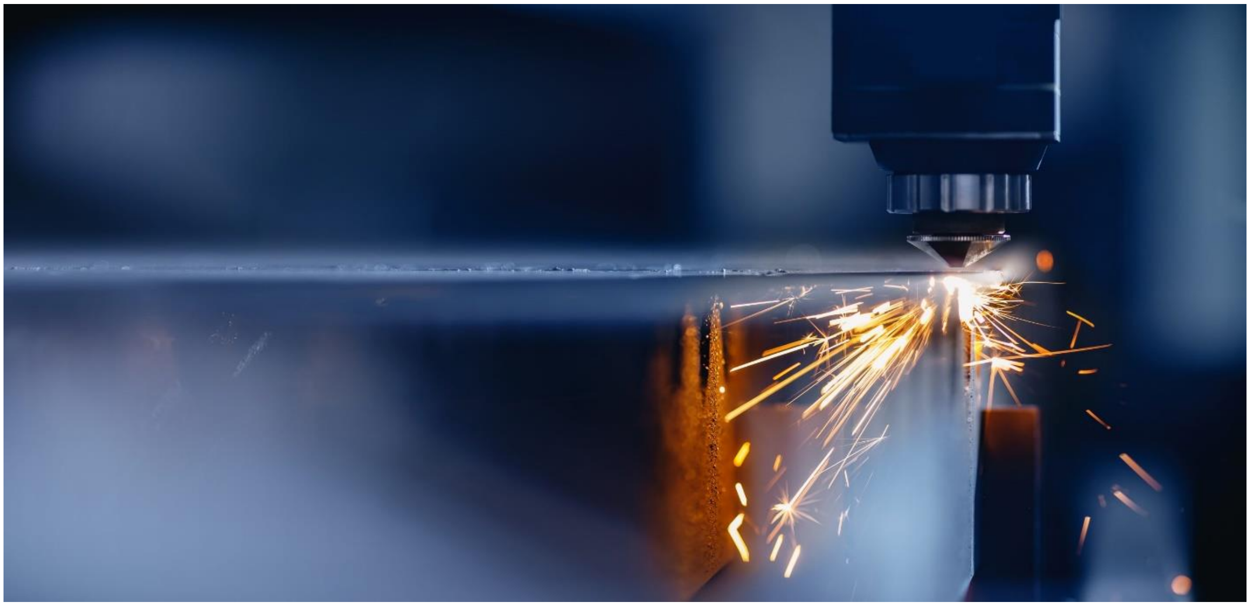
# Intelligent Manufacturing for Extreme Environments

CENTER FOR ADVANCED ENERGY STUDIES

2-3 May, 2024



# Abstract Book

https://imee2024.org

CAES Center for Advanced Energy Studies

University of Idaho

Idaho National Laboratory

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| 9:40 AM - 10:20 AM | "Advanced Materials & Manufacturing for Extreme Environments" | | | Allen Roach, INL |
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| 11:00 AM - 11:10 AM | Closing Remarks<br>*Everyone can go! Except those contributing to report writing!* | | | Indrajit Charit, U of I<br>John Russell, U of I<br>CAES Director |
| 11:10 AM - 12:00 PM | Conference Report Writing Session | | | Indrajit Charit, U of I |
| *Lunch is on your own, thank you for participating!* | | | | |

# Center for Advanced Energy Studies (CAES) Building Information

- In the event of a fire alarm or an emergency, please exit the building and proceed to the grassy area beyond the parking lot on the north side of the building.
- Bathrooms are located at the west end of the CAES Building on both the ground and second floor.
- The CAES building has a dedicated, private lactation room available.
- The auditorium and conference rooms are on the second floor. Snake River is the west conference room and Teton is the east conference room.
- Please join the "CAES Guest" network for Wifi internet service. No password is required.
- The workshop website is https://imee2024.org .

# About the Workshop

The NSF EPSCoR Workshop on Intelligent Manufacturing for Extreme Environments will convene world-class experts, researchers, educators, and students to identify gaps and envision solutions for five inter-related challenges for intelligent manufacturing in extreme environments.

Key Challenges:

- printable electronics that can survive extreme environments,
- in-situ manufacturing process monitoring and feedback control,
- machine learning to optimize process variables in manufacturing and materials composition,
- extreme temperature qualification and testing, and
- workforce development and community college engagement.

The novelty of the conference is the convergent integration of computational design, process control, materials discovery, materials characterization, and workforce development. The conference will draw expertise from multiple fields to discuss use-inspired basic research problems of strong interest from the community. This event will provide a venue for researchers to share their research results, to foster new collaborations, and to develop a conference report that will highlight the intellectual challenges and opportunities to the research community and policy makers.

# Organizing Committee

**Indrajit Charit**
Professor and Chair
Department of Nuclear Engineering and Industrial Management, University of Idaho
**Dave Estrada**
Associate Professor and Associate Director
Center for Advanced Energy Studies, Boise State University
**Patrick A. Johnson**
Professor
Materials Science and Engineering, Iowa State University
**Katie Dongmei Li-Oakey**
Professor and Presidential Fellow
Department of Chemical and Biomedical Engineering, University of Wyoming
**John Russell**
Associate Director
Center for Advanced Energy Studies, University of Idaho
**Marco Schoen**
Professor and Director
Measurement Controls Engineering Research Center, Idaho State University

# Code of Conduct

- In accordance with NSF Policy on Sexual Harassment, Other Forms of Harassment, or Sexual Assault (NSF PAPPG Chapter XI.A.1.g), the conference will foster a harassment-free environment wherever science is conducted.

- The CAES building where the conference will be held is operated by Idaho State University (ISU) on behalf of the CAES Consortium. Complaints will be managed in accordance with Idaho State University (ISU) policy, "ISUPP 3100: Policy on Equal Opportunity, Harassment and Non-discrimination" , with notification to CAES institutional representatives for Idaho National Laboratory, Boise State University, and University of Idaho.

- Emergency resources will be provided by ISU Public Safety, with notification of CAES institutional representatives for INL, BSU, and U of I. ISU Public Safety is responsible for the enforcement of university rules and regulations. ISU Public Safety Officers are authorized to make citizen's arrests when necessary and to detain suspicious subjects for questioning by police. As a department, ISU Public Safety has also received accreditation by the Idaho Chiefs of Police Association (ICOPA), which recognizes the university's level of law enforcement standards.

- Workshop participants can report any harassment or other issue to the workshop organizers or CAES staff members. The workshop organizers or CAES staff members will immediately report it to Idaho State University (ISU) Title IX Coordinator Ian Parker and their home institution Title IX Coordinator for mandatory reporting requirements.

- Issues will be addressed during the conference by contacting ISU Public Safety to help resolve any potential violations of ISU policy.

- Reports can be submitted here.

- ISU Title IX Coordinator Ian Parker can be contacted directly by email.

# Resources for Childcare and Family Care

- The City of Idaho Falls is home to many high quality child care providers. **Idaho STARS** is the leading expert and resource for quality child care in Idaho. Idaho STARS empowers parents and early childhood professionals to make safe, healthy, nurturing, and educational child care a top priority. Idaho STARS supports child care professionals to continually improve early care and educational practices. This is a joint project between the Idaho Center on Disabilities and Human Development and the Idaho Association for the Education of Young Children. It is funded by the Idaho Department of Health and Welfare and the Child Care and Development Block Grant.

- About Idaho STARS:

- Idaho STARS list of child care providers in Idaho Falls:

- The University of Idaho does not assume responsibility or liability for childcare services. It is the responsibility of the parents to thoroughly investigate all childcare providers.

- The CAES building has a dedicated, private lactation room available.

# Travel Reimbursement

- The maximum amount that will be reimbursed is $1375. Participants needing additional support may request an exception to policy.

- Participants requesting reimbursement will be emailed a link to register on Payment Works. Please register with Payment Works so that the reimbursement can be processed.

- Travel reimbursements require original receipts. Providing an itemization of the expenses whenever provided by the vendors. Please email your receipts and reimbursement questions to Erendira Valdez, Executive Assistant II, UI-Idaho Falls Center. Her email is evaldez@uidaho.edu.

- Reimbursements will follow FY 2024 Per Diem Rates for Idaho.
    - Daily lodging rates, standard rate, $107
    - Meals & Incidentals (M&IE) rates, standard rate, $59

- Airfare will be reimbursed for the most economical way to travel (i.e. upgrades will not be reimbursed). Reimbursement will only be for the amount actually paid for a ticket.

- We request that participants take advantage of Greater Idaho Falls Transit (GIFT) and/or Hotel shuttles to the conference site and hotels, rather than renting a car. GIFT provides door-to-door transportation through a phone app, much like Uber or Lyft. On-demand rides are $4, and scheduled rides are $6. For prompt service, scheduled rides are recommended to get to and from the workshop in a timely manner.

# Acknowledgements

This work was primarily supported by National Science Foundation under Grant No. 2328585. This work was also supported by State of Idaho appropriated funding for the Center for Advanced Energy Studies (CAES) and utilized equipment at CAES provided by Idaho National Laboratory under the Department of Energy (DOE) Idaho Operations Office (an agency of the U.S. Government) Contract DE-AC07-05ID145142.

# Professor Rajiv Mishra

Dr. Rajiv Mishra is a Regents Professor at University of North Texas. He serves as the Director of the Advanced Materials and Manufacturing Processes Institute (AMMPI) at UNT. He is a Fellow of ASM International. He is a past-chair of the Structural Materials Division of TMS and served on the TMS Board of Directors (2013-16). He has authored/co-authored 441 papers in peer-reviewed journals and proceedings and is principal inventor of four U.S. patents. His current Google Scholar h-index is 88 and his papers have been cited more than 40000 times. He has co-authored three books; (1) Friction Stir Welding and Processing, (2) Metallurgy and Design of Alloys with Hierarchical Microstructures, (3) High Entropy Materials: Processing, Properties, and Applications. He has edited or co-edited fifteen TMS conference proceedings. He is a recipient of TMS-SMD Distinguished Scientist Award in 2020 and TMS-MPMD Distinguished Scientist Award in 2024 Annual Meeting of TMS.

## Convergence of Computationally Designed Alloys and Processes

The evolution of alloy design and process innovation in first half of the last hundred years was primarily empirical. The computational approaches in the last 50 years have accelerated the pace of discovery exponentially. In the last century, the production of metals at increased volumes established the statistical approach of qualification and certification. While the capabilities and capacity to come up with new alloy composition increased, qualification strategies for new alloys for structural applications lagged. Disruptive manufacturing processes like additive manufacturing are going to disrupt the conventional supply-chain. Manufacturing can now be done at the point-of-need and digital imprint can change the qualification approach. In this overview, I will capture a few examples of the path traveled and what lessons we can take to build a future that discovers and uses structural materials more effectively. Can machine learning and artificial intelligence be used to completely alter the current discovery-use paradigm?

# Dr. Allen Roach

Allen is the Director of Advanced Materials and Manufacturing Initiative and Department Manager of the Irradiated Fuels and Materials at Idaho National Laboratory. Prior to becoming a department manager at INL, he was Distinguished Staff Scientist and director for the Nuclear Materials Discovery and Qualification initiative (NMDQi). Allen started his career at PPG Industries in the advanced engineering group at the Fiber Glass Research Center in Pittsburgh, PA. He then worked as a technical staff member and department manager at Sandia National Labs in Albuquerque for 20 years where he led the Born Qualified project with the goal to use additive manufacturing to change the qualification paradigm.

## Advanced Materials & Manufacturing for Extreme Environments

Shifting from design-build-test to digital design and manufacturing enables simultaneous fabrication with process monitoring and control for applications including advanced nuclear reactors, lightweight materials, and advanced survivability materials. Digital design and manufacturing integrates experimental, computational, and data-driven design approaches to rapidly design materials and fabrication processes. This is achieved by linking advanced manufacturing process parameters to the component microstructure and properties to achieve desired component performance in demanding service environments, such as nuclear reactors, hydrogen generation and fuel cells, and kinetic applications. In this talk the efforts needed to accelerate innovation in advanced materials and manufacturing for extreme environments will be covered and include: (1) expanding advanced manufacturing process development; (2) developing advanced manufacturing process-informed material design; (3) integrating comprehensive data analytics, modeling, and simulation techniques; and (4) enabling rapid material characterization and testing designed for advanced manufacturing.

# Professor Duane Johnson

Anson Marston Distinguished Professor of Engineering, Iowa State University. Previously, he served as the F. Wendell Miller Professor of Energy Science in the materials science and engineering department and chief research officer at the U.S. Department of Energy's Ames Laboratory, joined Iowa State in 2010. Previously, he served for 13 years at the University of Illinois, Urbana-Champaign, and nine years at Sandia National Laboratories. Johnson earned bachelor's and doctoral degrees in physics from the University of Cincinnati.

# Dr. Isabella van Rooyen

Dr. Isabella J. van Rooyen is a Senior Technical Advisor for Advanced Material Systems at Pacific Northwest National Laboratory (PNNL), following 10.5 years at Idaho National Laboratory (INL) as a Distinguished Staff Scientist. Dr van Rooyen supports the Department of Energy, Nuclear Engineering Office as (1) United States representative and co-chair on the International Advanced Manufacturing and Materials Engineering Working Group for Generation IV reactors; (2) Material development technical area lead for Advanced Materials and Manufacturing Technologies (AMMT) program; and (3) previously as National Technical Director for the "Advanced Methods for Manufacturing" (AMM) program. Experience spans nuclear, aerospace, and automotive industries for high temperature materials development (e.g., SiC, Zircaloy, beryllium, titanium, nickel alloys, tungsten-copper, composite materials, HEA), nuclear fuels (UO2, UCO, U3Si2, TRISO) and advanced manufacturing (AM). Dr. van Rooyen has more than 60 journal publications, 40 conference contributions, 6 granted patents and holds a PhD (physics), MSc(metallurgy), and MBA.

## Enabling Manufacturing Technologies Changing the Material Landscape for Extreme Environments

Manufacturing technologies have been highlighted as an enabler for achieving unique properties for components operational in material challenging environments that often need to simultaneously support conflicting properties like creep, strength, corrosion, and irradiation effects. Various national programs are performing groundbreaking research in selected areas to address specific challenges, but often the science-based understanding for the simultaneous multi-effects mechanisms is not fully developed yet. This presentation provides examples of key successes of how the full integration of advanced manufacturing techniques within the material and component life cycle, leap forward in innovation. It is paramount that the fundamental studies performed, be sufficiently communicated, and applied to R&D programs, to ensure the future of next generation reactors. Potential gaps to stimulate future work, are also discussed, changing "advanced manufacturing" from a buzz word to a part of a science lifestyle.

# Dr. Michael McMurtrey

Dr. Michael McMurtrey is a Materials Scientist at INL and leads high temperature alloys projects in the Advanced Materials and Manufacturing Technologies and Advance Reactor Technologies Programs. His research is primarily focused on elevated temperature mechanical testing (tensile, fatigue, creep, creep-fatigue, crack growth rates), ASME code qualification, accelerated materials testing, and advanced manufacturing. He is a member of four ASME Boiler and Pressure Vessel Code committees/working groups: Allowable Stress Criteria (secretary), Creep-Fatigue and Negligible Creep, Div.5 Advanced Manufacturing, and the Special Committee on Additive Manufacturing for Pressure Retaining Components. Prior to joining INL, he studied fatigue and stress corrosion crack growth behavior of aerospace materials (primarily aluminum and steel alloys) at the University of Virginia as a postdoctoral research associate and received his PhD studying the role of localized deformation in irradiation assisted stress corrosion cracking of austenitic steels from the University of Michigan.

## The Role of Characterization in Intelligent Advanced Manufacturing

Characterization plays a major role in advanced manufacturing in determining the properties (microstructural, mechanical, etc.) that resulted from the processing parameters. For intelligent advanced manufacturing, both in-situ (during the manufacturing process) and ex-situ (post-build examination) are critical. In-situ characterization provides direct feedback during the manufacturing process that can be used for feedback control, layer by layer material information, and input for modeling/simulation. Ex-situ characterization, both non-destructive and destructive, is used to identify defects, map microstructure, and evaluate the results of the manufacturing process on the material properties. Characterization needs to be more than just information gathering. Intelligent manufacturing requires characterization to be actively used, in feedback control, modeling/simulations, and qualification of the final build.

# Professor Brian Jaques

Dr. Brian J. Jaques is an Assistant Professor in the Micron School of Materials Science and Engineering and the director of the Boise State Advanced Materials Laboratory (AML) at Boise State University. He is a Center for Advanced Energy Studies (CAES) affiliate and fellow, holds a joint appointment with the INL, and is a licensed Professional Engineer in Metallurgy and Materials Science in the state of Idaho. Dr. Jaques' research interests are primarily related to advanced manufacturing techniques for materials for extreme environments, energy materials, and nuclear enabling technologies, including: nuclear fuel synthesis, sensor design, sintering, corrosion, gas-solid reaction kinetics, mechanochemistry, particle science/powder synthesis, and mechanical behavior of materials.

## Characterization of AM components and materials for extreme environments

Advancing knowledge at the frontiers of energy sciences will require innovations in materials tailored for energy applications. Accordingly, advanced manufacturing (AM) is revolutionizing the manufacturing industry due to the unparalleled design flexibility of the build process that allows fast innovation and production of complex optimized parts. Despite the transformative potential of AM, the full utility of this material fabrication technology remains unrealized due to an incomplete understanding of the relationship between processing conditions, the evolution of microstructure, mechanical properties, and the stability of printed parts in extreme environments. In this presentation, characterization of several AM techniques will be discussed, including materials jetting and extrusion, laser powder bed fusion, and laser/arc wire AM. A multifaceted approach to high throughput and robust materials characterization and testing to relate AM processing parameters to relevant performance in extreme environments will be discussed.

# Dr. Triratna Shrestha

Triratna (Tri) Shrestha is the manager of Material Analysis Laboratory and Central Coatings Laboratory at Metcut Research Inc. He has worked on testing, qualification, characterization, and quality control of materials for power generation, aerospace, transportation, and petrochemical industries. He manages Central Coatings Laboratory (CCL) for GE Aerospace and is involved in failure analysis. As a certified Lean Six Sigma Black Belt practitioner, he implements Lean and Six Sigma methodologies to drive efficiency and effectiveness across materials manufacturing, testing, and evaluation processes. Tri received his B.S and Ph.D. in Materials Science and Engineering from the University of Idaho.

## Extreme Temperature Material/Part Testing in Commercial Laboratory

Materials used in gas turbines, space, and nuclear applications experience extreme environments, such as radiation, pressure, erosion, wear, corrosion, and extremely low and high temperatures. Above conditions put limitations on material performance in terms of embrittlement, deformation, corrosion, fatigue, and corrosion-fatigue. In addition, parts/products see structural challenges. Material/product testing and qualification support identifying technologies, defining and prioritizing customer needs, translating them into critical part/assembly characteristics/target values, developing testing equipment requirements, and establishing process control methods/parameters. Importance of standardized extreme temperature testing, preparation, evaluation, and characterization techniques is underestimated in some sectors, which has led to acceptance of non-optimal materials and rejection of good ones. Either scenario is unacceptable. With increased commercialization of additive manufactured parts, usage of computational alloy design, and expanded reliance on predictive materials property and performance models, it is paramount that we have standardized materials / product testing and qualification programs. And the parts manufactured via novel techniques have some degree of correlation with traditional manufacturing and processing methods. This presentation delves into Metcut’s capabilities, challenges, and opportunities in extreme temperature testing of metals, polymer matrix composites (PMC), and ceramic matrix composite (CMC). Furthermore, utilization of design of experiment, Lean and Six Sigma methodologies will be introduced for intelligent and efficient material/part qualification.

# Professor Krishnan S Raja

Krishnan S Raja is a full professor of nuclear engineering at the University of Idaho. He has been with the University since 2011. Prior to that, he held research faculty positions at the University of Utah, University of Nevada, Reno, USA, and Tohoku University, Sendai, Japan. His areas of research are the environmental degradation of nuclear materials, pyroprocessing of used nuclear fuels, molten salt reactors, molten salt batteries, additive manufacturing of nuclear components for micro-reactors, and electrochemical engineering. Currently, he is working on two DOE-funded projects related to molten salts.

## Design Considerations of Structural Materials for Molten Salt Applications

Molten salts are used in various applications, such as storing thermal energy in concentrated solar power plants, as a heat transfer fluid in molten salt nuclear reactors, and as heat transfer media in heat treatment facilities. Chloride and fluoride-based salts are widely investigated among molten salts due to their high-temperature chemical stability and enhanced heat transfer properties. Corrosion of salt-facing structural components is the main challenge among the many challenges presented by the use of molten halide salts. The electrochemistry of corrosion of various materials in molten salt will be elucidated in this presentation. The influence of impurities present in the salts such as oxygen, moisture, corrosion products and other oxidants, fission products, and impurities from the structural alloys will be discussed. Corrosion mitigation strategies such as the design of sacrificial anodes, the use of hot corrosion inhibitors, and redox control methods will be discussed.

# Professor Yaqiao Wu

Dr. Yaqiao Wu is a Research Professor in the Micron School of Materials Science & Engineering at Boise State University (BSU). He is the Director of the Microscopy and Characterization Suite (MaCS) at the Center for Advanced Energy Studies (CAES). He received his Ph.D. degree at Institute of Metal Research, Chinese Academy of Sciences in 2000. Before joined BSU, Dr. Wu was with the Ames Laboratory of USDOE. Dr. Wu's expertise is in nanoscale structural and chemistry characterization achieved by the combination of transmission electron microscopy and atom probe tomography techniques. His research interests are in materials design, synthesis, property analysis, nanoscale structure and chemistry characterization, establishing critical connections between structure, chemistry and behavior down to atomic level. He has studied a large range of material systems of nanostructured magnetic materials, semiconductors, ceramics, quasicrystals, carbon nanotubes, and nuclear materials, and authored/co-authored over 120 papers in peer-reviewed journals.

## Characterization and Fabrication Capabilities for Advanced Manufacturing at MaCS, CAES

Microscopy Characterization Suite (MaCS) is a service center built by Center for Advanced Energy Studies (CAES) and managed by Boise State University (BSU). As a partner facility of the Nuclear Science Users Facilities (NSUF), the MaCS lab is specially designed to characterize both radiological and non-radiological materials for post-irradiation-examination (PIE). MaCS houses advanced materials characterization equipment for research (in particularly, to do quantitative analysis) down to the atomic level (STEM, FIB, LEAP, SEM, XRD, etc.). MaCS also equipped with mechanical testing tools (Nanoindenter, microhardness tester, Instron Test Frame), sample fabrication (LPBF 3D metal printer, SPS, ball-mill) and preparation (glovebox, cutter, polisher, furnace, ion-mill, etc) tools. This presentation will review the MaCS instruments, current and improved capabilities for advanced manufacturing, introduce the new Spectra 300 STEM and OA Panda 3D printer, as well as how to access these instruments for researchers.

# Professor Somayeh Pasebani

Somayeh Pasebani is an associate professor in advanced manufacturing within the School of Mechanical Engineering at Oregon State University. She has co-authored over 50 peer-reviewed publications and secured numerous grants from prestigious organizations such as NSF, DOE, ONR, AFRL, and industrial partners. She has been honored with the NSF CAREER award for understanding the joining mechanisms in dissimilar metal additive manufacturing. Her research primarily focuses on metal additive manufacturing, particularly in high-temperature alloys, ODS alloys, multi-material AM (graded alloys), and tailored alloys. Prior to joining OSU, Pasebani worked at Hoganas, contributing to their research and development endeavors. Holding a PhD in Materials Science, her expertise lies in powder metallurgy and metal additive manufacturing.

## Advanced Manufacturing of ODS Alloys: from Spark Plasma Sintering to Additive Manufacturing

In this study, oxide dispersion strengthened (ODS) alloys are additively manufactured through laser powder bed fusion (LPBF) and laser directed energy deposition (LDED), utilizing both powder and wire feedstock. Processing parameters are correlated with defects and microstructure evolution, and mechanical properties are evaluated at ambient and elevated temperatures. Various techniques have been explored, including blending matrix powder with oxide nanoparticles, jetting oxide nanoparticles onto the matrix, coating wires with oxide nanoparticles, and atomizing matrix powder with rare earth elements. In all instances, oxide nanoparticles were uniformly dispersed within the matrix, a characteristic feature of ODS alloys. However, the average size of oxide nanoparticles was found to be coarser than that of oxide nanoclusters in conventionally manufactured ODS alloys. Current findings highlight AM as a viable alternative to traditional solid-state powder processing, potentially streamlining the supply chain by bypassing certain steps altogether.

# Professor Somayeh Pasebani

## Wire-Powder Laser Directed Energy Deposition of Inconel-GRCop

The joining of Inconel 625 and GRCop42 using additive manufacturing is required for thermal management of high operating temperature components. In this study, Inconel 625-GRCop 42 dissimilar joints are fabricated by wire- powder laser directed energy deposition (WPLDED) at various laser powers and subsequently subjected to characterization in terms of present defects, grain morphology, and phases. As a powerful but complex process, understanding the thermal profile of the WPLDED process along with solidification morphology such as dimensional accuracy and weight percentages of each material are important to study. Thus, a coaxial wire-fed powder-fed system is simulated through the development of a computational fluid dynamics (CFD) numerical model. This model can capture in-situ thermal profiling and heat transfer interactions within the process, while simultaneously capable of providing bead dimensions and weight percentages of the individual materials for wire and powder. Simulation results were validated against experimental data, providing a prediction method for the CWP-DED process.

# Professor Haiyan Zhao

Dr. Haiyan Zhao is an associate professor in Chemical and Biological Engineering department and affiliated faculty in nuclear engineering program and environmental science program at the University of Idaho, Idaho Falls. She is Center for Advanced Energy Studies fellow and program director for chemical engineering on Idaho Falls campus. Before she joined the University of Idaho in 2014, she worked at Advanced Photon Source in Argonne National Laboratory using Synchrotron X-ray probes for advanced materials characterization as postdoctoral research associate then assistant chemist. She has developed combined synchrotron X-ray probes with complementary spectroscopy at the Advanced Photon Source at Argonne National Laboratory. She received her Bachelor of Science degree in chemistry from Tianjin University, M.S. degree in chemical engineering from Tsinghua University, and Ph.D. in chemical engineering from Virginia Tech.

## Fast and Furious: In Situ Characterization and Testing under Extreme Temperature Conditions

Rapid characterization and testing of AM components under extreme temperature conditions are crucial for developing processes and materials that meet performance criteria. This talk explores the significance of such testing by discussing case studies including TRISO fuel coating high-temperature oxidation, structural metal alloy corrosion in molten salts, and off-gas capturing materials synthesis. These case studies utilize in situ data for kinetics and mechanistic understanding, with a focus on enhancing material performance and safety. Furthermore, this presentation highlights the integration of physics-guided AI data analysis. This approach facilitates the analysis of experimental data and the integration of computational and experimental models to accurately predict TRISO coating behavior at extreme temperatures (>1000 °C), showcasing the synergistic relationship between advanced characterization techniques and AI-driven analytics in material science.

# Dr. Boopathy Koombaiah

Dr. Boopathy Kombaiah is a senior scientist in the Characterization and Post Irradiation Examination division at the Idaho National Laboratory. His research focuses on understanding materials degradation processes under extreme stress, temperature, corrosion, and radiation environments. To this end, he has applied advanced mechanical and microstructural characterization techniques to uncover damage mechanisms in materials. He participates in several projects on reactor structural materials funded by Laboratory Directed Research and Development, Department of Energy (DOE) – Nuclear Energy, and DOE - Office of Science programs. Notable projects include investigating basic creep mechanisms in nickel-based alloys, studying abnormal radiation-induced growth in zirconium alloys, and understanding the effect of additive manufacturing on the radiation damage in reactor materials. He has published over 40 peer-reviewed journal articles and presented his work at several international conferences. He is a recipient of 2015 American Nuclear Society (ANS)- Mark Mills award, 2000 Department of Energy Office of Science Early Career award, and 2024 INL Early Career award.

## Microstructural evolution in doped high entropy alloys NiCoFeCr-3X (X=Pd/Al/Cu) under irradiation

The growth of advanced energy technologies for power generation is enabled by the design, development, and integration of structural materials that can withstand extreme environments,. High-entropy alloys (HEAs) are a class of structural materials generally exhibiting good radiation tolerance like limited void swelling and hardening up to relatively medium radiation doses (tens of displacements per atom (dpa)); however, at higher radiation damage levels (>50 dpa), some HEAs suffer from considerable void swelling limiting their near-term acceptance for advanced nuclear reactor concepts. In the current talk, I will present the effect of alloying on the radiation effects of model HEAs. The influence of major alloying effects like lattice distortion, ordering and clustering tendencies by adding low concentration of Pd, Al, or Cu, respectively, on the ion irradiation response of NiCoFeCr alloy will be discussed. The microstructural evolution upon irradiation i.e., formation of dislocation networks, radiation induced segregation and precipitation, and void formation will be discussed in detail.

# Dr. Boopathy Koombaiah

## Transitional Creep Mechanisms in Zircaloys

Zircaloys have been used as nuclear fuel cladding in light water reactors due to their low absorption cross-section for thermal neutrons, good mechanical properties, and good corrosion resistance. Creep is one of the primary performance degrading mechanisms in Zircaloys during reactor service owing to the presence of high temperature and stresses at the reactor core. As a result, prediction of creep life of Zircaloys under relevant reactor service conditions becomes critical for structural integrity and safety of nuclear reactors. To this end, knowledge of transitions in creep mechanisms and descriptive models of creep rates as a function of stress, temperature and microstructure are essential components in creep life prediction. In this paper, details of the creep mechanisms such as diffusional creep, dislocation climb, dislocation cross-slip and Orowan bypassing active in the Zircaloys and their implications on creep-life prediction during dry storage will be discussed in this presentation.

# Dr. Jorgen Rufner

Jorgen Rufner, PhD is the Advanced Manufacturing Group Lead within Energy, Environment, Science and Technology (EES&T) directorate at Idaho National Laboratory. He joined INL in 2020 from industry as a material scientist and program lead for INL's effort at developing advanced powder processing/sintering technologies such as Electric Field Assisted Sintering (EFAS) for manufacturing and industrial use.

## Processing and Manufacturing of Advanced Materials and Systems at INL

Advanced manufacturing is no longer a niche discipline and the Advanced Manufacturing Groups at INL are focused on developing new materials, methods and processing pathways that enable INL's Initiative for Advanced Materials and Manufacturing for Extreme Environments. Research in this realm touches every aspect of INL's mission space to change the world's energy future and secure our nations infrastructure. This presentation will showcase various capabilities, challenges and projects at Idaho National Laboratory across the directorates that focus specifically on material processing and methods being developed to enable advanced manufacturing and materials for extreme environments.

# Mr. Luis Nuñez III

Luis Nuñez III is a mechanical engineering doctoral candidate at the University of Idaho and a researcher at Idaho National Laboratory. He has an MSME from Northern Illinois University and his field of research is in additive manufacturing centered on directed energy deposition with LENS. He has experience and expertise in experimental design, fabrication, in-situ data collection, microstructural characterization, and analysis of metals with machine learning and numerical modeling. His dissertation focuses on process-structure-property analysis, and he currently works on experimental validation and process model development in the MOOSE application MALAMUTE. His studies are in process parameter optimization, surface roughness, and performance modeling emphasized on nuclear structural materials and heat exchanger applications. He has filed non-provisional patents regarding DED in-situ fabrication of high entropy alloys and controlling surface properties of flow channels for heat exchanger design and is interested in topics such as functionally graded materials and sensor embedment.

## In-situ embedment of type K sheathed thermocouples with directed energy deposition

This study focuses on experiments investigating the feasibility of in-situ sensor embedment using directed energy deposition (DED). Type K thermocouples are embedded into 316L stainless steel (SS) samples using two different configurations (e.g., exposed and embedded tips) and two designs, one with the sensor placed directly onto the substrate (e.g., flush to substrate) and the second using a DED base. Samples are analyzed via in-situ measurements and high-temperature performance validation tests at 350 and 900 ºC. Results of temperature performance show good agreement with manufacturer specifications. Optimization experiments are performed using a surrogate thermocouple to improve the embedment process and lead to improved tolerances, lower porosity, smaller gaps between the sensor and base, and better junction contact for the sensor and results demonstrate feasibility for DED sensor embedment. Additionally, an overview is presented of ongoing publications regarding AM process variable optimization with in-situ monitoring, machine learning, and numerical modeling.

# Professor Ritesh Sachan

Dr. Ritesh Sachan is an assistant professor, Department of Mechanical and Aerospace Engineering at Oklahoma State University. His research interests primarily lie in developing a quantitative understanding of structure-property correlations in high entropy materials using combinatorial thin film approaches and advanced electron microscopy. His current research interest is developing nanosecond laser-based processes to create high entropy alloy nanoparticles and understanding the evolution mechanism for nanoparticle formation. Previously, Dr. Sachan worked at Army Research Office as an NRC researcher (2016-2018) and Oak Ridge National Laboratory as a postdoctoral researcher (2013-2016). His research efforts have resulted in 90+ journal papers, ~2500 citations, 1 book chapter and numerous invited/contributed talks. He received NSF-CAREER (2023) and ASM-IIM lectureship award (2019). Earlier, he was awarded the prestigious NRC fellowship by the National Academy of Sciences in 2016 and the TMS Young Leader Professional Award by The Minerals, Metals and Materials Society (TMS) in 2015.

## Multi-Principal Element Nanostructures via Nanosecond Laser-Induced Dewetting

Multi-principal element alloy (MPEA) nanostructures have recently gained a great deal of attention due to their promising properties relevant to energy-relevant applications. However, the development of processing techniques that could fabricate MPEA nanoparticles with spatial order and tunable physical characteristics, such as size and microstructure, has been challenging owing to achieving a homogeneous mixing of constituent elements. Here we discuss how pulsed laser melting of ultrathin alloy films can be a powerful but simple and cost-effective technique to fabricate MPEA nanostructures. Ultrathin metal films (1-30 nm) on inert substrates such as SiO2 are generally unstable, with their free energy resembling that of a spinodal system. Such films can spontaneously evolve into predictable nanomorphologies with well-defined length scales. Here we review this laser-based experimental technique and provide examples of resulting robust nanostructures that can have applications in catalysis and optics.

# Professor Matthew Swenson

Dr. Swenson received his Ph.D. in Materials Science and Engineering at Boise State University in 2017. Prior to attending graduate school, he spent 14+ years in industry as a mechanical engineer. During this time, he developed expertise in product development, project management, and business administration. Dr. Swenson has extensive experience conducting research on the effects of irradiation on oxide dispersion strengthened and other nano-featured alloys and has launched a campaign to understand and develop laser welding techniques for advanced energy applications. Dr. Swenson also serves as the Director of the Interdisciplinary Capstone Design Program and the Executive Director for Invent Idaho, a pre-collegiate inventor’s competition program spanning the entire state of Idaho. Last year, Dr. Swenson began collaborating with the College of Business to help implement a $15m NSF-funded I-Corps program designed to help entrepreneurs having affiliation with the University of Idaho to successfully launch their startup businesses.

## Effects of laser welding on microstructure and mechanical properties of SS and ODS alloys

Nanofeatured alloys such as oxide dispersion strengthened (ODS) alloys have emerged as leading candidates for nuclear reactor applications due to their dimensional stability upon irradiation and their high temperature mechanical properties. However, most established joining processes (arc welding and friction stir welding) result in significant alteration of the microstructures, including elimination of the same nanoscale features that make these alloys highly desirable and irradiation resistant. Laser welding is a promising candidate for joining nanostructured alloys due to its small length scales and fast cooling rates that can limit the impact of joining on the microstructure and mechanical properties of the alloys, likely maintaining the desired irradiation resistance. In this study, we have evaluated the effects of laser welding on a commercial 304 SS alloy and a ferritic ODS alloy MA956, demonstrating a positive impact on the mechanical properties while maintaining the desirable nanofeatures within the fused material.

# Professor Yang Cao

Yang Cao is an Assistant Professor in the Mechanical & Industrial Engineering Department at Montana State University. He received his Ph.D. degree in Industrial Engineering from North Carolina State University in 2020, M.S. degree in Mechatronic Engineering from Chongqing University in 2016, and B.S. degree in Mechanical Design and Manufacturing Automation from Wuhan University of Technology in 2013. His research focuses on high-resolution additive manufacturing and micro/nano manufacturing. He is particularly interested in applying these manufacturing techniques to fabricate innovative devices, such as flexible electronics, wearable sensors, soft actuators and robotics.

## Electrohydrodynamic printing of electronics

Electrohydrodynamic (EHD) printing is a maskless printing technology that uses an electric field to induce fluid flows from micro capillary nozzles. It can realize direct high-resolution patterning with more modest instrumentation requirements and simpler processing than lithography and etching based technologies. EHD printing has a wide range of printable materials including low melting point metals, nanomaterial solution, polymer-based ink, and biomaterial suspensions. In this talk, Dr. Cao will present his recent work in EHD printing of electronics, including electrothermal actuators, electrochemical sensors, as well as EHD printing for in-space electronics manufacturing.

# Dr. Kiyo T Fujimoto

Dr. Kiyo T. Fujimoto holds a B.S. in Chemistry and recently earned her Ph.D. from the Materials Science and Engineering Department at Boise State University. Her dissertation investigated the use of additive manufacturing methods for developing and fabricating sensors for harsh service conditions. In 2022, Kiyo was hired as a staff scientist at Idaho National Laboratory and as the Laboratory Lead for the Advanced Manufacturing Laboratory at the Center for Advanced Energy Studies. Her research interests are broad but mostly encompass the integration of additive manufacturing methods for the development of advanced sensors and microelectronics for extreme environments.

## Additive Manufacturing of Nuclear Instrumentation

Advanced manufacturing-based direct-write technologies have emerged as the predominant enabler for the fabrication of active and passive sensors for use in harsh operating environments. The ability to directly write and integrate electronic components onto physical packaging can be achieved with additive manufacturing (AM) methods such as direct write technologies (DWT) which include Aerosol Jet Printing (AJP), Ink Jet Printing(IJP), Plasma Jet Printing (PJP), and Micro-Dispense Printing (MDP). Recent demonstrations with DWTs to include novel feedstock with sensor development have shown DWTs as potential solutions for the development of miniature and robust sensors that are difficult to achieve with traditional fabrication methods.

# Professor Samrat Choudhury

Dr. Samrat Choudhury is an Associate Professor in the Department of Mechanical Engineering at the University of Mississippi (UM). He is also serving as an Adjunct faculty in the Nuclear Engineering and Industrial Management at the University of Idaho. Prior to joining UM, Dr. Choudhury served as a faculty at the University of Idaho and a staff scientist at the Los Alamos National Laboratory (LANL) where he initially joined as a Director's Postdoctoral Fellow. Dr. Choudhury's expertise is in multi-length scale computational materials science and machine learning.

## Machine Learning Guided Design and Manufacturing of Materials

Traditional computational investigation of processing-chemistry-structure-property linkage in materials science involves usage of highly complex set of interactions spanning over multiple length and time scales. Alternatively, this presentation is focused on the application on machine learning tools to guide simulations at multiple length scales in order to augment the capabilities of traditional computational tools. It will be shown that machine learning enabled computational approach provides a fast and efficient pathway to navigate the vast processing, microstructure and chemical search space for a targeted property, a departure from the traditional time-consuming and expensive Edisonian trial-and-error approach based on synthesis-testing experimental cycles. Finally, the application of machine learning tools to determine the processing parameters needed for a targeted performance during Electrohydrodynamic (EHD) printing (an additive manufacturing approach) will also be discussed.

# Professor Dilpuneet Aidhy

Dilpuneet Aidhy is an Associate Professor in the Department of Materials Science and Engineering at Clemson University. His expertise is in computational materials science including density functional theory, molecular dynamics simulations and machine learning applied to solid state materials. His areas of interest include metallic alloys and ceramic oxides. His work is primarily focused on understanding thermodynamics and kinetics of defects, grain boundaries, mechanical and radiation damage properties, ion-transport and electrochemistry in functional oxides. In the past few years, his work has extensively focused on developing data-science based methods to predict properties of high entropy materials. He has published over 50 peer-reviewed papers, and has an h-index of 25. He is on the editorial board of Computational Materials Science, Scientific Reports, Frontiers in Materials. He received his PhD in Materials Science and Engineering from University of Florida in 2009.

## Integrated Data-Science and Computational Materials Science to Tackle Challenges of Complex Materials

As we push the boundaries of materials for applications in ever increasing extreme environments, novel and often complex materials are needed that require creative design strategies from electron-to-microstructure levels. To understand the intertwined electronic and atomic mechanisms in complex materials, the traditional computational tools, that have been highly successful, now need to be integrated with sophisticated methods. A fitting example are high entropy materials (HEMs) that consist of multiple principal elements in large proportions in contrast to one principal element in conventional/dilute alloys. Robust data-science methods offer a rigorous path forward to overcome the multi-dimensional challenge. In our group, we use machine learning algorithms in conjunction with physics-based principles and databases to unveil key structure-property correlations that are otherwise unintuitive in complex materials. In this presentation, I will discuss our new data-science integrated computational materials science approach namely PREDICT (Predict properties from Existing Databases in Complex materials Territory) whereby properties in complex alloys are predicted by learning from simpler alloys. I will also discuss how charge-density can be a used as a universal descriptor for properties' prediction. I will also discuss database frameworks being developed in our group.

# Professor Katie D. Li-Oakey

Dr. Li-Oakey received her Ph.D. at University of Colorado, Boulder, with a focus on modeling and experimental studies of polymeric membrane morphology. Before she joined the faculty of the University of Wyoming Department of Chemical Engineering, Dr. Li-Oakey has worked in companies ranging from startups to Fortune 100. Her research program at UW employs surface and interface chemistry, engineering, and bottom-up nanomaterial design and synthesis to address challenges in energy and healthcare. Over the course of her career, Dr. Li-Oakey has been recognized with the prestigious Presidential Fellow in Entrepreneurship and the UW Chemical Engineering Outstanding Teacher of the Year, NASA EPSCoR Space Grant Faculty Award and Anardako Faculty Award, in addition to Fab Achievement Awards at Intel Corporation. Dr. Li-Oakey holds several patents in the emerging areas of hydrogen sensing with interference gases, catalysts for converting CO2 to valuable industry feedstocks, catalytic membrane reactors, transition carbide catalysts for hydrogen fuel cells, and covalent organic framework membranes. She founded TLS Materials LLC in 2016, with the goal to commercialize the IP portfolio.

## Linking Materials and Processes Design with Molecular Interactions to Enable On-demand High Volume Manufacturing

As we combine artificial intelligence and new materials and process design, the dream of on-demand manufacturing is becoming more and more reachable. In this talk, a popular family of separation materials, covalent organic framework (COF), is used to show the feasible pathway for an integrated material and process design for COFs in organic solvent nanofiltration (OSN), which incorporates atomistic/molecular modeling with lab scale experimental observations. Specifically, complex solvent environments continue to limit the widespread adoption of OSN in many chemical industry applications. Reactive force field (ReaxFF) and nonreactive force field models have been recently developed to molecularly map separation performance of a commercial covalent organic framework (COF), TpPa-1, and a carboxylated COF (C-COF). Specifically, the following factors have been characterized using these atomistic models: layer stacking, effective vs. designed pore size, and solvated solute size in various single organic solvents or solvent pairs. Model predications can be directly compared with experimental filtration results after normalizing model outcomes and filtration data with a common solvent, such as water, to minimize time and length scale mismatch between atomistic modeling and

# Linking Materials and Processes Design with Molecular Interactions to Enable On-demand High Volume Manufacturing (Continued from page 32)

experiments. Model outputs, such as organic solvent permeance and solute rejection rate, matched experimental filtration results well. These findings demonstrate how solvated solute state and effective pore size in mixed solvents cumulatively dictate membrane performance. Additionally, ion effects on selectivity were probed theoretically and experimentally by adding NaOH and HCl to organic solvents, such as DMF and methanol. In sum, force field models can serve as digital twins of COF membranes to simulate separation processes while capturing the effects of COF structure, chemistry, and crystallinity on membrane performance in complex organic solvent environments. This approach will provide insight into future COF design and synthesis for persisting separation challenges.

# Professor Lars Kothoff

Lars Kotthoff is an Associate Professor of Computer Science at the University of Wyoming. His research has contributed to fundamental advances in machine learning and the application of machine learning in areas outside of Computer Science, in particular Materials Science.

## Title TBD

I will give a brief overview of Bayesian Optimization, a state-of-the-art methodology to optimize black-box systems like those found in Materials Science. I will then illustrate a few applications in Materials Science, including results.

# Professor Michael Tonks

Dr. Michael Tonks is the Associate Chair of the Materials Science and Engineering Department at UF and is the Alumni Professor of Materials Science and Engineering and Nuclear Engineering. Prior to joining UF in Fall 2017, he was an Assistant Professor of Nuclear Engineering at Pennsylvania State University for two years and a staff scientist in the Fuels Modeling and Simulation Department at INL for six years. His research is focused on using mesoscale modeling and simulation results coupled with experimental data to investigate the impact of irradiation induced microstructure evolution on material performance. He has authored over 120 publications. He has won numerous awards, including the NEAMS Excellence Award in 2014, the Presidential Early Career Award for Scientists and Engineers in 2017, and the TMS Brimacombe Medal in 2022.

## Applying Machine Learning to Accelerate Materials Discovery Via Mesoscale Simulation

Mesoscale simulations provide a powerful tool for discovering degradation mechanisms of materials in harsh environments. However, such simulations can be computationally expensive, limiting their utility. We are applying machine learning tools to create surrogate models that can predict microstructure evolution and structure-property relationships orders of magnitude faster than the mesoscale simulations. We are also using a combination of simulation and experimental data to train interpretable models that can also help us to discover critical evolution mechanisms.

# Professor Min Xian

Dr. Min Xian is an associate professor in the Department of Computer Science at the University of Idaho. He received his Ph.D. in Computer Science from Utah State University, Logan, Utah, in 2017 and an M.S. in Pattern Recognition and Intelligence Systems from Harbin Institute of Technology, Harbin, China, in 2011. Dr. Xian is now the director of the Machine Intelligence and Data Analytics (MIDA) lab, a research-oriented collaborative and synergistic core to impel interdisciplinary research. Dr. Xian is an affiliate Professor and Doctoral Supervisor of the Bioinformatics and Computational Biology (BCB) program at the University of Idaho, an affiliate of the Center for Advanced Energy Studies (CAES), and a participating faculty of the Institute for Modeling Collaboration and Innovation (IMCI). He is leading projects on AI-enhanced cancer detection (NIH), material characterization and development (DOE), and operating data analysis (NRC). His research interests include artificial intelligence, pattern recognition, machine learning, deep neural networks, adversarial learning, biomedical data analytics, material informatics, and digital image understanding. Dr. Xian is a guest editor at Healthcare, session chair for AAAI conference, and is an active reviewer for many prestigious international journals, e.g., Pattern Recognition, IEEE Trans. Medical Imaging, Medical Image Analysis, Medical Physics, Scientific Reports, Neurocomputing, and Artificial Intelligence in Medicine.

## Connecting Dots Between Materials Microstructures and Properties Evolution in Extreme Environments Using Modern Artificial Intelligence

Modern artificial intelligence (AI) approaches (e.g., deep learning) have been proven effective and efficient in exploring complex and big datasets to gain insights and accelerate scientific discoveries. Leveraging AI can greatly accelerate the testing, design, and manufacturing of materials. In this talk, Dr. Xian will discuss his recent research on developing AI approaches and tools for accurate and automated materials characterization and performance prediction.

# Professor Leslie Kerby

Dr. Kerby is an Associate Professor of Computer Science at Idaho State University, and affiliate faculty in Nuclear Engineering. Her research and capabilities center around designing, building, and securing data-driven modeling and simulation software within science and engineering. Projects are varied and include scientific machine learning applied to nuclear reactor operation and monitoring, scientific machine learning applied to Li-ion battery performance and quantum chemistry, and the security of machine learning systems as applied in nuclear engineering. Other projects involving applications of data science, machine learning, and artificial intelligence, and computational science are welcome.

## A Machine Learning Engineer's Toolkit

This presentation will be a crash course in common tools utilized in building machine learning systems, with examples given from Dr. Kerby's research group.

# Mr. John Jenks

John is currently Economic Initiatives Director at the Wyoming Business Council (WBC) which is the State of Wyoming's economic development agency. He joined the WBC in August of 2022. In his capacity, John identifies policies, strategies, and opportunities to achieve sustained and vibrant economic growth for the State of Wyoming. Prior to this role, he was Director of Public Policy at the Greater Kansas City Chamber of Commerce where he oversaw the Chamber's advocacy work in the Kansas and Missouri Legislatures. He also founded and led the Chamber's Workforce Opportunities for Returning Citizens Initiative that reemploys and reintegrates justice involved individuals. John has a deep passion for economic development, policy, and politics. John recently successfully completed three executive education courses at the Harvard Kennedy School of Government earning his Executive Certificate in Public Leadership in 2024. He graduated from the University of Mississippi's Sally McDonnell Barksdale Honors College and Trent Lott Public Policy Leadership School with a degree in Public Policy Leadership and Economics and earned a Master's Degree in Integrated Marketing Communications from the University of Mississippi.

## The Future of Workforce: Where are the Workers and How Can We Get Them Back in the Workforce?

The State of Wyoming and the Wyoming Business Council (WBC) have been undergoing an economic development project with the Harvard Kennedy School Economic Growth Lab for over a year and a half. The purpose of the project is to identify barriers to economic growth and economic diversification in the state and one of the primary barriers that we are working to address is on workforce development. The work has broken out into four sub-workstreams including: Out of state worker attraction, justice-involved individuals, childcare, and higher education alignment.
We have identified and begun work on these sects of the labor force due to these groups being identified as significant labor pools being underutilized in Wyoming and for the potential returns on investments in addressing the shortcomings with these labor pools. With the changing demographics in the country, it is more important than ever to find workers and to upskill labor to address the challenges faced by employers in all industries.

# Mr. Wyatt Petersen

Wyatt Petersen is the Director of the Department of Energy at the Shoshone Bannock Tribes and a proud member of the Tribes. With a Master's degree in GIS, his expertise in geospatial technologies and environmental management has significantly contributed to land use and natural resource management on the Fort Hall Reservation. Previously, Wyatt served as the Interim Director of the Tribes Land Use Department, demonstrating strong leadership in tribal governance and infrastructure development. His career is marked by a commitment to integrating advanced technology with traditional knowledge to improve tribal services and sustainability practices. As a devoted musician and family man, Wyatt is dedicated to cultural engagement and community empowerment, aiming to guide his tribe toward a sustainable and prosperous future.

## Forging Futures: Community and Collaboration in Nuclear Workforce Development

This presentation will focus on the critical role of collaborative workforce development initiatives in integrating the Shoshone Bannock Tribes into the expanding nuclear energy sector in eastern Idaho and Wyoming. The absence of a local community college presents unique challenges and opportunities for developing alternative educational partnerships. This talk will explore practical strategies for collaboration between the Tribes, nearby educational institutions, and industry stakeholders to facilitate accessible training and employment opportunities for tribal members. The potential for creating tailored training programs on tribal lands or through digital platforms will be discussed as a means to leverage tribal knowledge and cultural competencies in the nuclear industry. Emphasizing the mutual benefits of such collaborations, this presentation aims to outline actionable steps for creating a skilled workforce that supports both tribal economic development and the regional growth of advanced nuclear technologies.

# Dr. Mitch Meyer

Dr. Meyer has served in technical and technical leadership positions in the area of nuclear fuels and materials at Argonne and Idaho national laboratories and in industry for nearly 3 decades. His responsibilities have included National Technical Lead for NNSA programs for eliminating commerce in highly enriched uranium, U.S. lead for the Gen IV Gas Fast Reactor fuel program, Director of DOE's Nuclear Science User Facility (NSUF) program, Technical Lead for DOE's Light Water Reactor Advanced Fuel program, Director of Idaho National Laboratory's Nuclear Fuels and Materials and Advanced Characterization and PIE Divisions, Director of Fuel Qualification and Testing at Ultra Safe Nuclear. Dr. Meyer is currently the Director of Nuclear Fuels and Materials at NuCube Energy.

## Manufacturing Challenges for Nuclear Materials in Advanced Reactors

The commercial availability of specialty materials is the limiting factor in the development and deployment of many advanced reactor technologies. This talk provides a brief overview of nuclear material design constraints, potential material systems that address these constraints, and gaps in manufacturing technology that currently limit the commercialization and use of these materials in advanced nuclear energy systems.

# Professor Amin Mirkouei

I am an Associate Professor at University of Idaho, Forbes sustainability contributor, certified Professional Engineer (PE), and experienced Technologist. I have over 12 years of experience contributing and leading cross-disciplinary projects in decarbonization technologies, renewable materials, sustainable design and manufacturing, cyber-physical control and optimization, and operations research, particularly renewable fuels, green chemicals, and rare earth elements and minerals from various resources, such as biomass feedstocks, plastics wastes, e-wastes, and animal manure. Currently, I am a major advisor in Industrial Technology, Technology Management, Mechanical Engineering, Biological Engineering, Computer Science, and Environmental Science programs at University of Idaho. I have served as a federal and state agency panelist (NSF and USDA), editorial board member, conference and symposium organizer (ASME and IISE), and journal and conference reviewer. I also have served on several university committees, such as UI President's Sustainability Working Group, Safety and Loss Control Committee, and Environmental, Health, and Safety Committee.

## Deepen the Integration of Diverse Interdisciplinary Professionals in Intermountain West Region with the Cyberinfrastructure Research Ecosystem

The Intermountain West region (encompassing states such as Idaho and Utah) plays a crucial role in economic growth and national progress due to its abundant natural resources, including fertile lands, mineral deposits, and water sources. In this era, confronting complex global and regional challenges, from energy and food security to environmental hurdles, it is increasingly essential to utilize unprecedented cyberinfrastructure (CI) advancements driven by high-performance computing (HPC) systems, machine learning (ML), and generative artificial intelligence (GenAI). CI Professionals (CIPs) with expertise in HPC and ML/GenAI are instrumental and indispensable in advancing fundamental science and engineering (S&E) domains. Our overarching goal is to create long-term CIP career paths in Idaho (EPSCoR state) and Utah to address Intermountain West regional priorities (e.g., economic growth, environmental protection, and education) by harnessing the power of HPC and ML/AI. Our primary focus will be on the Intermountain West regional projects, particularly energy-water systems, mining and quarrying, crop and animal production, fisheries and aquaculture, geosciences, construction, and community-engaged education.

## Phytomining Pathway for Mixed Rare Earth Elements Extraction from Idaho-Sourced Minerals

Kathryn Richardson and Amin Mirkouei

Worldwide demand for rare earth element (REE) based technology has drastically increased in recent years within the renewable energy, transportation, and consumer electronics sectors. The United States Geological Survey (USGS) reports high REE levels in the soil of some regions in the state of Idaho (up to 12% total soil content). This unique soil provides opportunity to explore the viability of phytomining, the use of plants to extract REEs from soil. Four plant species were grown in a greenhouse using this soil and analyzed for their REE extraction ability: Phalaris arundinacea (reed canary grass), Phytolacca americana (pokeweed), Solanum nigrum (black nightshade), and Brassica juncea (brown mustard). Results show that P. arundinacea drastically outperforms all other species accumulating over 18,000 ppm Ce, 11,000 ppm Y, and 8,000 ppm Nd. Phytomining is a promising net-negative emission solution for mixed REE extraction in Idaho-sourced soil and has potential to be applicable at the commercial level in Idaho.

## Bioleaching Pathway for Mixed Rare Earth Elements Extraction from Idaho-Sourced Minerals

Rebecca Brown, Amin Mirkouei, and Ethan Struhs

Rare earth elements are critical materials due to their unique properties. They are necessary components of various advanced technologies, such as batteries, catalysts, and magnets, and play a crucial role in energy security, economic growth, and environmental sustainability. The United States (U.S.) is heavily reliant on rare earth imports, mainly from China. Traditional extraction of rare earth elements involves the use of harsh chemicals and leaves behind hazardous waste. Biological methods of extraction, such as bioleaching, are a promising alternative to mitigate these wastes. Bioleaching is often performed under milder conditions than traditional extraction, using organic acid. In addition, organic acids can be produced from renewable sources, such as agricultural waste or by-products. Previous bioleaching studies, using the bacterium Gluconobacter oxydans to produce gluconic acid have shown promising performance. We investigated the sustainability of a gluconic acid bioleaching and molten salt electrolysis production process of mixed rare earth metals from surface soil sourced in Idaho. Most process emissions are due to high energy usage during bioleaching. We found that utilizing a novel ultrasound leaching technique can improve the REE leaching rate and can significantly decrease process emissions and energy.

## An efficient instance segmentation approach for studying fission gas bubbles in irradiated metallic nuclear fuel

Shoukun Sun[1], Fei Xu[2], Lu Cai[2], Daniele Salvato[2], Luca Capriotti[2], Min Xian[1], Tiankai Yao[2]
[1]Department of Computer Science, University of Idaho
[2]Idaho National Laboratory

Gaseous fission products from nuclear fission reactions tend to form fission gas bubbles of various shapes and sizes inside nuclear fuel. The behavior of fission gas bubbles dictates nuclear fuel performances, such as fission gas release, grain growth, swelling, and fuel cladding mechanical interaction. Although mechanical understanding of the overall evolution behavior of fission gas bubbles is well known, lacking the quantitative data and high-level correlation between burnup/temperature and microstructure evolution blocks the development of predictive models and reduces the possibility of accelerating the qualification for new fuel forms. Historical characterization of fission gas bubbles in irradiated nuclear fuel relied on a simple threshold method working on low-resolution optical microscopy images. Advanced characterization of fission gas bubbles using scanning electron microscopic images reveals unprecedented details and extensive morphological data, which strains the effectiveness of conventional methods. This paper proposes a hybrid framework, based on digital image processing and deep learning models, to efficiently detect and classify fission gas bubbles from scanning electron microscopic images. The developed bubble annotation tool used a multitask deep learning network that integrates U-Net and ResNet to accomplish instance-level bubble segmentation. With limited annotated data, the model achieves a recall ratio of more than 90%, a leap forward compared to the threshold method. The model has the capability to identify fission gas bubbles with and without lanthanides to better understand the movement of lanthanide fission products and fuel cladding chemical interaction. Lastly, the deep learning model is versatile and applicable to the micro-structure segmentation of similar materials.

**CFR-ICL: Cascade-Forward Refinement with Iterative Click Loss for Interactive Image Segmentation**

Shoukun Sun[1], Min Xian[1], Fei Xu[2], Luca Capriotti[2], Tiankai Yao[2]
[1]Department of Computer Science, University of Idaho
[2]Idaho National Laboratory

Fuel cladding chemical interaction (FCCI) is one of the main factors that could limit the fuel performance of metallic fuels at high burnups. In this talk, we will focus on how the electron energy loss spectrum helps to reveal chemical and electronic structure information of light elements as well as heavy elements to improve mechanistic understanding of FCCI. EELS data was collected from FCCI region of U-10Zr solid fuel pin (with HT9 cladding) irradiated to burnup of 13 at% and analyzed using Hyperspy, an open-source python library. Elements namely C, O, Fe, Zr and lanthanides were mapped using the integration method. Decomposition was used to denoise the data while power law background subtraction was performed following deconvolution. The results show formation of different crystallographic phases with distribution of lanthanides, especially Ce and Nd, throughout the FCCI region. A C rich Zr-C rind was observed in the middle region of FCCI.

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**Synthesis of Metal Core Oxide Shell (MCOS) by Low-Temperature Oxidation of Iron Nanoparticles: The Role of Gibbs-Thomson Effect**

Kavindan Balakrishnan[1], Krishnan S Raja[1], Indrajit Charit[1], Josephine Selvaraj[2], Vaidyanathan (Ravi) Subramanian[2]
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Iron nanoparticles (NPs) exhibit unique oxidation behaviors at low temperatures due to their high surface area-to-volume ratio and the associated curvature effects. This paper reviews the oxidation kinetics and models of iron NPs, focusing on achieving the core-shell structure and the role of surface energy. The variation of the chemical potential due to the curvature of the nanoparticles alters the oxidation kinetics and oxide phase stability when compared to the planar surfaces. Iron nanoparticles in the size range of 20 – 120 nm were oxidized in air at 200 °C at different times. Metal core oxide shell (MCOS) formation was observed when the initial particles were larger than 20 nm. Particles smaller than 20 nm were completely oxidized revealing an empty core hallow oxide structure. The oxidation parameters suitable for the formation of the MCOS are developed in this study which will be helpful for preparing a self-healing composite material.

## Electron Energy Loss Spectroscopy (EELS) Characterization of a high burnup U-Zr Metallic Fuel

Arnold Pradhan, Tiankai Yao, and Fei Xu

Fuel cladding chemical interaction (FCCI) is one of the main factors that could limit the fuel performance of metallic fuels at high burnups. In this talk, we will focus on how the electron energy loss spectrum helps to reveal chemical and electronic structure information of light elements as well as heavy elements to improve mechanistic understanding of FCCI. EELS data was collected from FCCI region of U-10Zr solid fuel pin (with HT9 cladding) irradiated to burnup of 13 at% and analyzed using Hyperspy, an open-source python library. Elements namely C, O, Fe, Zr and lanthanides were mapped using the integration method. Decomposition was used to denoise the data while power law background subtraction was performed following deconvolution. The results show formation of different crystallographic phases with distribution of lanthanides, especially Ce and Nd, throughout the FCCI region. A C rich Zr-C rind was observed in the middle region of FCCI.

## Model-Based Reinforcement Learning with System Identification and Fuzzy Reward Applied to Advanced Manufacturing

Nusrat Farheen and Marco Schoen
Idaho State University

A model-based reinforcement learning (MBRL) allows intelligent control development from series of dynamic experiences without exhaustively interacting with the target plant. This enables wider application of reinforcement learning including Advanced Manufacturing. The study explores MBRL design for a virtually unknown system dynamics. The approach considered in the study utilizes system identification and fuzzy reward formulation. In addition, a minimum order estimation gets applied first to determine the system order. This aids transfer function approximation of the linear time-invariant system. The fuzzy reward for the MBRL is defined using a Mamdani Fuzzy Inference mechanism. The model obtained integrates into the Q-learning process to simulate experiences bypassing the environment. The proposed framework showcases sample-efficient learning without interacting with the true system. The applicability currently limits to linear systems. Extending the techniques to nonlinear, time-varying dynamics could increase applicability to real-world systems.

## Data Driven Controller Design Strategies Applied to Advanced Manufacturing

Golam Gause Jaman and Marco Schoen
Measurement and Control Engineering, Idaho State University,
Pocatello, Idaho, 83209

System identification techniques offer a data-driven approach to modeling the dynamics of complex plants or systems based on experimental data. This study presents an end-to-end pipeline for system identification and control that begins with designing informative experiments to generate rich data capturing the system's characteristic behavior. The identified system model is then utilized to design and evaluate different control strategies, including classical PID and LQG controllers as well as model-free reinforcement learning controllers. The study further investigates the adaptive capabilities of these controllers by introducing perturbations to the plant model. The framework is demonstrated on a rapid joule heating process, which has applications in advanced manufacturing. By combining tailored experiment design, system identification, and control synthesis, the proposed pipeline provides a comprehensive methodology for modeling and controlling complex dynamical systems from data. The comparative analysis highlights the relative strengths of different control approaches and their robustness to model uncertainties.

## American Nuclear Society at the University of Wyoming

Drew Rone, Raymond Nowak, Caleb Hill

As the largest producer of uranium in the United States, Wyoming has always been a key contributor to nuclear power. With TerraPower’s announcement that Wyoming will be home to their new first-of-a-kind Natrium reactor, and BWXT evaluating deploying microreactors in the state, interest in nuclear development has never been higher. Because of this, a new student chapter of the American Nuclear Society was started at the state’s flagship university, the University of Wyoming. The goal of the chapter is to promote and advance knowledge of nuclear energy, and other nuclear related fields, among students, faculty, and community at UW. The ANS at the University of Wyoming was started in November of 2023, and since then has held frequent chapter meetings for their members to learn about things happening in the nuclear industry, meet with faculty and industry members, and learn how they can foster nuclear development in the state.