Intelligent Manufacturing for Extreme Environments

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Indrajit Charit and John Russell

University of Idaho

Idaho National Laboratory

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May 2024

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FOREWORD

The Center for Advanced Energy Studies (CAES) hosted the "Intelligent Manufacturing for Extreme Environments" workshop at the CAES building located at 995 MK Simpson Blvd, Idaho Falls, ID 83402 on May 2–3, 2024, sponsored by the National Science Foundation (Award 2328585). The workshop convened world-class experts, researchers, educators, and students to identify gaps and envision solutions for five interrelated challenges for intelligent manufacturing in extreme environments.

The key challenges discussed that were discussed included:

- 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
- Workforce development and community college engagement.

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

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ACKNOWLEDGEMENTS

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Disclaimer: Any opinions, findings, and conclusions or recommendations expressed at this workshop are those of the author(s) and do not necessarily reflect NSF views.

The organizing committee would like to thank Eréndira Valdez, Madeline Sticht, Meladi Lanier, Gina Wilson, Donna Wuthrich, Jessica Ward, Sunny Katseanes, and Hyrum Wray for their assistance with organizing the workshop. The organizing committee also would like to acknowledge and thank the workshop participants for their engagement and expertise.

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ACRONYMS

AI	artificial intelligence
AM	advanced manufacturing
AMMT	Advanced Materials and Manufacturing Technologies
ASME	American Society of Mechanical Engineers
BSU	Boise State University
CAES	Center for Advanced Energy Studies
CIEIM	International Conference on Industrial Engineering and Intelligent Manufacturing
COF	covalent organic framework
CFIMA	International Conference on Frontiers of Intelligent Manufacturing and Automation
DED	directed energy deposition
DOE	U.S. Department of Energy
DWT	direct-write technologies
EELS	electron energy loss spectroscopy
EHD	electrohydrodynamic
EPSCoR	Established Program to Stimulate Competitive Research
EPSCoR-WO	Established Program to Stimulate Competitive Research Workshop Opportunities
FAIM	Flexible Automation and Intelligent Manufacturing
FCCI	fuel cladding chemical interaction
FMS	flexible manufacturing system
GenAI	generative artificial intelligence
GRCop	Glenn Research Copper
HEA	high-entropy alloy
HPC	high-performance computing
ICAMIM	International Conference on Advanced Materials and Intelligent Manufacturing
ICIMA	International Conference on Intelligent Manufacturing and Automation Engineering
ICIMES	International Conference on Intelligent Manufacturing and Energy Sustainability
ICMIM	International Conference on Materials and Intelligent Manufacturing
ICMTIM	International Conference on Mechatronics Technology and Intelligent Manufacturing
IEEE	Institute of Electrical and Electronics Engineers
IM	intelligent manufacturing
IMEE	intelligent manufacturing for extreme environments
IMS	Intelligent Manufacturing System
INL	Idaho National Laboratory

ISU	Idaho State University
LWR	light water reactor
MaCS	microscopy and characterization suite
MBRL	model-based reinforcement learning
MCOS	metal core oxide shell
MFC	Materials and Fuels Complex
ML	machine learning
NACE	National Association of Colleges and Employers
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
NRIC	National Reactor Innovation Center
NSF	U.S. National Science Foundation
ODS	oxide-dispersion-strengthened
OSTI	Office of Scientific and Technical Information
R&D	research and development
REE	rare earth element
RMS	reconfigurable manufacturing system
SACI	International Symposium on Applied Computational Intelligence and Informatics
SBIR	Small Business Innovation Research
SEM	scanning electron microscopy
SISY	International Symposium on Intelligent Systems and Informatics
SM	smart manufacturing
SMLC	Smart Manufacturing Leadership Coalition
SMR	small modular reactor
STEM	Science, Technology, Engineering, and Mathematics
STTR	Small Business Technology Transfer
TEM	transmission electron microscopy
TMS	Minerals, Metals, and Materials Society
TRISO	tristructural isotropic
UI	University of Idaho
U.S.	United States
UNT	University of North Texas
WCMEIM	IEEE World Conference on Mechanical Engineering and Intelligent Manufacturing
WIMS	World Intelligent Manufacturing Summit

Intelligent Manufacturing for Extreme Environments

1. OBJECTIVE

The Intelligent Manufacturing for Extreme Environments (IMEE) workshop was held at the Center for Advanced Energy Studies (CAES) in Idaho Falls, Idaho, May 2–3, 2023, in support of the United States (U.S.) National Science Foundation (NSF) Established Program to Stimulate Competitive Research: Workshop Opportunities (EPSCoR-WO) program. This workshop featured keynote speakers, panels, and breakout sessions with 58 participants. Nuclear reactors need to operate under extreme service conditions, such as high temperatures, corrosive environments, and high-radiation doses. Hence, reactor components must be able to withstand those conditions. The participants envision a future where on-demand manufacture of components for small modular reactors (SMRs), microreactors, and other advanced reactor designs are possible. In this future, regulatory bodies accept validated manufacturing processes and standardized feedstocks, thus eliminating the need for individual component testing. However, the necessary technologies and regulatory policies needed for this future do not exist today. Successful innovation would revolutionize the nuclear power sector, enable fast commercial development, create economic opportunities in the U.S., reduce the carbon footprint and associated risks, and promote a skilled and highly competitive workforce. The objective of the workshop was to convene world-class experts, researchers, educators, and students to identify gaps and envision solutions for five interrelated challenges for intelligent manufacturing in extreme environments.

The key outcomes of the conference were: (1) to take the opportunity for researchers and educators to network and form collaborations; and (2) to produce a full report to inform policy-makers, industry, and the academic community of various challenges and opportunities in the nuclear energy sector.

2. BRIEF BACKGROUND ON INTELLIGENT MANUFACTURING AND SURVEY OF RECENT CONFERENCES ON INTELLIGENT MANUFACTURING

Before discussing other details of the IMEE Conference, a succinct background on intelligent manufacturing is provided along with a near-comprehensive survey of different international conferences that focus on this area. The keywords of the workshop were “intelligent manufacturing” and “extreme environments.” However, an Internet search using these keywords did not yield any significant conference/workshop or stand-alone symposium with the same or similar title. The attendees also attempted to find some variation of these terms under “smart manufacturing” and “harsh environments.” Again, not much significant information was returned. What was discovered was a wealth of information and high-activity in this space when “extreme environments” is left out of the search. That is why this survey went on to collect conference information mainly on “intelligent manufacturing.” In addition, the limitation in not finding enough information is that the topic area of the IMEE workshop has not matured yet and is relatively novel in nature. A conscious attempt has been undertaken by academic, government, and industrial researchers to transform the manufacturing sector through digitalization, networking, and smartness/intelligence. Even though it has been reasoned that “intelligent manufacturing (IM)” and “smart manufacturing (SM)” are not exactly the same [1], it is often contended that they are used interchangeably.

According to the Google Gemini tool, "IM, also known as SM, is a manufacturing process that uses artificial intelligence (AI), machine learning (ML), and real-time data analysis to optimize operations." However, if one delves deeper into the meaning of this definition, it can be seen that different descriptions have been proposed for IM based on the importance of the technology driving the IM operation. The definitions of IM in the past decades have evolved based on the tool/concept used. If IM is based on replacing human intelligence completely and depending on AI solely, *IM automation* then performs functions involved in manufacturing operations [2,3]. Here, the AI techniques are used to restrict the level of human intervention into these manufacturing activities and corresponding systems. Conversely, if a *system integration view* is taken, IM combines manufacturing processes and systems with different degrees of machine intelligence, including AI-supported systems, AI-integrated systems, and total intelligent manufacturing systems (IMSs) [3]. Based on an *intelligence science* perspective [4], the objective of IM is geared toward establishing adaptive manufacturing operations and systems by adopting integrated and sophisticated information technology, computing capacity, and AI. From a *data-driven intelligence* view, the timely acquisition, distribution, analysis, and utilization of real-time data from humans, machines, and processes from factory floors and across product life cycles are key. Based on a *human-cyber-physical system viewpoint* [5,6], IM is a unique complex system balancing the integration of human, cyber, and physical systems through coordination between each to obtain a set of manufacturing objectives.

SM is considered to be the underlying technology that uses interconnected machines and tools to enhance manufacturing performance and optimizes the energy and workforce needed by the implementation of big data processing, AI, and advanced robotics technology, as well as their interconnectivity [7]. There are several benefits to this kind of manufacturing, such as reduced waste, better efficiency, less expense, less labor-intensiveness, and so forth.

Interest in intelligent (smart) manufacturing has been quite intense. Even a Springer journal known as the *Journal of Intelligent Manufacturing* [8] is named specifically for this important field. This journal is a peer-reviewed publication dedicated to the application of AI principles/methods in manufacturing and publishes research related to product development, manufacturing, and service systems. It attempts to connect the research community with industry. The journal features papers covering new methodologies and developments, case studies, and surveys. Furthermore, emerging topical areas involving additive manufacturing, digital manufacturing, cyber-physical solutions, cloud applications, and deep learning are covered. This journal publishes the highest number of IM- or SM-based articles of any journals. A publications survey in the Scopus database using both IM and SM terminologies yielded a host of articles. In addition, there are journals like the *Institute of Electrical and Electronics Engineers (IEEE) Access*, *Journal of Manufacturing Systems* (Elsevier), *International Journal of Advanced Manufacturing Technology* (Springer Nature), *IFAC-PapersOnline* (Elsevier), etc., which publish a significant number of articles in this field. Great interest have been generated over the last decade with ever increasing publications in the IM and SM areas. The countries that are the most prolific in IM and SM research are China, the U.S., the United Kingdom (UK), Japan, South Korea, and many others.

The original concept of IM is believed to have originated from the field of artificial and manufacturing intelligence [9]. Early IM publications appeared in articles published in the latter half of the 1980s [9] that continued into the present day. In the 1990s, Japan initiated IM research that led to the establishment of the Intelligent Manufacturing System (IMS) Program [10]. In parallel, the U.S. and the European Union also established IM research programs [11]. In recent years, efforts in IM and IMS have culminated in more focused manufacturing research and implementation with a higher degree of intelligence.

SM terminology, on the other hand, started being used during the late 1980s with an article entitled "Artificial intelligence: A tool for smart manufacturing" [12], which appears to be the first publication where an expert AI system was associated with SM. This article was closely followed in 1987 by a book addressing how SM and AI can improve productivity and profitability in manufacturing operations [13].

This book includes topics ranging from AI, expert systems, and computer-aided process planning to robots and vision, flexible manufacturing systems, inspection, and process control. After nearly two decades of limited activity, the modern concept of SM re-emerged—in many cases in close association with the development of the *Industry 4.0* program, which was first initiated by the government of the Federal Republic of Germany more than a decade ago [14]. The main concept of today's SM came from definitions created by the National Institute of Standards and Technology (NIST) and the Smart Manufacturing Leadership Coalition (SMLC). Figure 1 shows the chronology of the smart manufacturing timeline associated with the development of SM areas per the Clean Energy Smart Manufacturing Innovation Institute (CESMII).

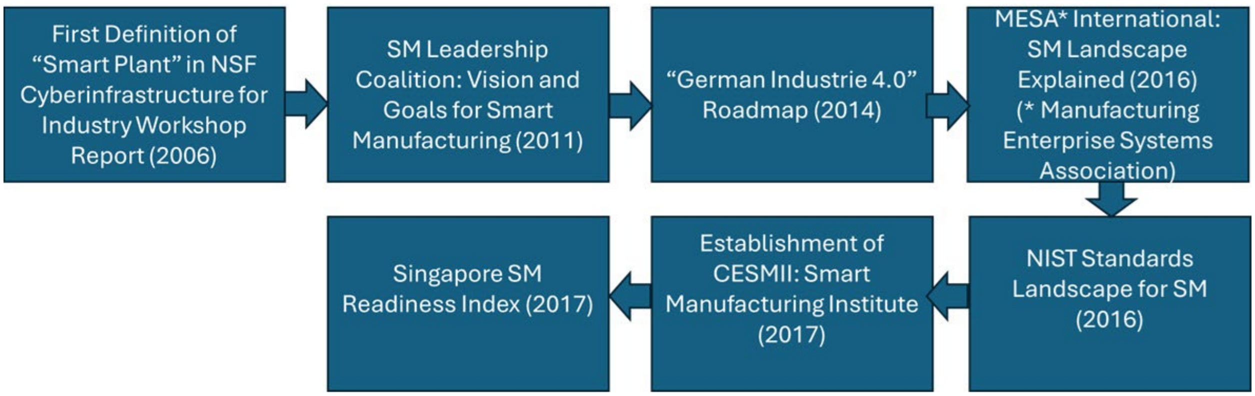

Figure 1. SM timeline chronology according to the Smart Manufacturing Institute (source: www.cesmii.org).

A simple Google search did not yield any conference or workshop with the exact name or theme, "Intelligent Manufacturing for Extreme Environments." It is interesting to see that the NSF Established Program to Stimulate Competitive Research (EPSCoR) IMEE workshop 2024 webpage appears in this Google search and is one of the most relevant due to its position near the top of the search. Several other conferences worldwide—mostly held annually in series—have covered some aspects of "Intelligent Manufacturing" since it has become a vast and multifaceted field by itself. In some cases, similar topics are also covered in different advanced manufacturing conferences, as well as those bearing "Smart Manufacturing" in their names. However, the search was limited to just those areas only to keep the focus on the topic of interest. It is hard to do a fully comprehensive review on each intelligent manufacturing conference that has ever been held. So, the approach taken here was focused on just the recent conferences. The authors hope this succinct summary will provide the readers with the state of the field and the interest surrounding the overarching theme of "Intelligent Manufacturing."

The Flexible Automation and Intelligent Manufacturing (FAIM) Conference (https://www.faimconference.org/) is a long-running continuing conference series held annually since 1991. It is a world-renowned conference for its contributions to advancing research, theories, and practices in automation and manufacturing, as well as offering insights into technological advancements and relevant managerial strategies. The conference holds scientific sessions, workshops, tutorials, and industry tours. Throughout its history, FAIM has been hosted by several universities across the U.S., Europe, and Asia. The FAIM conference traditionally presents 250–300 high-quality research papers submitted by reputed researchers in this field. The upcoming 36th FAIM Conference will be held from June 21–24, 2025, at Binghampton University, New York.

Outside the U.S., a World Intelligent Manufacturing Summit (WIMS) has been organized annually for about eight years in Nanjing, China. At least from the Internet search, no evidence of WIMS was discovered prior to 2018. So, it is believed that this was the first large event for this conference that took place during October 11–13, 2018. Over 1,900 exhibitors from different countries showcased their latest products and technologies, development trends, and advanced solutions in the field of intelligent manufacturing. Recently, the 2024 WIMS conference was held from December 20–22, 2024. The conference featured a comprehensive program with the theme, "Accelerating the Creation of an Upgraded Version of Intelligent Manufacturing and Developing New Quality Productive Forces in Line with Local Conditions." The conference was held along with various special activities, thematic forums, and market-oriented exhibitions by several Fortune 500 companies from ten different countries, showcasing future intelligent manufacturing trends.

In Table 1, the authors attempted to summarize a few of the recently held international conferences, which have a common theme of intelligent manufacturing among them. Many of these conferences are held annually in a series, which confirms the great interest existing in this field.

Table 1. A list of the international conferences fully focusing or in part on "Intelligent Manufacturing." (Some information included below are collected from a website at www.resurchify.com.)

Conference Name	Dates	Location	Thrust or Topic Areas	Website Address, If Available
CFIMA 2024: 2nd International Conference on Frontiers of Intelligent Manufacturing and Automation (CFIMA)	August 23–25, 2024	Baotou, China	Industrial Robotics, Automation, and Process Control; Medical Equipment and Healthcare Systems; Micro, Nano, and Desktop Manufacturing Modeling and Simulation; Process Control Flexible Robots; Soft Robots, Medical Robots, Advanced Control Theory, End-of-Life Management, and Reverse Logistics; Green and Lean Supply Chains, Logistics, and Procurement Knowledge; Change and Risk Management; Production Planning and Scheduling; Total Quality Management	https://www.cfima.org/ This is a conference in a series occurring on an annual basis. The 2025 conference is scheduled to occur during August 22–24, 2025 in Wuhan, China. The topics of interest for this upcoming conference have been expanded further than the 2024 conference.
ICMIMT 2024: 15th International Conference on Mechanical and Intelligent Manufacturing Technologies (ICMIMT)	May 17–19, 2024	Cape Town, South Africa	Advanced Materials Engineering: Composite Materials; Micro-/ Nano-Materials; Ceramic Materials; Metal Alloy Materials; Biomaterials; Optical/Electronic/ Magnetic Materials; Building Materials; New Energy Materials; Environmentally Friendly Materials; Thin Films; *Smart/Intelligent Materials and Systems*; New Functional Materials; Materials Testing and Evaluation; Materials Physics and Chemistry; Tooling Testing and Evaluation.	https://www.mimt.us/cfp.html This is a conference in a series that was started in 2013 in Bali, Indonesia. The 2025 conference is scheduled to take place in Cape Town, South Africa.

Conference Name	Dates	Location	Thrust or Topic Areas	Website Address, If Available
			General Mechanical Engineering–Theory and Application: Aerodynamics; Aerospace Systems and Technology; Artificial Intelligence Techniques in Design and Manufacturing; Applied Mechanics; Automation; Biomechanics; Computational Fluid Dynamics; Fluid Dynamics; Fuels and Combustion; Heat and Mass Transfer; Heating, Ventilation, and Air Conditioning; Industrial Tribology; Internal Combustion Engines; Mechatronics; Micro-Electromechanical Systems; Micromachining; Modeling of Processes; Nanotechnology; Nano-Electromechanical Systems; Industrial Design and Manufacturing Innovative Design Methodology; Product Life Cycle Design; *Intelligent Optimization Design*; Industrial Product Design; Computer-Aided Design (CAD)/ Computer-Aided Manufacturing (CAM)/ Computer-Aided Engineering (CAE); Mechanical Transmission Theory and Applications; Vibration and Noise Analysis and Control; Friction and Wear Theory and Application; Advanced Manufacturing Production Mode; Virtual and Network Manufacturing; Quality Monitoring and Control of the Manufacturing Process; System Analysis and Industrial Engineering; Production and Operation Management; Micro-Electronic Packaging Technology and Equipment; Engineering Optimization; Industrial Robots and Automatic Production Line; Green Manufacturing	

Conference Name	Dates	Location	Thrust or Topic Areas	Website Address, If Available
SACI 2024: 18th International Symposium on Applied Computational Intelligence and Informatics (SACI)	May 21–24, 2024	Siofok, Hungary	Computational Intelligence; Systems Engineering; Intelligent Manufacturing; Intelligent Mechatronics; Informatics	https://conf.uni-obuda.hu/saci2024/ While the conference name does not include intelligent manufacturing directly, it is a topic of interest for the conference.
ICMIM 2024: 6th International Conference on Materials and Intelligent Manufacturing (ICMIM)	August 1–3, 2024	Incheon, South Korea	Broad Areas—Materials, Nanotechnology; Industrial Engineering; Artificial Intelligence; Specific Topics—Superconducting Materials; Materials Testing and Evaluation; Production and Operation Management; Advanced Forming Manufacturing and Equipment; Green Supply Chain; Manufacturing E-commerce System	https://www.icmim.org/ The 7th ICMIM (2025) will be held in Singapore from June 30–July 2, 2025.
WCMEIM 2023: 6th Institute of Electrical and Electronics Engineers (IEEE) World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM)	November 17–19, 2023	Wuhan, China	Intelligent Control; Control Theory; Fuzzy Logic; Neural Network; Expert System; Adaptive Control; Self-organizing Control; Self-learning Control; Intelligent Control System; Application of Intelligent Control Technology; Artificial Intelligence; *Intelligent Manufacturing*; Intelligent Control System; Computer Integrated Manufacturing System; Advanced Control and Optimization Technology; Applications of AI Techniques in Design and Manufacturing; New Sensing Technology; Precision Manufacturing Technology; Advanced Manufacturing Production Mode; Virtual Manufacturing and Network Manufacturing; Quality Monitoring and Control of the Manufacturing Process System Analysis and Industrial Engineering; Micro-Electronic Packaging Technology Equipment; Industrial Robots and Automatic Production Line. (Other topics are not included as they are not relevant to the intelligent manufacturing theme.)	https://www.wcmeim.org/

Conference Name	Dates	Location	Thrust or Topic Areas	Website Address, If Available
SISY 2023: 21st International Symposium on Intelligent Systems and Informatics (SISY)	September 21–23, 2023	Pula, Croatia	Computational Intelligence; Machine Learning; Intelligent Robotics; *Intelligent Manufacturing*	https://conf.uni-obuda.hu/sisy2023/
ICIMA 2023: 7th International Conference on Intelligent Manufacturing and Automation Engineering (ICIMA)	December 22–24, 2023	Changsha, China	Manufacturing and Service Systems; Flexible Automation and Intelligent Manufacturing; Industrial Engineering and Operations Management; Business Strategies and Intelligence in Manufacturing and Services, Knowledge, Change, and Risk Management; Value Creation by Sustainable Manufacturing; Green and Lean Supply Chains, Logistics, and Procurement; End-of-Life Management and Reverse Logistics; Manufacturing Paradigms (Flexible Manufacturing System (FMS)/Reconfigurable Manufacturing System (RMS), Lean, Agile, etc.); Manufacturing Education and Training; Modeling and Simulation; Production Planning and Scheduling; Social Media in Manufacturing; Internet-of-Things in Manufacturing; Multi-Level Measurement and Metrics; Social Aspects, Health, and Safety in Manufacturing; Services Science, Management, and Engineering; Integrated Product and Production Development; Product Design/Design for Manufacture/Assembly; Design for X Modular and Configurable Structures and Development Processes; Product Development; Rapid Prototyping; Concurrent Engineering; Value Creation for Customers and Stakeholders; Total Quality Management; Product and Production System Life Cycle Assessment and Interaction; Manufacturing Technology and Processes; Cognitive and *Artificial Intelligence in Manufacturing*;	https://www.icima.org/ This next conference in this series (ICIMA 2024) was held in Penang, Malayasia.

Conference Name	Dates	Location	Thrust or Topic Areas	Website Address, If Available
			Biological Engineering, Medical Equipment and Healthcare Systems; Industrial Robotics, Automation, and Process Control; Micro-, Nano- and Desktop-Manufacturing; *Digital Manufacturing*; Sensor-Based Process Monitoring and Control	
ICAMIM 2022: 3rd International Conference on Advanced Materials and Intelligent Manufacturing (ICAMIM)	August 5–7, 2022	Guangzhou, China	Advanced Materials: Non-ferrous, Steel Polymer Material, Composites; Micro-/Nano-Materials, Optical/Electronic/ Magnetic Materials, New Feature Materials *Intelligent Manufacturing*: Biomimicry Mechanisms; Integrated Manufacturing Systems, Industrial and Manufacturing Systems Analysis and Decision-Making, Digital Manufacturing, Modeling and Design, Intelligent Systems, Intelligent Mechatronics, Micromachining Technology, Advanced Manufacturing Technology	https://www.icamim.org/
ICMTIM 2020: International Conference on Mechatronics Technology and Intelligent Manufacturing (ICMTIM)	August 28–30, 2020	Xi'an, China	Details not available. The topics of submissions are most likely related to Mechatronics Technology and *Intelligent Manufacturing*	https://www.icmtim.org/ This is a conference in a series that was started in 2013 in Bali, Indonesia. The 2025 conference is scheduled to take place in Cape Town, South Africa. The next conference in this series (the 6th) is scheduled to be held from April 11–13, 2025, in Nanjing, China.
Scopus-2IM 2020: International Conference on Intelligent Manufacturing and Intelligent Materials	June 25–28, 2020	Stockholm, Sweden	Intelligent Materials and Applications; Intelligent Information Systems; Manufacturing Systems and Technologies; Automation in Manufacturing; *Intelligent Manufacturing* Applications	http://www.2im2020.org (No longer accessible or inactive.)
CIEIM 2019: 2nd International Conference on Industrial Engineering and Intelligent Manufacturing (CIEM)	August 14–16, 2019	Shanghai, China	Industrial Design; Industrial Informatics; Decision Analysis and Methods; Operations Research; Information Processing and Engineering; Production Planning and Control; Project Management; Information Processing and Engineering; Quality Control and Management; Reliability and Maintenance Engineering; Safety,	http://cieim.org/cfp.html (No longer accessible or inactive.)

Conference Name	Dates	Location	Thrust or Topic Areas	Website Address, If Available
			Security and Risk Management; Service Innovation and Management; Supply Chain Management; Systems Modeling and Simulation; Technology and Knowledge Management; Intelligent Systems; Engineering Education; Manufacturing Systems; Healthcare Systems; Industrial Management; Manufacturing Process Simulation; Modern Production Equipment Design and Manufacture; PC-Guided Design and Manufacture; Micromachining Technology; Virtual Manufacturing and Network Manufacturing; Microwave Processing of Materials; System Analysis and Industrial Engineering; Production and Operation Management; Advanced Forming Manufacturing and Equipment; NEMS/MEMS Technology and Equipment; Thermal Engineering Theory and Applications; Manufacturing Systems and Industry Application; Modeling, Analysis and Simulation of Manufacturing Processes; Advanced Manufacturing Technology	
ICIMES 2019: International Conference on Intelligent Manufacturing and Energy Sustainability (ICIMES)	June 21–22, 2019	Hyderabad, India	Smart Manufacturing; Tribology; Polymers and Composites; Micro-Spectroscopy; Hybrid Machining; Flexible Manufacturing; Digital Twin; Artificial Intelligence; Automation and Robotics; Computer Vision; Electric and Hybrid Cars; Vibration and Acoustics; Computational Mechanics and Fluid Dynamics; Modeling, Simulation, and Optimization; Sustainable Energy Systems; Cryogenics and Jet Propulsion; Renewable Energy Systems; Heat and Mass Transfer; Smart Grids; Biomass and Biofuels; CO_2 Capture	https://icimes.com/ (This domain name has been taken over by another unrelated conference.) The information presented here was taken from: http://www.wikicfp.com/cfp/servlet/event.showcfp?eventid=85167

3. WORKSHOP ORGANIZATION

CAES is a research, education, and innovation consortium comprising Idaho National Laboratory (INL) and the three public research universities of Idaho—Boise State University (BSU), Idaho State University (ISU), and the University of Idaho (UI). Students and researchers perform collaborative research at locations across all four institutions and at the 55,000 sq. ft. CAES building in Idaho Falls, Idaho. The workshop utilized the CAES gallery, with a seating capacity of over 100 people, for the plenary session, poster session, and registration. The CAES Auditorium, with a seating capacity of 40 people, was used for the breakout sessions. The Snake River Conference Room and the Teton Conference Room, with a seating capacity of 15 people each, were utilized for the breakout sessions as well. Staff members from the University of Idaho–Idaho Falls Center provided support for the workshop.

The Workshop Organizing Committee included:

Indrajit Charit
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Department of Nuclear Engineering and Industrial Management, UI

Dave Estrada
Associate Professor and Associate Director
Center for Advanced Energy Studies, BSU

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Professor and Presidential Fellow
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John Russell
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Center for Advanced Energy Studies, UI

Marco Schoen
Professor and Director
Measurement Controls Engineering Research Center, ISU

4. STATEMENT OF NEED

The authors envision future manufacturing for the nuclear power industry as on-demand manufacture of SMR and microreactor components. In this future, regulatory bodies accept validated manufacturing processes and standardized feedstocks, thus eliminating the need for the testing of individual components. The necessary technologies and regulatory polices do not exist today. Successful innovation would revolutionize the nuclear power sector, enable fast commercial development, create economic opportunities for the U.S., reduce the carbon footprint and the associated climate risks, and promote a skilled and highly competitive workforce.

Eastern Idaho and the state of Wyoming are poised for a manufacturing boom. The entire region faces a critical need to grow a skilled workforce, trained in the latest advanced manufacturing (AM) techniques to support commercial deployment of microreactors and SMRs. TerraPower plans to build a Natrium advanced reactor at a retiring coal power plant located in Kemmerer, WY. This effort is supported by the U.S. Department of Energy (DOE) Advanced Reactor Demonstration Project, which is expected to create 1,600 construction jobs and 250 operational jobs to run the plant, including security [15]. In addition, the U.S. Congress authorized the establishment of the National Reactor Innovation Center (NRIC) at INL [16]. NRIC will draw nuclear energy manufacturers nationwide to eastern Idaho.

Nationally, 98 aging light water reactors (LWRs) at 60 nuclear power plants in 30 states provide 20% of the electricity that is generated nationwide [17,18]. SMRs are a new technology that is carbon-free and cooled by natural convection. SMRs will provide baseload electric generation with load-following features that allow for seamless integration with intermittent renewable energy sources, such as solar and wind. Importantly, SMRs are portable, small enough to be manufactured at a factory, and shipped by truck to the point of use. The manufacturability of SMRs provides both added flexibility in siting and lower capital costs as well.

Internationally, the U.S. is falling behind Russia and China, which are aggressively exporting advanced nuclear power technology [19]. The U.S. can leapfrog the competition through innovation. Failure to act risks loss of market leadership.

Key manufacturing science and engineering challenges still remain for SMR deployment. As stated previously, nuclear reactors provide an extreme environment requiring components withstand high temperatures, radiation, and corrosion over decades. The future of manufacturing in the nuclear industry depends on overcoming these five interrelated challenges: (1) printable electronics that can survive extreme environments, (2) in situ manufacturing process monitoring and feedback control, (3) ML to optimize process variables in manufacturing and materials composition, (4) extreme temperature qualification and testing, and (5) workforce development and engagement with community colleges.

5. THRUSTS

5.1. THRUST 1: Manufacturing Embedded Electronics and Sensors for Extreme Environments

An important future manufacturing challenge for nuclear reactors is the ability to manufacture electronic components that are capable of withstanding the extreme environment of the reactor core, including high temperatures and high radiation, for multi-year durations. Autonomous operation and supervised semi-autonomous operation of nuclear reactors for power generation is crucial to enable a cost-competitive process and avoid hazardous accidents by integrating preventive maintenance. Autonomous operation will require distributed and reliable sensors for continuous monitoring and load following to integrate with intermittent renewable power generation.

Standardization is a significant challenge for the manufacturing and testing of electronic components in extreme environments. Standards and metrics for reliability and durability in extreme environments are currently lacking. Variables and mitigations that impact performance are not well-understood. A suitable fabrication modality for embedded and distributed sensors, including additive electronics manufacturing, needs to be identified. Sequentially, novel nanomaterial-based inks compatible with various direct deposition techniques need to be developed, characterized, and qualified. This also means a mitigation of variability in ink composition batch-to-batch. A standardized library of material-process relationships would be highly valuable. The manufacture of electronic components for extreme environments requires a highly skilled workforce with specialized training.

5.2. THRUST 2: In Situ Manufacturing Process Monitoring and Feedback Control

Due to outdated regulation, the nuclear industry relies on long-settled manufacturing designs, processes, practices, and products. The advent of SMR technology requires innovation across the entire design, development, and production life cycle. The nuclear industry would greatly benefit from future manufacturing technologies, such as digital design and statistical quality assurance techniques, for monitoring and controlling production. Future manufacturing will incorporate digital design with robotic fabrication in a workflow called a process. Controlling this process, and hence changing its behavior, requires the characterization of the process itself in a suitable form. Identifying and integrating sensors are necessary to provide a feedback loop that can feed machine-based learning algorithms. These sensors also process parameters to minimize unwanted changes or to affect process movement in a desired direction.

Based on this description and a control objective, the structure of the control algorithm can be formulated. For control of AM processes, identification algorithms that directly estimate the resulting feedback controller based on the observed process dynamics may also incorporate robustness and adaptive features. Methods and algorithms to extract process model parameters and process model structures need exploration. This way, feedback control principles and extracted process models can address product quality and process variations.

5.3. THRUST 3: Machine Learning for Manufacturing Processes and Materials Composition

Future manufacturing will use AI and integrated ML techniques in a materials-and-process-by-design approach. Designing new materials is a slow and laborious process, requiring significant investments in capital and labor. Recent AI advances would allow for improvements and speeding up this process. ML techniques can replace expensive and time-consuming laboratory processes and computational simulations to quickly and reliably predict how to create materials with desired properties in specific circumstances. ML can identify the processing conditions needed to obtain the desired microstructure-property relationship. This approach can help develop physics-based understanding of materials at the atomic and electronic levels, explore the materials phase space, and optimize the manufacturing process variables.

5.4. THRUST 4: Extreme Temperature Qualification and Testing (Cross-Cutting)

Qualification is the key to future manufacturing, especially for SMRs. Performance of a component manufactured by AM techniques needs to be predictable and comparable to a component manufactured by traditional techniques. Behavior characterization of AM components in extreme environments is essential. Mechanisms and processes at high temperatures are significantly different than from low temperatures. Understanding such behavior is critical to developing processes and materials that meet the performance criteria.

Developing integrated computational and experimental models to accurately predict materials behavior at extreme temperatures is critical to the qualification of processes and components. Creep and creep-fatigue at extreme temperatures are of special interest. A cybersecurity-testing approach will elucidate complex interactions of high-temperature and other extreme conditions, such as irradiation, corrosion, external fields, and their cumulative interaction. ML techniques will be necessary to determine the relative contributions of these mechanisms in extreme conditions. Innovative in situ characterization techniques can inform computational models to explore multilength-scale phenomena.

5.5. THRUST 5: Workforce Development and Community College Engagement

Workforce development is needed for local communities to provide the large number of highly trained workers to support growth in the nuclear energy industry in eastern Idaho and Wyoming. Nuclear facilities have unique requirements, such as Nuclear Quality Assurance-1 (NQA-1), an industry consensus standard created and maintained by the Society of Mechanical Engineers. Community colleges play a unique role in the workforce development ecosystem and can provide the necessary technical training, such as NQA-1 orientation and radiation safety, for workers seeking on-ramps to the nuclear energy industry. Workforce development needs for the expected growth in advanced reactors in the region include a wide variety of different job areas including construction, trades, technology, health and human services, and business.

6. DISCUSSION

The workshop included technical discussions with suggested questions that participants were asked to answer. Participants also were invited to modify any questions and create new ones for the group to address. The following is a summary of the questions that were asked and the subsequent discussion that followed. The primary purpose of this workshop segment was to gather feedback from the participants about the potential challenges and opportunities for advancing materials for extreme environments.

PROMPT 1: What are the key technical challenges to advancing materials characterization for extreme environments?

Discussion:

- Reproducing the conditions of the harsh environment with in situ property and structure characterization.
- Surrogacy of materials limits the ability to gather data related to the actual material (i.e., CeO_2 versus UO_2).
- Complexity can be challenging for models to predict real systems. A baseline is needed for certain properties that are reproducible between both experiment and theory, and the properties are quantitatively and qualitatively agreeable.
- Electronic structure properties of f-element materials are difficult to reproduce experimental properties (i.e., bandgap in UO_2).
- Lack of access to past data. ML can take advantage of existing data. How do we compile all the information from hundreds of thousands of publications? Making sense of the data in a systematic way can benefit the community in the long run. Most data is open science and can benefit the community:
    - DOE databases are not very usable by the community.
    - A large language model (LLM) could be used to help make sense of the available data.
    - Other agencies, such as the Army Research Laboratory, are already doing this
    - Data may be difficult to access due to competitive concerns or proprietary data.
    - Data format is a challenge. A standard format requirement from the funding agencies might be helpful.
    - A central data repository would be helpful. Multiple databases are hosted by different laboratories.

- International partners also host large datasets that could be useful (UK). Currently DOE has ongoing discussions with international partners on data (France):
    - Materials-sharing as sponsored by the U.S. Nuclear Regulatory Commission (NRC) between international partners is also quite valuable. Partnerships can be helpful to advance the science. Materials that have been inside reactors for several decades are rare and valuable.
    - Countries with Generation IV Advanced Reactors (GIF) have exchanged information between international partners.
- Data curation should be consistent with other hosted data.
- Hosting structural materials and alloys might be a good place to start.
- ML would particularly benefit from the broad sharing of data.

• Data from extreme environments is valuable because it is hard to come by. The science is "data poor" due to the scarcity of data. Easy access to new data can be helpful for the generation of new ideas. More research is needed to develop ML methods for "data poor" applications.
- Generative AI can be used to generate new data. It is important that this model is trustworthy to generate useful data. An example of this is the use of limited data for cancer models and generating new data is a technique. Another example is generative AI to make pictures from the text.
- Federally funded ML projects can be shared with the community, including ML codes and scripts. Sharing will always be helpful, although competitiveness may limit some sharing.

• X-ray diffraction data is an example for how successful data can be shared across the scientific community.

• AI/ML literacy: How can experimentalists talk to modelers so that a synergy can be developed to solve larger problems:
- AI might be introduced at an earlier stage of education. AI integration with the learning process should be included in coursework. For example: How can ML help with learning the concepts presented in a chemistry course?
- Most researchers do not need to know the mathematics of AI/ML. It is possible that there could be courses formatted more closely to the interests of domain experts in materials science or other fields.
- Introductory classes focused on creating AI and ML awareness would be valuable to researchers from many different domains.
- ML-integrated course development would be helpful.
- Interfaces for non-experts in ML would be useful. An illustration is the MatLab interface. For example: How can content be user-friendly for Pharmacy students who do not have a programming background? Software-as-a-service is a concept that would be useful.
- There can be cultural differences between Computer Science (CS) and Engineering domains. CS experts try not to redevelop existing tools. Engineering experts frequently modify/adapt existing tools. Is there a way that computer scientists could make tools that would be more appealing so that others do not try to make their own:
    - Community codes would be valuable to advance science. Community codes are written in a way to be usable by others. This would incorporate documentation and testing.

- In situ data generates a large amount of data. A major difficulty is the lack of a data processing tool that can extract useful information. ML might be helpful with the analysis of large quantities of data:
  - Many data processing tools are not user-friendly for non-domain experts. It would be very helpful to have more accessible tools to reach a broader part of the community.
  - Challenging experimental tasks do not necessarily align with challenging modeling tasks.
  - Aligning ion irradiations with neutron irradiations to monitor properties/performance.

PROMPT 2: What the key pieces of lacking equipment that would enable research and advance materials characterization for extreme environments?

Discussion:

- Nuclear materials testing and qualification requires access to test reactors and hot cells outfitted with appropriate test equipment. There are few of these facilities available, and key capabilities, such as high-temperature creep testing of active materials, do not currently exist.
- Very limited instrumentation commercially available can survive in extreme environments to gather data. In ten years this could be different, but it causes a bottleneck now.
- In situ environments and creep experiments inside test reactors. But instrumentation that can do that also might be needed. Environments might include stress, temperature, radiation, corrosion, gas environments, and molten salt.
- Transmission electron microscopy (TEM)/scanning electron microscopy (SEM) instruments are available. More x-ray absorption tools would be useful for in situ experiments without limitation on the in situ environment (gas, pressure, etc.). X-ray tools would help with chemistry and local structure, which plays a critical role for material science and chemistry. These are also relatively low cost with respect to maintenance.
- Refractory metal property characterizations at high temperatures are not available. In these cases, measurements at 3000K are needed. The industry wants and needs to complete work on nuclear power propulsion but cannot achieve these temperatures.
- The community working with high-entropy alloys (HEAs) is only looking at the tensile test data. All of this data is at compression strength to obtain the stress/strain curves. This is a limitation of the equipment.
- It is difficult to match time and length scales. It is not possible to create a 1:1 model of the physical world. Some simulation tools can be difficult to validate. Multiscale modeling approaches (MD->Phase Field->Macroscale) can get closer to matching real-world length/time scales. ML can help with this:
  - Multidimensional (MD) models at lower-length scales can sometimes have difficulty in accurately predicting experimental results. Multiscale models can help provide a better result. Creep is a problem that happens on multiple length and time scale tests.
  - Fast rupture tests are sometimes performed to predict creep rupture life, but this approach may not be accurate.
  - Creep is a time-dependent phenomena. The language in the literature can be confused when simulations are performed with unrealistic conditions (i.e., short-term tests). The mechanism changes based on the stress. Sometimes, short-term tests cannot be used to accurately predict long-term life.
- More engineering in processing—development that needs to receive attention. Development is not often being acknowledged. Funding should also get to the experimental side to demonstrate manufacturing. To get to commercialization, a code case is needed, which requires a lot of mundane engineering and takes a long time to obtain.

- Testing and qualifying parts is completed regularly for a living in the industry, but where the rubber meets the road is where things get commercialized. There is a large gap to take new concepts to mass production. How can this gap be reduced in terms of technology and workforce development to get new science from the laboratory to mass production:
    - A majority of testing is completed for the American Society for Testing and Materials (ASTM) and the National Association of Colleges and Employers (NACE) per spec requirement, and those are in addition to the company requirements. Large equipment manufacturers such as General Electric (GE) Aerospace, Pratt & Whitney, Rolls Royce, and Chevron have their own requirements to qualify materials, coatings, and parts. Having such a large variability creates challenges to qualify parts.

PROMPT 3: What are the opportunities for partnership with industry? What are the barriers to increasing partnership with industry?

Discussion:

- For opportunities, specific industry sectors (nuclear, etc.) can supply performance requirements such as temperature, stress, creep rate, ductility, radiation-damage envelope, and environment. The specification of performance goals provides the research and development (R&D) community with specific targets that can be used to design and test potential microstructures and processing routes. The development process can be aided from the beginning by ML from published data. Commercial vendors also should be engaged early on to ensure a commercial supply. DOE's Advanced Gas Reactor (AGR) tristructural-isotropic (TRISO) qualification program provides an excellent template for this process. Data can be made available for non-nuclear and nuclear use as it is generated. Potential materials with wide market applicability include high-temperature, high-strength oxide-dispersion-strengthened (ODS) metallic nanostructured ferritic alloys (NFAs) and robust methods for joining silicon carbide (SiC).
- Barriers to success include: (1) the relatively small size and instability of the emerging advanced nuclear market often are not attractive for private investment. The developed materials should therefore address several markets. Careful selection and qualification of a small set of materials through irradiation and post-irradiation testing by DOE would provide a selection of "off-the-shelf" materials available to broad industrial and nuclear markets. (2) The current (traditional) process for qualification of nuclear materials is cumbersome. The time for nuclear qualification may require 10–20 years. The time required for testing and development of an American Society of Mechanical Engineers (ASME) code case may require 5–10 years. Leveraging of the current irradiation performance database may reduce the amount for data required for qualification.
- AGR TRISO fuel program was a huge success that resulted in NRC approved fuel that reactor vendors now take off-the-shelf and will soon be able to buy commercially. This saves ~$50 million in 10 years.
- A commercial company cannot make a case for a specialty material just for the nuclear industry. There needs to be customers from multiple markets. An example of this is Kanthal APMT.
- Biomedical field could benefit from this approach.
- Solar energy overlaps with nuclear materials as well, such as solar concentrators.
- How can University Assistant and Associate Professors engage with industry partners? On the nuclear side, there are independent reactor working groups (NEI - nuclear energy institute) are places where junior faculty may engage with potential industry partners. Gateway for Accelerated Innovation in Nuclear (GAIN) may also be a place to find potential partners.

PROMPT 4: What would success look like?

Discussion:

- Currently there are few materials qualified for use in high-temperature reactors. Close cooperation between reactor developers, universities, national laboratories, vendors, and regulators results in a small and versatile set of qualified and commercially available high-temperature materials for use in a wide range of non-nuclear and nuclear applications. Development of an ASME Division III Section 5 code case provides bounding specifications and design rules. The ASME code case can be presented to regulators for adoption. Once adopted, the code case can be used to analyze and justify the performance of individual structures, systems, and components (SSCs) in Topical Report(s) submitted to the regulators.
- Vendor engagement is a hard thing to do. It is important to find the right vendor and convince them it is beneficial to form a partnership. Small businesses and start-ups going after Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) is another avenue to industry partnership.
- Collaboration without barriers is what success would look like in advanced manufacturing for extreme environments.

PROMPT 5: What topics and what new directions are most ready for future investments?

Discussion:

- High-temperature radiation-resistant materials. It recently has become evident that nuclear energy will play a large role in decarbonization, and that advanced reactors also will play a role. Currently, there are few qualified materials available to support the development and deployment of advanced reactors, which can provide improvements in time to deployment, economics, and safety. The development and qualification of a small but diverse set of very high-temperature metal alloys and ceramics that support nuclear and non-nuclear processes would enable the transition of a wide range of essential commercial processes to transition to carbon-free sources of electricity and process heat.
- ML, AI, and data science.
- Automation with smart robots working on systems instead of humans may have reduced costs for manufacturers. Is it possible to have a future nuclear material laboratory without human involvement? An example might be the Intel fabrication labs. Another example, the Specimen Preparation Laboratory at the Materials and Fuels Complex (MFC), which has hot cells with robotic arms that can help with testing structural materials and fewer humans involved. NIST may also do some robotic fabrication as well.
- Materials testing in complex environments, and corresponding instrumentation development for testing.
- NSF EPSCoR program should consider broader partnerships with DOE National Laboratories. In addition, the research enterprise and community would benefit with greater Laboratory-University partnerships sponsored by DOE and DoD.
- NSF AI Institutes had an opportunity for AI for Materials Discovery, and this area would be a good area for the community to continue.
- Waste water recycling from nuclear plants would be an area of interest.
- Materials for fusion applications would be of interest.
- Advanced materials precursor synthesis and characterization would be of interest.

7. OUTCOMES

The key outcomes of the conference were: (1) to take the opportunity for researchers and educators to network and form collaborations; and (2) to produce a full report to inform policy-makers, industry, and the academic community of various challenges and opportunities in the nuclear energy sector. This workshop was funded with support from the EPSCoR-WO program and is aligned with EPSCoR goals, as shown in Table 2. This summary of workshop outcomes is in accordance with the requirements outlined in the solicitation as follows:

Metrics and measures of workshop programmatic success:

- The workshop had 58 participants from four EPSCoR jurisdictions, including Idaho, Wyoming, Montana, and Oklahoma.

Extent of the inclusion of individuals from groups underrepresented in Science, Technology, Engineering and Mathematics (STEM):

- The workshop was joined by many participants from groups traditionally underrepresented in science and engineering, including participants from the Shoshone-Bannock Tribes, women in science and engineering, and veterans.
- Participants from groups underrepresented in STEM participated as plenary speakers, invited speakers, and students.

Plan for widespread dissemination of results:

- Results from the workshop will be disseminated via a full report submitted to INL for inclusion in the DOE Office of Scientific and Technical Information (OSTI). In addition, the report will be hosted on the CAES website and the workshop website.

Table 2. Workshop alignment with EPSCoR goals.

EPSCoR Goals	NSF EPSCoR Workshop Outcomes
Catalyze the development of research capabilities and the creation of new knowledge that expand jurisdictions' contributions to scientific discovery, innovation, learning, and knowledge-based prosperity.	The workshop catalyzed new collaborations and research directions that will support the growth of carbon-free advanced nuclear energy research in Idaho, Wyoming, Montana, and Oklahoma.
Establish sustainable STEM education, training, and professional development pathways that advance jurisdiction-identified research areas and workforce development.	The workshop provided opportunities for junior researchers to advance their career through networking and presentations, and for community college educators to learn about what is happening in advanced nuclear energy science and technologies.
Broaden direct participation of diverse individuals, institutions, and organizations in science and engineering research and education initiatives.	The workshop was joined by many participants from groups traditionally underrepresented in science and engineering, including from the Shoshone-Bannock Tribes.

EPSCoR Goals	NSF EPSCoR Workshop Outcomes
Effect sustainable engagement of participants and partners, the jurisdiction, the national research community, and the general public through data-sharing, communication, outreach, and dissemination.	The workshop organizers will prepare a full-length report to inform policy-makers, industry, and the academic community of the workshop outcomes. The report will be broadly disseminated and submitted as an INL Technical Report to OSTI.
Impact research, education, and economic development at academic, government, and private sector levels.	The workshop is aligned with efforts by INL, the City of Idaho Falls, and the State of Idaho to form an innovation district in Idaho Falls and develop an advanced nuclear energy workforce.

8. WORKSHOP AGENDA

Thursday, May 2, 2024				
Start Time	**Event**			**Name/Location**
8:00–8:30 a.m.	*Registration and Catered Continental Breakfast*			*Gallery*
8:30–9:00 a.m.	Welcome to CAES			Phil Reppert, INL
Plenary Sessions in the Gallery				
Start Time	**Title**			**Name**
9:00–9:40 a.m.	"Convergence of Computationally Designed Alloys and Processes"			R.S. Mishra, UNT
9:40–10:20 a.m.	"Advanced M aterials & Manufacturing for Extreme Environments"			Allen Roach, INL
10:20–10:40 a.m.	**20 Minute Break** Catered coffee & snacks served			
10:40–11:20 a.m.	TBD			Duane Johnson, Ames Lab
11:20 a.m.–12:00 p.m.	"Enabling Manufacturing Technologies Changing the Material Landscape for Extreme Environments"			Isabella van Rooyen, PNNL
12:00–1:00 p.m.	*Catered Lunch*			*Gallery*
Technical Sessions in Breakout Locations				
	Characterization Session Gallery	**Processing Session Auditorium**	**Modeling Session Snake River Conference Room**	**Workforce Session Teton Conference Room**
Start Time	**Name**	**Name**	**Name**	**Name**
1:00–1:20 p.m.	Michael McMurtrey, INL	Jorgen Rufner, INL	Samrat Choudhury, UMiss	Rick Aman, CEI & Eleanor Taylor, INL
1:20–1:40 p.m.	Brian Jaques, BSU	Luis Nuñez, INL	Dilpuneet Aidhy, Clemson	Tod Schwartz, CSI
1:40–2:00 p.m.	Triratna Shrestha, Metcut Research	Ritesh Sachan, OK State	Katie Dongmei Li-Oakey, UWYO	John Jenks, Wyoming Business Council
2:00–2:20 p.m.	Raja Krishnan, U of I	Matthew Swenson, U of I	Lars Kotthoff, UWYO	Wyatt Petersen, Shoshone-Bannock Tribes
2:20–2:40 p.m.	**20 Minute Break** Catered coffee & snacks served			
2:40–3:00 p.m.	Yaqiao Wu, BSU	Yang Cao, MT State	Michael Tonks, U. Florida	Mitch Meyer, NuCube Energy
3:00–3:20 p.m.	Somayeh Pasebani, OSU	Kiyo Fujimoto, INL	Min Xian, U of I	Amin Mirkouei, U of I

3:20–3:40 p.m.	Haiyan Zhao, U of I	TBD	Leslie Kerby, ISU	Caleb Hill, UWYO
3:40–4:00 p.m.	Boopathy Koombaiah, INL	TBD	TBD	TBD
4:00–6:00 p.m.	*Catered Dinner and* ***Poster Session***			*Gallery*
Friday, May 3, 2024				
Start Time	**Event**			**Name/Location**
8:00–8:30 a.m.	*Registration and Catered Continental Breakfast*			*Gallery*
8:30–9:00 a.m.	Brief Remarks: Recap of Day 1 and Goals for Day 2 Breakout Sessions			John Russell, U of I
Breakout Sessions in Breakout Locations				
Start Time	**Characterization Session Gallery**	**Processing Session Auditorium**	**Modeling Session Snake River Conference Rm**	**Workforce Session Teton Conference Rm**
9:00–11:00 a.m.	Breakout Sessions Catered Coffee & Snacks served 10:20 AM			
11:00–11:10 a.m.	Closing Remarks *Everyone can go! Except those contributing to report writing!*			Indrajit Charit, U of I John Russell, U of I CAES Director
11:10 a.m.–12:00 p.m.	Conference Report Writing Session			Indrajit Charit, U of I
Lunch is on your own, thank you for participating!				

9. PARTICIPANTS

Name	Affiliation	Role
Aleksandar Vakanski	University of Idaho	Professor
Zhe Wang	University of Idaho	Student
Parikshit Bajpai	Idaho National Laboratory	National Laboratory Researcher
Lynn Munday	Idaho National Laboratory	National Laboratory Researcher
Marco Schoen	Idaho State University	Professor
Michael Moorehead	Idaho National Laboratory	National Laboratory Researcher
Michael McMurtrey	Idaho National Laboratory	National Laboratory Researcher
Linu Malakkal	Idaho National Laboratory	National Laboratory Researcher
Kathryn Richardson	University of Idaho	Student
Amin Mirkouei	University of Idaho	Professor
Priyanshi Agrawal	Idaho National Laboratory	National Laboratory Researcher
Leslie Kerby	Idaho State University	Professor
Sriswaroop Dasari	Idaho National Laboratory	National Laboratory Researcher
Sid Nair	Boise State University	Other
Shoukun Sun	University of Idaho	Student
Min Xian	University of Idaho	Professor
Zyed Ansary	University of Idaho	Student
Kavindan Balakrishnan	University of Idaho	Student
Ritesh Sachan	Oklahoma State University	Professor
Simon M Pimblott	Idaho National Laboratory	National Laboratory Researcher
James Smith	Idaho National Laboratory	National Laboratory Researcher
Mitch Meyer	NuCube Energy	Industry
Arnold Pradhan	Idaho National Laboratory	Student
Kevin Walpole	University of Idaho–Idaho Falls	Student
Amey Khanolkar	Idaho National Laboratory	National Laboratory Researcher
Chaitanya Bhave	Idaho National Laboratory	National Laboratory Researcher
Wyatt Petersen	Shoshone-Bannock Tribes	Government
Boopathy Kombaiah	Idaho National Laboratory	National Laboratory Researcher
Philip Reppert	Idaho National Laboratory	National Laboratory Researcher
Haiyan Zhao	University of Idaho	Professor
Brian Jaques	Boise State University	Professor
Kiyo T Fujimoto	Idaho National Laboratory	National Laboratory Researcher
Eleanor Taylor	Idaho National Laboratory	Other
Jorgen Rufner	Idaho National Laboratory	National Laboratory Researcher
Rajiv Mishra	University of North Texas	Professor
Yaqiao Wu	Boise State University	Professor
Krishnan S Raja	University of Idaho	Professor
Isabella van Rooyen	Pacific Northwest National Laboratory	National Laboratory Researcher

Name	Affiliation	Role
Name	**Affiliation**	**Role**
John Jenks	Wyoming Business Council	Government
Michael Tonks	University of Florida	Professor
Dilpuneet Aidhy	Clemson University	Professor
Lars Kotthoff	University of Wyoming	Professor
Caleb Hill	University of Wyoming	Professor
Luis Nuñez III	Idaho National Laboratory	National Laboratory Researcher
Nusrat Farheen	Idaho State University	Student
Golam Gause Jaman	Idaho State University	Student
Drew Thomas Rone	University of Wyoming	Student
Samrat Choudhury	University of Mississippi	Professor
Matthew Swenson	University of Idaho	Professor
Raymond Nowak	University of Wyoming	Student
Somayeh Pasebani	Oregon State University	Professor
Rongjie Song	Idaho National Laboratory	National Laboratory Researcher
Triratna Shrestha	Metcut Research Inc.	Industry
Allen Roach	Idaho National Laboratory	National Laboratory Researcher
Yang Cao	Montana State University	Professor
John Russell	University of Idaho	CAES Associate Director
Indrajit Charit	University of Idaho	NEIM Chair and Professor
Katie Dongmei Li-Oakey	University of Wyoming	Professor

10. SPEAKER BIOS AND ABSTRACTS

10.1. Plenary Session

10.1.1. Professor Rajiv Mishra: Convergence of Computationally Designed Alloys and Processes

Dr. Rajiv Mishra is a Regents Professor at the University of North Texas (UNT). He serves as the Director of the Advanced Materials and Manufacturing Processes Institute (AMMPI) at UNT. He is a Fellow of American Society for Metals (ASM) International. He is a past-chair of the Structural Materials Division of the Minerals, Metals, and Materials Society (TMS) and served on the TMS Board of Directors (2013–2016). He has authored/coauthored 441 papers in peer-reviewed journals and proceedings and is the principal inventor of four U.S. patents. His current Google Scholar h-index is 88 and his papers have been cited more than 40,000 times. He has coauthored three books: (1) *Friction Stir Welding and Processing*, (2) *Metallurgy and Design of Alloys with Hierarchical Microstructures*, and (3) *High-Entropy Materials: Processing, Properties, and Applications*. He has edited or coedited fifteen TMS conference proceedings. He is a recipient of the TMS–Structural Materials Division (SMD) Distinguished Scientist Award in 2020 and the TMS–Materials Processing and Manufacturing Division (MPMD) Distinguished Scientist Award at the 2024 TMS Annual Meeting.

Convergence of Computationally Designed Alloys and Processes

The evolution of alloy design and process innovation in the first half of the past century was primarily empirical. 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, Dr. Mishra will capture a few examples of the path traveled and what lessons can be learned to build a future that discovers and uses structural materials more effectively. Can ML and AI be used to completely alter the current discovery-use paradigm?

10.1.2. Dr. Allen Roach: Advanced Materials & Manufacturing for Extreme Environments

Dr. Allen Roach is the Director of the Advanced Materials and Manufacturing Initiative, and Department Manager for the Irradiated Fuels and Materials department at INL. Prior to becoming an INL department manager, Dr. Roach was a Distinguished Staff Scientist and director for the Nuclear Materials Discovery and Qualification initiative (NMDQi). Dr. Roach started his career at Pittsburgh Plate Glass (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 Laboratory 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 a design-build-test perspective 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 the desired component performance in demanding service environments, such as nuclear reactors, hydrogen generation and fuel cells, and kinetic applications. In this presentation, the efforts needed to accelerate innovation in advanced materials and manufacturing for extreme environments will be covered, which 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.

10.1.3. Dr. Isabella van Rooyen: Enabling Manufacturing Technologies Changing the Material Landscape for Extreme Environments

Dr. Isabella J. van Rooyen is a Senior Technical Advisor for the Advanced Material Systems department at Pacific Northwest National Laboratory (PNNL), following 10.5 years at INL as a Distinguished Staff Scientist. Dr. van Rooyen supports the DOE Office of Nuclear Engineering as: (1) the U.S. 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 the Advanced Materials and Manufacturing Technologies (AMMT) program; and (3) previously as the National Technical Director for the Advanced Methods for Manufacturing (AMM) program. Her experience spans the nuclear, aerospace, and automotive industries for high-temperature materials development (e.g., SiC, zircaloy, beryllium, titanium, nickel, tungsten-copper, composite materials, HEAs), nuclear fuels (UO_2, UCO, U_3Si_2, TRISO) and AM. Dr. van Rooyen has more than 60 journal publications, 40 conference contributions, 6 granted patents, and holds a Ph.D. (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 that are operational in material-challenging environments, which 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 has not fully been developed yet. This presentation provides examples of key successes regarding how the full integration of AM 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.

10.2. Characterization Session

10.2.1. Dr. Michael McMurtrey: The Role of Characterization in Intelligent Advanced Manufacturing

Dr. Michael McMurtrey is a Materials Scientist at INL and leads high-temperature alloy projects in the AMMT and Advanced Reactor Technologies (ART) 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 AM. 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 AM, and the Special Committee on Additive Manufacturing for Pressure Retaining Components. Prior to joining INL, Dr. McMurtrey 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. He received his Ph.D. 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 AM in determining the properties (microstructural, mechanical, etc.) resulting from the processing parameters. For intelligent AM, 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 destructive and non-destructive—is used to identify defects, map microstructure, and evaluate the results of the manufacturing process on 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.

10.2.2. Dr. Brian Jaques: Characterization of AM Components and Materials for Extreme Environments

Dr. Brian J. Jaques is an Assistant Professor in the Micron School of Materials Science and Engineering and the director of the Advanced Materials Laboratory (AML) at BSU. He is a CAES affiliate and fellow, holds a joint appointment with INL, and is a licensed Professional Engineer (PE) in Metallurgy and Materials Science in the State of Idaho. Dr. Jaques' research interests are primarily related to AM techniques for materials to be used in 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, AM is revolutionizing the manufacturing industry due to the unparalleled design flexibility of the build process that allows for 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, the 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.

10.2.3. Dr. Triratna Shrestha: Extreme Temperature Material/Part Testing in Commercial Laboratory

Dr. Triratna (Tri) Shrestha is the manager of the Material Analysis Laboratory and Central Coatings Laboratory at Metcut Research Inc. He has worked on testing, qualification, characterization, and quality control of materials for the power generation, aerospace, transportation, and petrochemical industries. He manages the Central Coatings Laboratory for General Electric (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 UI.

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. These 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. The 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 the rejection of good ones. Either scenario is unacceptable. With increased commercialization of parts produced by additive manufacturing, usage of computational alloy design, and expanded reliance on predictive materials property and performance models, it is paramount that standardized materials and product testing and qualification programs are in place. And the parts manufactured via novel techniques have some degree of correlation with traditional manufacturing and processing methods. This presentation delves into the capabilities, challenges, and opportunities at Metcut Research in the extreme temperature testing of metals, polymer matrix composite (PMC), and ceramic matrix composite (CMC). Furthermore, using the design of experiment, Lean, and Six Sigma methodologies will be introduced for intelligent and efficient material/part qualification.

10.2.4. Professor Krishnan S Raja: Design Considerations of Structural Materials for Molten Salt Applications

Professor Krishnan S Raja is a Full Professor of Nuclear Engineering at UI. He has been with UI since 2011. Prior to that, he held research faculty positions at University of Utah, University of Nevada, and Tohoku University in 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 microreactors, 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, a heat transfer fluid in molten salt nuclear reactors, and a 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. The 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.

10.2.5. Professor Yaqiao Wu: Characterization and Fabrication Capabilities for Advanced Manufacturing at MaCS, CAES

Dr. Yaqiao Wu is a Research Professor in the Micron School of Materials Science and Engineering at BSU. He is the Director of the Microscopy and Characterization Suite (MaCS) at CAES. He received his Ph.D. at the Institute of Metal Research, Chinese Academy of Sciences in 2000. Before joining BSU, Dr. Wu worked at Ames Laboratory. 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 the 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/coauthored over 120 papers in peer-reviewed journals.

Characterization and Fabrication Capabilities for AM at MaCS, CAES

Microscopy Characterization Suite (MaCS) is a service center built by CAES and managed by BSU. As a partner facility for 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 particular, to do quantitative analysis—down to the atomic level using scanning transmission electron microscopy, focused ion beam, local electrode atom probe tomography, scanning electron microscopy, x-ray diffraction, etc. MaCS also is equipped with mechanical testing tools (Nanoindenter, microhardness tester, Instron Test Frame), sample fabrication (laser powder bed fusion three-dimensional [3D]-metal printer, spark plasma sintering, ball-mill, etc.) and preparation (glovebox, cutter, polisher, furnace, ion-mill, etc.) tools. This presentation will review the MaCS instruments, current and improved AM capabilities, introduce the new Spectra 300 scanning transmission electron microscope and the Open Additive Panda 3D printer, as well as how to access these instruments for researchers.

10.2.6. Professor Somayeh Pasebani: AM of ODS Alloys: from Spark Plasma Sintering to Additive Manufacturing

Somayeh Pasebani is an associate professor in AM at the School of Mechanical Engineering at Oregon State University (OSU). She has coauthored over 50 peer-reviewed publications and secured numerous grants from prestigious organizations such as NSF, DOE, Office of Naval Research, Air Force Research Laboratory, 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, oxide-dispersion-strengthened (ODS) alloys, multi-material AM (graded alloys), and tailored alloys. Prior to joining OSU, Pasebani worked at Hoganas, contributing to their R&D endeavors. Holding a Ph.D. in Materials Science, her expertise lies in powder metallurgy and metal additive manufacturing.

AM of ODS Alloys: from Spark Plasma Sintering to Additive Manufacturing

In this study, ODS alloys are additively manufactured through laser powder bed fusion (LPBF) and laser directed energy deposition (DED), 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 (REEs). 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.

10.2.7. Professor Somayeh Pasebani: Wire-Powder Laser Directed Energy Deposition of Inconel-GRCop

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 the 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 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.

10.2.8. Professor Haiyan Zhao: Fast and Furious: In Situ Characterization and Testing Under Extreme Temperature Conditions

Dr. Haiyan Zhao is an associate professor in the Chemical and Biological Engineering department and an affiliated faculty member in the Nuclear Engineering program and the Environmental Science Program at UI–Idaho Falls. She is a CAES fellow and Program Director for Chemical Engineering on the UI–Idaho Falls campus. Before she joined UI in 2014, she worked at the Advanced Photon Source (APS) at Argonne National Laboratory (ANL) 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 APS at ANL. She received her Bachelor of Science degree in chemistry from Tianjin University, her M.S. degree in chemical engineering from Tsinghua University, and her 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.

10.2.9. Dr. Boopathy Koombaiah: Microstructural Evolution in Doped High-Entropy Alloys NiCoFeCr-3X (X=Pd/Al/Cu) Under Irradiation

Dr. Boopathy Kombaiah is a senior scientist in the Characterization and Post-Irradiation Examination division at INL. 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 (LDRD), the DOE Office of Nuclear Energy, and the 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 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 the 2015 American Nuclear Society (ANS) Mark Mills award, the 2000 DOE Office of Science Early Career award, and the 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. HEAs are a class of structural materials generally exhibiting good radiation tolerance like limited void swelling and hardening up to relatively medium radiation doses up to 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 concentrations of Pd, Al, or Cu, respectively, on the ion irradiation response of NiCoFeCr alloy will be discussed. The microstructural evolution upon irradiation (i.e., the formation of dislocation networks), radiation-induced segregation and precipitation, and void formation will be discussed in detail.

10.2.10. Dr. Boopathy Koombaiah: Transitional Creep Mechanisms in Zircaloys

Transitional Creep Mechanisms in Zircaloys

Zircaloys have been used as nuclear fuel cladding in LWRs 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, creep-life prediction 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 presentation, 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.

10.3. Processing Session

10.3.1. Dr. Jorgen Rufner: Processing and Manufacturing of Advanced Materials and Systems at INL

Dr. Jorgen Rufner is the AM Group Lead within the Energy, Environment, Science, and Technology (EES&T) directorate at INL. Dr. Rufner 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

AM is no longer a niche discipline and the AM 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 nation's infrastructure. This presentation will showcase various capabilities, challenges, and projects at INL across directorates that focus specifically on material processing and methods being developed to enable AM and materials for extreme environments.

10.3.2. Mr. Luis Nuñez III: In Situ Embedment of Type K Sheathed Thermocouples with Directed Energy Deposition

Luis Nuñez III is a mechanical engineering doctoral candidate at UI and a researcher at INL. He has an M.S. in Mechanical Engineering from Northern Illinois University and his field of research is in additive manufacturing centered on DED with laser engineering net shaping. He has experience and expertise in experimental design, fabrication, in situ data collection, microstructural characterization, and analysis of metals with ML and numerical modeling. His dissertation focuses on process-structure-property analysis, and he currently works on experimental validation and process model development in the Multiphysics Object-Oriented Simulation Environment (MOOSE) Application Library for Advanced Manufacturing UTiliEs (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 HEAs 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 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°C and 900°C. 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 the base, and better junction contact for the sensor; results demonstrate feasibility for DED sensor embedment. Additionally, an overview of ongoing publications regarding AM process variable optimization with in situ monitoring, ML, and numerical modeling is presented.

10.3.3. Dr. Ritesh Sachan: Multi-Principal Element Nanostructures via Nanosecond Laser-Induced Dewetting

Dr. Ritesh Sachan is an assistant professor in the 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 in developing nanosecond laser-based processes to create HEA nanoparticles and understanding the evolution mechanism for nanoparticle formation. Dr. Sachan previously worked at the Army Research Office as an NRC researcher (2016–2018) and at Oak Ridge National Laboratory as a postdoctoral researcher (2013–2016). His efforts have resulted in 90+ journal articles, ~2500 citations, one book chapter, and numerous invited/contributed talks. He received the NSF-CAREER (2023) and ASM-IIM lectureship awards (2019). Earlier, he was awarded the prestigious NRC fellowship by the National Academy of Sciences in 2016 and the TMS Young Leader Professional Award 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. This presentation will 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 SiO_2 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. A review of this laser-based experimental technique also will be presented, as well as examples of resulting robust nanostructures that can have applications in catalysis and optics.

10.3.4. Dr. Matthew Swenson: Effects of Laser Welding on Microstructure and Mechanical Properties of SS and ODS Alloys

Dr. Swenson received his Ph.D. in Materials Science and Engineering at BSU 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 ODS 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 UI affiliation to successfully launch their startup businesses.

Effects of Laser Welding on Microstructure and Mechanical Properties of SS and ODS Alloys

Nano-featured alloys, such as 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 such as 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.

10.3.5. Dr. Yang Cao: Electrohydrodynamic Printing of Electronics

Dr. Yang Cao is an Assistant Professor in the Mechanical and Industrial Engineering Department at Montana State University. He received his Ph.D. degree in Industrial Engineering from North Carolina State University in 2020, his M.S. degree in Mechatronic Engineering from Chongqing University in 2016, and his 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, and EHD printing for in-space electronics manufacturing.

10.4. Modeling Session

10.4.1. Dr. Samrat Choudhury: Machine Learning Guided Design and Manufacturing of Materials

Dr. Samrat Choudhury is an Associate Professor in the Department of Mechanical Engineering at the University of Mississippi (UM). He also serves as an adjunct faculty member in the Nuclear Engineering and Industrial Management department at UI. Prior to joining UM, Dr. Choudhury served as a UI faculty member and a staff scientist at 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 ML.

Machine Learning Guided Design and Manufacturing of Materials

Traditional computational investigation of processing-chemistry-structure-property linkage in materials science involves the usage of a highly complex set of interactions spanning over multiple length and time scales. Alternatively, this presentation is focused on the application of ML tools to guide simulations at multiple length scales in order to augment the capabilities of traditional computational tools. It will be shown that an ML-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 ML tools to determine the processing parameters needed for a targeted performance during EHD printing, which is an additive manufacturing approach, also will be discussed.

10.4.2. Dr. Dilpuneet Aidhy: Integrated Data Science and Computational Materials Science to Tackle Challenges of Complex Materials

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 ML 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*, and *Frontiers in Materials*. He received his Ph.D. in Materials Science and Engineering from the University of Florida in 2009.

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

As the boundaries of materials for applications in ever-increasing extreme environments are pushed forward, 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, traditional computational tools, that have been highly successful, now need to be integrated with sophisticated methods. A fitting example are high-entropy materials 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 the Materials Science and Engineering group at Clemson University, ML algorithms are used in conjunction with physics-based principles and databases to unveil key structure-property correlations that are otherwise unintuitive in complex materials. In this presentation, Dr. Aidhy will discuss a new data science-integrated computational materials science approach named the PRedict properties from Existing Databases In Complex materials Territory (PREDICT), whereby properties in complex alloys are predicted by learning from simpler alloys. He also will also discuss how charge-density can be a used as a universal descriptor for properties' prediction and how database frameworks are being developed.

10.4.1. Dr. Kiyo T Fujimoto: Additive Manufacturing of Nuclear Instrumentation

Dr. Kiyo T. Fujimoto holds a B.S. in Chemistry and recently earned her Ph.D. from the Materials Science and Engineering Department at BSU. 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 INL and as the Laboratory Lead for the Advanced Manufacturing Laboratory at CAES. 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 (DWT) 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 methods such as 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.

10.4.2. Professor Katie D. Li-Oakey: Linking Materials and Processes Design with Molecular Interactions to Enable On-demand High Volume Manufacturing

Dr. Li-Oakey received her Ph.D. at the University of Colorado, Boulder, with a focus on modeling and experimental studies of polymeric membrane morphology. Before she joined the faculty in the Department of Chemical Engineering at the University of Wyoming, Dr. Li-Oakey worked in companies ranging from startups to Fortune 100. Her research program at the University of Wyoming 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 University of Wyoming Chemical Engineering Outstanding Teacher of the Year, National Aeronautics and Space Administration (NASA) EPSCoR Space Grant Faculty Award, and the 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 CO_2 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 intellectual property (IP) portfolio.

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

As AI is combined with 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, the 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 laboratory-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 recently have been developed to molecularly map separation performance of a commercial COF, TpPa-1, and a carboxylated COF (C-COF). Specifically, the following factors have been characterized using these atomistic models—layer stacking, effective versus 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 the time and length scale mismatch between atomistic modeling and 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 sodium hydroxide (NaOH) and hydrogen chloride (HCl) to organic solvents, such as dimethylformamide (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.

10.4.3. Professor Lars Kothoff: AI for Materials Science

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

AI for Materials Science

Professor Kothoff 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. He will then illustrate a few applications in Materials Science, including results.

10.4.4. Dr. Michael Tonks: AI for Materials Science

Dr. Michael Tonks is the Associate Chair of the Materials Science and Engineering Department at the University of Florida and is the Alumni Professor of Materials Science and Engineering and Nuclear Engineering. Prior to joining the University of Florida 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 Nuclear Energy Advanced Modeling and Simulation (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. ML tools are being applied to create surrogate models that can predict microstructure evolution and structure-property relationships orders of magnitude faster than the mesoscale simulations. Researchers are also using a combination of simulation and experimental data to train interpretable models that can help to discover critical evolution mechanisms.

10.4.5. Dr. Min Xian: Connecting Dots Between Materials Microstructures and Properties Evolution in Extreme Environments Using Modern AI

Dr. Min Xian is an associate professor in the Department of Computer Science at UI. He received his Ph.D. in Computer Science from Utah State University 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 UI, an affiliate of CAES, and a participating faculty member 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 AI, pattern recognition, ML, deep neural networks, adversarial learning, biomedical data analytics, material informatics, and digital image understanding. Dr. Xian is a guest editor at Healthcare, a session chair for the Association for the Advancement of Artificial Intelligence (AAAI) conference, and is an active reviewer for many prestigious international journals, such as *Pattern Recognition*, *IEEE Trans. Medical Imaging*, *Medical Image Analysis*, *Medical Physics*, *Scientific Reports*, *Neurocomputing*, and *AI in Medicine*.

Connecting Dots Between Materials Microstructures and Properties Evolution in Extreme Environments Using Modern AI

Modern AI approaches, such as deep learning, have been proven to be effective and efficient in exploring complex and large 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.

10.4.6. Dr. Leslie Kerby: A Machine Learning Engineer's Toolkit

Dr. Kerby is an Associate Professor of Computer Science at ISU, and an affiliate faculty member 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 ML applied to nuclear reactor operation and monitoring, scientific ML applied to Li-ion battery performance and quantum chemistry, and the security of ML systems as applied in nuclear engineering. Other projects involving applications of data science, ML, and AI, and computational science are welcome.

A Machine Learning Engineer's Toolkit

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

10.5. Workforce Session

10.5.1. Mr. John Jenks: The Future of Workforce: Where are the Workers and How Can We Get Them Back in the Workforce?

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 2022. In this capacity, John identifies policies, strategies, and opportunities to achieve sustained and vibrant economic growth for the State of Wyoming. Prior to this role, he served as the 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 completed three executive education courses successfully at the Harvard Kennedy School of Government, earning his Executive Certificate in Public Leadership in 2024. He graduated from the University of Mississippi Sally McDonnell Barksdale Honors College and Trent Lott Public Policy Leadership School with a degree in Public Policy Leadership and Economics and earned a M.A. 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 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. One of the primary barriers efforts are being undertaken to address is workforce development. The work has broken out into four sub-work streams including: (1) out of state worker attraction, (2) justice-involved individuals, (3) childcare, and (4) higher education alignment. These sects of the labor force have been identified as significant labor pools being underutilized in Wyoming and work has begun to address the shortcomings in these groups with an eye towards the potential returns on investments. 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.

10.5.2. Mr. Wyatt Petersen: Forging Futures: Community and Collaboration in Nuclear Workforce Development

Wyatt Petersen is the Director of the Department of Energy at the Shoshone-Bannock Tribes and a proud member of the Tribes. With a M.S. degree in geographic information systems (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, Mr. Petersen 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.

10.5.3. Dr. Mitch Meyer: Manufacturing Challenges for Nuclear Materials in Advanced Reactors

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 National Nuclear Security Administration (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 NSUF program, Technical Lead for DOE's LWR Advanced Fuel program, Director of the Nuclear Fuels and Materials and Advanced Characterization and PIE Divisions at INL, 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.

10.5.4. Professor Amin Mirkouei: Deepen the Integration of Diverse Interdisciplinary Professionals in Intermountain West Region with the Cyberinfrastructure Research Ecosystem

Professor Mirkouei is an Associate Professor at UI, a Forbes sustainability contributor, a licensed PE, and an experienced technologist with 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, he is a major advisor in Industrial Technology, Technology Management, Mechanical Engineering, Biological Engineering, Computer Science, and Environmental Science programs at UI. He has served as a federal and state agency panelist (NSF and USDA), an editorial board member, a conference and symposium organizer (ASME and IISE), and a journal and conference reviewer. He also has 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, which encompasses 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 cyber-infrastructure (CI) advancements driven by high-performance computing (HPC) systems, 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.

10.6. Poster Session

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

Kathryn Richardson and Amin Mirkouei

Worldwide demand for 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 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 the potential to be applicable at the commercial level in Idaho.

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

Rebecca Brown, Amin Mirkouei, and Ethan Struhs

REEs 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 U.S. is heavily reliant on REE imports, mainly from China. Traditional extraction of REEs 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 *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.

10.6.3. 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 presentation 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 as compared with 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 (FCCI). Lastly, the deep learning model is versatile and applicable to the microstructure segmentation of similar materials.

10.6.4. 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

FCCI is one of the main factors that could limit the fuel performance of metallic fuels at high burnups. In this presentation, 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 the 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.

10.6.5. 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]
[1]Nuclear Engineering and Industrial Management, University of Idaho, Idaho Falls, ID 83402, [2]GenNext Materials & Technologies, LLC, Reno, NV 89502

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 rang to 120 nm were oxidized in air at 200°C at different times. 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.

10.6.6. Electron Energy Loss Spectroscopy (EELS) Characterization of a High Burnup U-Zr Metallic Fuel

Arnold Pradhan, Tiankai Yao, and Fei Xu

FCCI is one of the main factors that could limit the fuel performance of metallic fuels at high burnups. In this presentation, 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 the 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 the formation of different crystallographic phases with the 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.

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

Nusrat Farheen and Marco Schoen, ISU

A model-based reinforcement learning (MBRL) allows intelligent control development from a series of dynamic experiences without exhaustively interacting with the target plant. This enables the wider application of reinforcement-learning, including AM. 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.

10.6.8. Data-driven Controller Design Strategies Applied to AM

Golam Gause Jaman and Marco Schoen
Measurement and Control Engineering, ISU, 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 proportional integral derivative (PID) and linear-quadratic-Gaussian (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 AM. 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.

10.6.9. 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 BWX Technologies, Inc. (BWXT), evaluating deploying microreactors in the state, interest in nuclear development has never been higher. Because of this, a new student ANS chapter 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 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.

11. 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 ISU on behalf of the CAES Consortium. Complaints will be managed in accordance with ISU policy [20], with notification to CAES institutional representatives for INL, BSU, and UI.

Emergency resources will be provided by ISU Public Safety, with notification of CAES institutional representatives for INL, BSU, and UI. ISU Public Safety [21] 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 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 by online form [22], or the ISU Title IX Coordinator Ian Parker can be contacted directly by email at *ianparker@isu.edu*.

12. 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 [23] and the Idaho Association for the Education of Young Children [24]. It is funded by the Idaho Department of Health and Welfare [25] and the Child Care and Development Block Grant.

Idaho STARS [26] provides a list of child care providers in Idaho Falls [27].

UI 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.

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