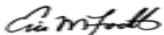




UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

December 13, 2023

MEMORANDUM TO: Steve Ruffin, Chief
Materials Engineering Branch
Division of Engineering
Office of Nuclear Regulatory Research

FROM: Eric Focht  Signed by Focht, Eric
Materials Engineering Branch
Division of Engineering
Office of Nuclear Regulatory Research

SUBJECT: SUMMARY OF THE OCTOBER 24-26, 2023, NRC WORKSHOP
ON ADVANCED MANUFACTURING TECHNOLOGIES FOR
NUCLEAR APPLICATIONS

The U.S. Nuclear Regulatory Commission (NRC) staff from the Office of Nuclear Regulatory Research (RES) and the Office of Nuclear Reactor Regulation (NRR) held a workshop on October 24-26, 2023, on advanced manufacturing technologies (AMTs) for nuclear applications. The purpose of this workshop was to discuss ongoing activities related to AMTs including nuclear and non-nuclear industry implementation plans, qualification and certification approaches, research, and codes and standards activities.

The public meeting summary, workshop agenda, and list of workshop participants are enclosed. The workshop presentations are in the Agencywide Documents Access and Management System (ADAMS) under ADAMS package accession number ML23324A231.

Enclosures:
As stated

CONTACT: Eric Focht, RES/DE/MEB
301-415-2094

Enclosure 1
U.S. Nuclear Regulatory Commission Public Meeting Summary

Title: 2023 NRC Workshop on Advanced Manufacturing Technologies for Nuclear Applications

Meeting Identifier: 20231129

Date of Meeting: October 24-26, 2023

Location: NRC One White Flint North, TWFN Auditorium (HQ-TWFN-P2AUD)
11555 Rockville Pike
Rockville, MD

Type of Meeting: Information Meeting with Question and Answer Session.

Purpose of the Meeting: The purpose of this workshop was to update the staff and stakeholders on (1) practical experience and plans for implementing advanced manufacturing technology (AMT) for nuclear and non-nuclear components, (2) AMT process/part qualification and certification approaches, including the incorporation of modeling and simulation, and (3) the latest developments in codes and standards pertaining to AMT adoption.

General Details: This workshop was conducted as a hybrid meeting over three days with about 50 in-person attendees and approximately 340 online attendees representing domestic and international research, academic, industry, and regulatory organizations. The workshop was organized into four sessions, which were chaired by NRC staff members:

Session 1: Implementation of AMTs in Nuclear and Non-Nuclear Applications

Session 2: Qualification and Certification

Session 3: Performance Characteristics

Session 4: Code and Standards

Session Summaries:

Session 1:

- Presentations were given by NRC, Rolls Royce, Sheffield Forgemasters, U.S. Navy, Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), Nuclear Energy Institute (NEI), Electric Power Research Institute (EPRI), Framatome, Lincoln Electric, Siemens Energy, and Westinghouse.
- The topics presented included experience with implementing powder metallurgy with hot isostatic pressing (PM-HIP) to manufacture nuclear components, implementing AMTs in the U.S. Navy fleet, electron beam welding, AMTs for nuclear fuel components, AMTs role in making spare parts on demand, AMTs role in the nuclear energy sector, and plans to develop a framework for qualifying AMT components and to conduct demonstrations for inserting AMT components in nuclear applications.

Session 2:

- Presentations were given by Pacific Northwest National Laboratory (PNNL), National Institute of Standards and Technology (NIST), ORNL, Siemens Energy, Barnes Global, Battelle, American Bureau of Shipbuilding, ANL, Pratt & Whitney, and the University of Texas San Antonio.
- The topics presented included qualification and certification approaches for materials, processes, and equipment, accelerated qualification, and modeling and simulation. Rapid high throughput testing and NDE were also covered.

Session 3:

- Presentations were given by Naval Nuclear Laboratory, ANL, Materials Testing Institute (U. of Stuttgart), Idaho National Laboratory (INL), and Rolls Royce.
- The topics presented included testing approaches and results for PM-HIP nickel-base alloys, laser power bed fusion (LPBF) of 316L stainless steel for high temperature applications, irradiation and corrosion testing of LPBF-manufactured materials, performance of LPBF 316L stainless steel in light water reactor relevant environments, data generation and fatigue design curve development for LPBF 316LN stainless steel, and an overview of a new project to perform a critical assessment of the safety of AMTs for international SMR concepts.

Session 4:

- Presentations were given by ASTM International, America Makes and GBR Consulting.
- The topics covered included overviews of activities related to the challenges and opportunities associated with additive manufacturing materials data, the current state of additively manufactured nickel-based super alloys and a future look at AMTs within the casting and forging industries, and ASME criteria for additive manufacturing.

Key Takeaways:**Session 1:**

- Several sectors are implementing AMT components to meet the needs of their stakeholders/customers, which satisfies a business case:
 - Improve parts availability to improve readiness
 - Broaden the supply chain
 - Manage component obsolescence
 - Optimize cost and performance
- Initial applications have been low risk to gather manufacturing and operating experience.
- Safety-significant applications are proceeding cautiously.
- It is important for designers to be proactive and intimately involved with fabrication process, especially as safety-significance increases.
- Significant opportunities exist for supporting both existing and future platforms.

Session 2:

- Multiple qualification pathways:
 - Traditional testing based
 - Traditional coupled with better process controls and monitoring

- Accelerated, with modeling and simulation (M&S) support (integrated computational materials engineering (ICME))
- Initial qualification and certification (Q&C) is largely following the traditional path used for conventional materials for adoption with Codes (e.g., ASME), material property databases (e.g., MMPDS) and applications (e.g., first article testing).
- M&S provides the opportunity to both identify critical tests for optimizing/demonstrating additive manufacturing (AM) systems while simultaneously accelerating Q&C:
 - Building trust in M&S approaches is needed to fully realize their benefits
- There may be opportunities to leverage Q&C efforts developed (or being developed) within other industries.

Session 3:

- Many studies are focusing on understanding and optimizing as-built performance to maximum AM value:
 - Anisotropy considerations are a stronger consideration within this approach
- Build variability needs to be addressed at the outset and identifying critical process variables is essential to assessing differences among machines and operators.
- Relevant performance metrics can be equivalent or better than conventional wrought materials:
 - Important to understand and address causal factors for differences
- M&S provides a needed tool to most efficiently understand environmental effects.

Session 4:

- Many standards already exist that support AM Qualification:
 - Powder quality and handling
 - Heat treatment
 - Testing and characterization
 - Post-fabrication inspection
- Augmented or new standards are needed to provide overall quality assurance:
 - Identification and control of essential process variables
 - Implementation of in-process monitoring
- Incentivize knowledge and data sharing among practitioners.
- Codification processes are incorporating AM but processes are lengthy by design and due to uncertainties:
 - Integrated design, surveillance, and inspection strategies, coupled with targeted key testing can be used to more quickly implement AM systems

Enclosure 2
Workshop Agenda

Tuesday Oct. 24 (Day 1)		
Time	Topic	Speaker
8:00	Welcome/Intro	NRC
8:10	Workshop Overview	NRC
8:30	NRC Overview	NRC
SESSION 1: IMPLEMENTATION OF AMTs IN NUCLEAR AND NON-NUCLEAR APPLICATIONS		
Session Coordinators: AM: Robert Tregoning PM: Eric Focht		
8:50	Rolls-Royce's Experience of Applying the PM-HIP Process to the Manufacture of Nuclear Plant Components	Rolls Royce (John Sulley)
9:20	Advancing Nuclear Component Manufacturing: Harnessing Local Vacuum Electron Beam Welding	Sheffield Forgemasters (Jesus Talamantes-Silva)
9:50	Break	
10:00	Implementation and Qualification of AMT Components in Support of the U.S. Navy Fleet	NAVSEA (Justin Rettaliata)
10:40	Overview of DOE Advance Materials & Manufacturing Technologies Program	DOE (Meimei Li)
11:10	Discussion	All
11:30	Lunch (on your own)	
1:00	Demonstrations Within the AMMT Program on Insertion of Advanced Manufactured Components in Applications	ORNL (Ryan Dehoff)
1:30	Securing the Future of the Nuclear Industry	NEI (Hilary Lane)
1:50	Break	
2:00	Advancements in Electron Beam Welding for Heavy Section Components	EPRI (David Gandy)
2:30	Overview of Framatome's Activities Supporting Additive Manufactured Nuclear Fuel Components	Framatome (Christopher Wiltz)
3:00	Current use of wire-DED materials	Lincoln Electric (Teresa Melfi)
3:30	Break	
3:40	“Spare Parts On Demand” by Additive Manufacturing	Siemens Energy (Ramesh Subramanian)
4:10	AM Activities at Westinghouse	Westinghouse (David Huegel)
4:40	Discussion	All
5:00	Adjourn	

Wednesday Oct. 25 (Day 2)		
Time	Topic	Speaker
8:00	Welcome	NRC
SESSION 2: QUALIFICATION AND CERTIFICATION		
Session Coordinators : AM: Amy Hull PM: Austin Young		

8:10	Accelerated Printability Feasibility and Prioritization of Additively Manufactured Structural Materials	PNNL (Isabella Van Rooyan)
8:40	Standards Considerations Towards the In-Process Quality Assurance of AM Parts	NIST (Paul Witherell)
9:10	Break	
9:20	Qualifying Laser Powder Bed Fusion 316H for Use With ASME Section III, Division 5	ANL (Mark Messner)
9:50	High Throughput, Rapid and Automated NDE for Optimizing Additive Manufacturing in Nuclear Applications	ORNL (Amir Ziabari)
10:20	High Throughput Measurement of Surface Roughness and Tensile Properties, Using Standardized AM Test Coupons	Siemens Energy (Ramesh Subramanian)
10:50	Discussion	All
11:10	Lunch (on your own)	
12:40	Data-Driven Framework for Qualifying Laser Powder Bed Fusion Additively Manufactured Parts Using Part-Specific Digital Twins	ORNL (Vincent Paquit or alternate)
1:10	Aerospace Framework for Certification and Qualification for Advanced Manufacturing Technologies with Examples in Additive Manufacturing Using 316L Laser Powder Bed Fusion	Barnes Global (Kevin Slattery)
1:40	Break	
1:50	MMPDS and Additive Metals	Battelle (Doug Hall)
2:20	Qualification and Certification for Additive Manufacturing Supported by Model-Based Approaches	ABS (Dongchun "Mary" Qiao)
2:50	Accelerating the Qualification of AM Materials Through Modeling and Simulation	ANL (Mark Messner)
3:20	Break	
3:30	Application of Model-Based Material Definitions	Pratt & Whitney (David Furrer)
4:00	Uncertainty Quantification of the Metal Laser Powder Bed Fusion Additive Manufacturing via the Hypercomplex-based Finite Element Method	UT San Antonio (Arturo Montoya)
4:30	Discussion	All
4:50	Adjourn	

Thursday Oct. 26 (Day 3)		
Time	Topic	Speaker
8:00	Welcome	NRC
SESSION 3: PERFORMANCE CHARACTERISTICS Session Coordinator: Eric Focht		
8:10	Testing Approach and Initial Results on PM-HIP Nickel Base Alloys	Fluor Marine Systems (Kevin Fisher)
8:40	Laser Powder Bed Fusion of 316H Stainless Steel for High-Temperature Nuclear Applications	ANL (Xuan Zhang)
9:10	Break	

9:20	Critical Assessment of the Safety of Advanced Manufacturing Processes for Internationally Relevant SMR Concepts: A Project Overview	MPA (Martin Werz)*
9:50	Irradiation And Corrosion Testing of Laser Powder Bed Fusion-Manufactured Materials in the Advanced Manufacturing and Materials Technologies Program	INL (Andrea Jokisaari)
10:20	Performance of Laser Additively-Manufactured SS 316L in LWR-relevant Environments	ANL (Bogdan Alexandreanu)
10:50	Break	
11:00	Generation of a Fatigue Design Curve Suitable for Use on Additive Manufacture Nuclear Plant Components Produced From 316LN Stainless Steel Using Laser Powder Bed Fusion	Rolls Royce (Bill Press)*
11:30	Discussion	All
11:50	Lunch (on your own)	
SESSION 4: CODES AND STANDARDS Session Coordinator: Mekonen Bayssie		
1:30	AM Materials Data – Challenges and Opportunities	ASTM (Richard Huff)
2:00	The Current State of Additively Manufactured Ni-Based Superalloys and a Future Look at AMT's within the Casting and Forging Industries	America Makes (John Martin)
2:30	ASME Criteria for Additive Manufacturing	GBR Consulting (George Rawls)
3:00	Discussion	All
3:20	Break	
3:30	Wrap-up & Conclusions	
4:00	Adjourn – end of workshop	

Enclosure 3
List of Workshop Participants

Name (last, first)	Organization
Allison, Amanda	UK Atomic Energy Authority
Abu-Eid, Boby	NRC
Addo, Fredrick Kwaku	Ghana Atomic Energy Commission
Adjei, Kyereme, Serwaa	Nuclear Regulatory Authority
Al Jaber, Hussain	Nawah Energy Company
Alekos, Bobby	NRC
Alexandreanu, Bogdan	ANL
Allik, Brian	NRC
Alvarado, Lydiana	NRC
Amin, Ankir	Nawah Energy Company
Anchondo-Lopez, Isaac	NRC
Anderson, J	NA
Andersson, David	LANL
Attanasio, Steven	NNL
Audrain, Meg	NRC
Barr, Christopher	DOE Office of Nuclear Energy
Bass, Joseph	NRC
Batra, Chirayu	Terra Praxis
Bayssie, Mekonen	NRC
Bechtel, William	NA
Bell, Edward	Holtec Govt Services
Benson, Michael	NRC
Bettes, Brian	NRC
Bjurman, Martin	Studsvik
Bloom, Steven	NRC
Boninger, Ron	Swift Current, LLC
Boruk, Reena	NRC
Bosley, Michael	Westinghouse
Bouffoux, Ryan A.	INL
Bowker, Brian	NRC

Name (last, first)	Organization
Bozga, John	NRC
Brand, Javier	NRC
Bream, Jeff	NRC
Bu, Jichao	Shanghai Institute of Applied Physics
Buford, Angie	NRC
Burton, Mat	NRC
Cairns-Gallimore, Dirk	DOE Office of Nuclear Energy
Carinne, Shannon	Battelle
Carlson, Jesse	NRC
Cataldo, Paul	NRC
Chandran, Nachiketh	NRC
Chang, Litao	Shanghai Institute of Applied Physics
Chen, Yiren	ANL
Cho, Sungwoo	DOOSAN Enerbility, South Korea
Christensen, Jason	INL
Christopher, Omoni	KEPCO
Clayton, Kelly	NRC
Cleary, William T	Westinghouse
Cohn, Brian	NRC
Colaccino, Joseph	NRC
Collins, Jay	NRC
Colon Fuentes, Luis	NRC
Colon Gonzale, Francheska	NRC
Como, Jen	DOJ/FBI
Condron, Thomas	US Navy
Constantinescu, Liliana	Technical Standards & Safety Authority
Contreras, Jonathan	NRC
Cooper, Paula	NRC
Couret, Ivonne	NRC

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Crabbe, Marcus	Sheffield Forgemasters Engineering LTD
Cumblidge, Stephen	NRC
Cunningham, Daniel	Lucideon
Daniel, Jason	NRC
Dave (Guest)	NA
Davis, Robert	NRC
Dehoff, Ryan	ORNL
Deleanu, Gabriela	Ontario Power generation
Delisle, Dale	NRC
Desai, Binoy	NRC
Dhakal, Sandeep	Boise State University
Diane, Mory	NA
Dijamco, David	NRC
DiLoreto, Edward,	Westinghouse
Donmez, Alkan	NIST
Dornke, Matthew	NRC
Douglas, Jared	Centrus Energy
Downey, Steve	NRC
Drake, James	NRC
Dudek, Michael	X-energy
Dunn, Darrell	NRC
Eckes, Scott	NA
Erling, Warren	NRC
Escobar Veras, Sam	NRC
Eve, Elise	NRC
Fabritiis, Nick	Constellation Energy
Fairbanks, Carolyn	NRC
Faraone, Kevin	ORNL
Feliz Adorno, Nestor	NRC
Feng, Shaw	NIST
Fernandez, Edison	NRC
Finch, Shannon	Westinghouse
Fisher, Kevin	NNL
Fitzgerald, Michael	NRC

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Floyd, Nik	NRC
Focht, Eric	NRC
Fong, CJ	NRC
Francis, Johns	Nawah Energy Company
Franzen, Michael	TAES (Toshiba American Energy Systems Corporation)
Fu, Bart	NRC
Furrer, David	Pratt & Whitney
Gandy, Dave	EPRI
Gardocki, Stanley	NRC
Gavula, James	NRC
Gee, Jess	GE Vernova
Geers, Christine	Chalmers Institute of Technology
Gibbons, Duncan	NIST (International Assoc)
Goldsmith, Jason	Westinghouse
Golumbfksie, Bill	NSWC Carderock
Gordon, Matthew	NRC
Goss, Sandra	DOD NSA
Goyer, Dennis	NNL
Graham, Jacqueline	Constellation Energy
Graves, Todd	Centrus Energy
Gray, Mel	NRC
Grewal, Harpreet	GE-H Nuclear Energy Americas & GE-H SMR Technologies
Griman, Brian	NRC
Grinsteinner, Todd James	LLNL
Gud, Menz	NRC Germany, te 234 Brlin
Guest	NA
Guieb, Angela	NRC
Gurdziel, Tom	Member of the public
Hall, Doug	Pratt & Whitney
Hannifin, Bridgette	Terrapower
Hansing, Nicholas	NRC
Harisis, Becki	Nebraska DHHS

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Harris, Brian	NRC
Harris, Doug	ORNL
Havrilak, Cody	DOE HQ
Haywood, Emma	NRC
Heath, Rick	Framatome
Heidrich, Brenden	INL
Heras, Marisa G	tecnatom
Hills, David	NRC
Hiser, Allen	formerly NRC, retired
Hiser, Matt	NRC
Hobbs, Alec	NRC
Homiack, Matthew	NRC
Honcharik, John	NRC
Hovanec, Susan	NSWC Carderock
Howard, Arlette	NRC
Huang, Jason	NRC
Huegel, David	Westinghouse
Huff, Richard	ASTM
Hull, Amy	NRC
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Iyengar, Raj	NRC
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Jacques, Brian	formerly NEI -retired?
Jayroe, Peter	NRC
Jedlan, Stepan	Czech Technical University in Prague, Faculty of Nuclear and Physical Engineering
Jenkins, Joel	NRC
Jensen, Paul	Arizona Public Service
Jerry (guest)	NA
jiang, Xiaodong	NA
Jiang, Yan	Shanghai University
Johnson, Andy	NRC
Jokisaari, Andrea	INL
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Jue, Tracy	California Dept of Public Health (CDPH)

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Kim, Hongdeok	KEPRI
Klein, Paul	NRC
Kobayashi, Tatsuro	TEPCO
Kochmanski, Andrzej	Urzad Dozoru Technicznego. Centrala
Koenigsfeld, David	PWROG
Korinchak, Nate	NSWC Carderock
Korzeniowski, Patrick	NSWC Carderock
Kulp, Jeff	NRC
Kumari, Geeta	ORNL
Lane, Hillary	NEI
Lane, John	NRC
Law, Yiu	NRC
Lawler, Steven	Frazer-Nash
Le, Tuan	NRC
Lee, Saya	Pennsylvania State University
Levine, Lyle	NIST
Levitus, Steven	NRC
Li, MeiMei	ANL
Lin, Bruce	NRC
Lisova, Dana	NA
Lizardi-Barreto, Jonathan	NRC
Magnuson, Eric	NRC
Magyar, Michael	NRC
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Mangan, Kevin	NRC

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Massey, Caleb	ORNL
Matrachisia, John	NRC
McClay, Samuel	NRC
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McCormick, Kevin	NRC
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McMurtrey, Michael D.	INL
Meadows, Tenisha	NRC
Meany, Joseph	ARPA-E (Booz Allen Hamilton)
Medoff, James	NRC
Meher, Subhashish	PNNL
Mejia, James	NRC
Melendez-Colon, Daneira	NRC
Melfi, Teresa	Lincoln Electric
Mentzer, Nate	NRC
Messner, Mark	ANL
Mills, Lloyd	Greenberry Industrial
Min, Seung	NRC
Mirmohammad, Hadi	Westinghouse
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Moyer, Carol	NRC
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Neumeyer, Gayla M.	University of Missouri
Nove, Carol	NRC

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Palmer, Eric	NRC
Paquit, Vincent	ORNL
Park, Dong	NRC
Park, Joon	NRC
Parker, Cory	NRC
Parsi, Arash	Westinghouse
Patel, Raju	NRC
Peterson, Alyse	NYSERDA
Philipps, Caleb	University of Missouri
Pica, Paul	NNL-Fluor Marine Propulsion
Poehler, Jeff	NRC
Ponko, Anthony	NRC
Pottle, David. W.	Lucideon
Press, Bill	Rolls-Royce
Prokofiev, Iouri	formerly NRC, retired
Puttscher, Pat	NRC
Qiao, Dongchun	American Bureau of Shipping
Raleigh, Deann	NA
Rawls, George	GBR Consulting
Ray, Devendra	NRC
Raynaud, Patrick	NRC
Reed, Wendy	NRC
Regener, Benjamin	Nuclear Power Plant Leibstadt AG
Reichelt, Eric	NRC
Rettaliata, Justin	M Civ USN COMNAVSEASYS CO M DC
Rettew, Andrew	NA
Rezai, Ali	NRC
Rivera Ortiz, Joel	NRC
Roach, Allen	INL

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Rudland, David	NRC
Ruffin, Steve	NRC
Rydlova, Jolana	State Office for Nuclear Safety, (SONS)
Sampson, Michelle	NRC
Sanchez Santiago, Elba	NRC
Sandra (guest)	NA
Savara, Aditya	NRC
Saya, Lee	NRC
Scarborough, Thomas	NRC
Scates, Erica	NSWC Carderock
Schoppy, Joseph	NRC
Scime, Luke	ORNL
Scott (guest)	NA
Semple, Jenny	NSWC Carderock
Sengupta, Abhijit	DOE Nuclear Safety
Sevecek, Martin	Czech Technical University
Sewing, Luke	Framatome
SG	NA
Shaikh, Atif	NRC
Shannon, Carinne	Battelle
Shoulders, Jacky	Constellation Energy
Sida, Karen	NRC
Sinclair, LaToya	NRC
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Smith, John	BWX Technologies
Smith, Laura	NRC
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Subramanian, Ramesh	Siemens Energy

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Sutton, Benjamin	EPRI
T., Janet	NA
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Taller, Stephen	ORNL
Talukdar, Priyam	NRC
Taylor, Nicholas	NRC
Terry, Leslie	NRC
Thompson, Scott	University of Missouri
Thompson, Spencer	EOS North America
Tokey, Jason	NRC
Tony (guest)	NA
Tran, Anthony	NRC
Travis, Adam	Westinghouse
Tregoning, Rob	NRC
Tsao, John	NRC
Turilin, Andrey	NRC
Twarek, Cameron	NNL
Tyree, Christopher	NRC
Ulmer, Christopher	NRC
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Valentino, Anita	WV House of Delegates
van Rooyen, Isabella J.	PNNL
Vasquez, Jose	NRC
Vener, Luisa	NNL
Verderber, Kimberly	NYSERDA
Vollmer, James	TerraPower
Walker, Shakur	NRC
Wallace, Jay	NRC
Webb, Tom	NNL
Wei, Xuejun	Canadian Nuclear Safety Commission
	Manufacturing Materials Testing Institute (MPA)
Werz, Martin	

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Wiltz, Christopher	Framatome
Wise, John	NRC
Witherell, Paul	NIST
Wolf, Carolyn	NRC
Xu, Peng	INL
Yee, On	NRC
Yoder, Matthew	NRC
Yoo, Mark	NRC
Young, Austin	NRC
Young, Garrett	Holtec Govt Services
Young, George A.	Kairos Power
Yu, Zefeng	Westinghouse
Yutaka, Kadoya	Embassy of Japan
Zhang, Xi-Ying	American Bureau of Shipping
Zhang, Xuan	ANL
Ziabari, Amir	ORNL

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