U.S.NRC
United States Nuclear Regulatory Commission
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NRC WORKSHOP ON ADVANCED MANUFACTURING TECHNOLOGIES FOR NUCLEAR APPLICATIONS

Part I – Workshop Summary

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Research Information Letter
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Disclaimer

EXECUTIVE SUMMARY

Advanced manufacturing technologies (AMTs) are defined by the U.S. Nuclear Regulatory Commission (NRC) as those techniques and material processing methods that have not been traditionally used or formally standardized/codified by the nuclear industry. In June 2020, the NRC released Revision 1 to the Agency Action Plan for AMTs (AMT AP) (Agencywide Documents Access and Management System Accession No. ML19333B980 (package)). The AMT AP is a strategic plan that responds to the rapid pace of developments in respective AMTs and industry implementation plans. The NRC's AMT activities are driven by industry interest in implementing specific AMTs and ensuring that the NRC staff are prepared to review potential AMT applications efficiently and effectively. The AMTs currently being evaluated include laser powder bed fusion, directed energy deposition, electron beam welding, powder metallurgy-hot isostatic pressing, and cold spray.

During December 7–10, 2020, the NRC hosted the "Workshop on Advanced Manufacturing Technologies for Nuclear Applications." This public workshop was intended to broadly address potential industry use of AMTs, including the replacement/repair of components in operating nuclear power plants and in the initial construction of small modular and advanced reactors. The primary objectives of the workshop were to do the following:

- Discuss ongoing activities related to AMTs, including nuclear industry implementation plans, codes and standards activities, research findings, and regulatory approaches in other industries.
- Inform the public of the NRC's activities and approach to approving the use of AMTs.
- Determine, with input from nuclear industry stakeholders and other technical organizations, areas where the NRC should focus to ensure the safe implementation of AMTs.

To support the objectives of the workshop, the NRC staff organized the following seven sessions:

- Session 1: Practical Experience Related to Implementing AMTs
- Session 2: Plans and Priorities for AMT Implementation in Commercial Nuclear Applications
- Session 3: Performance Characteristics of AMT-Fabricated Components
- Session 4: Approaches to Component Qualification and Aging Management
- Session 5: Codes and Standards Activities and Developments
- Session 6: Regulatory Approaches for AMTs
- Session 7: Research and Development of AMTs

These sessions were intended to broadly cover the range of AMT topics, emphasizing practical experience with and the application of AMTs. The staff solicited presentations from a range of national and international organizations, including vendors, utilities, the Electric Power Research

Institute, the Nuclear Energy Institute, the U.S. Department of Defense, the U.S. Department of Energy (including Department laboratories), the National Institute of Standards and Technology, the National Aeronautics and Space Administration, regulators (other U.S. Government and international), and universities. About 280 individuals from 80 organizations in 10 countries attended the workshop.

The workshop provided an opportunity to share information among U.S. and international counterparts on approaches to using AMTs. Participants agreed that, to support near- and medium-term use of AMTs in nuclear applications, industry and researchers should focus on developing data to support the qualification of additive manufacturing materials. These data can be used to support the development of codes and standards and provide a technical basis to support implementation. Initial use of AMTs in non- or low-safety-significant components may provide a path for their use in components of higher safety significance by building experience and confidence in the performance and properties of AMT components in representative environments. Combining this approach with innovative plans for inservice inspections and postservice destructive evaluation can further improve confidence in the performance of AMTs.

CONTENTS

ABBREVIATIONS AND ACRONYMS

Term	Description
3D	three dimensional
ADAMS	Agencywide Documents Access and Management System
AM	additive manufacturing
AMC	Additive Manufacturing Consortium
AMT	advanced manufacturing technologies
AMT AP	Advanced Manufacturing Technologies Action Plan
ANL	Argonne National Laboratory
ARL	Army Research Laboratory
ASME	American Society of Mechanical Engineers
ASTM	ASTM International (formerly American Society for Testing and Materials)
AWS	American Welding Society
CFR	*Code of Federal Regulations*
CS	cold spray
DED	directed energy deposition
DED-AM	directed energy deposition-additive manufacturing
DOE	U.S. Department of Energy
DOE-NE	DOE Office of Nuclear Energy
EBW	electron beam welding
ENGIE	French multinational electric utility company
EPRI	Electric Power Research Institute
EU	European Union
EWI	formerly known as Edison Welding Institute
FAA	U.S. Federal Aviation Administration
FDA	U.S. Food and Drug Administration
GE	General Electric Company
HIP	hot isostatic pressing
INL	Idaho National Laboratory
LPBF	laser powder bed fusion
LWR	light-water reactor
NASA	U.S. National Aeronautics and Space Administration
NEI	Nuclear Energy Institute
NIST	U.S. National Institute of Standards and Technology
NNL	U.S. Naval Nuclear Laboratory
NPP	nuclear power plant
NRC	U.S. Nuclear Regulatory Commission
NRL	U.S. Naval Research Laboratory
NUCOBAM	NUclear COmponents Based on Additive Manufacturing
ORNL	Oak Ridge National Laboratory
PM-HIP	powder metallurgy-hot isostatic pressing
PNNL	Pacific Northwest National Laboratory

Term	Description
SCC	stress-corrosion cracking
SLM	selective laser melting
SRNL	Savannah River National Laboratory
STUK	Finnish Radiation and Nuclear Safety Authority
TCR	Transformational Challenge Reactor
VTT	“Valtion Teknillinen Tutkimuskeskus” (English translation “Finnish Technical Research Centre”)

1. Introduction

This research information letter summarizes the presentations and discussions during the "Workshop on Advanced Manufacturing Technologies for Nuclear Applications," organized by the U.S. Nuclear Regulatory Commission (NRC). This public workshop took place virtually December 7–10, 2020, using a combination of WebEx and Microsoft Teams due to the ongoing Coronavirus Disease 2019 (COVID-19) pandemic.

1.1 Background on Advanced Manufacturing Technologies

The NRC's mission, in part, is to license and regulate the Nation's civilian use of radioactive materials in the United States. Advanced manufacturing technologies (AMTs) include techniques and material processing methods that have not traditionally been used in the U.S. nuclear industry or that have yet to be formally standardized by the nuclear industry (e.g., through nuclear codes and standards, or through other processes resulting in NRC approval or endorsement). In response to significant industry interest in the use of AMTs for commercial nuclear applications, the NRC has taken several steps in recent years to prepare the NRC staff to review industry submittals and regulate activities in this area.

In June 2020, the NRC released Revision 1 to the Agency Action Plan for AMTs (AMT AP) (Agencywide Documents Access and Management System (ADAMS) Accession No. ML19333B980). The AMT AP is intended to be a strategic plan that responds to the rapid pace of developments in respective AMTs and industry implementation plans. Revision 1 identified completed activities from the initial AMT AP (ADAMS Accession No. ML19029B355) and defined new and ongoing activities to better focus and organize NRC efforts related to AMTs. The NRC's activities on AMTs are driven by industry interest in implementing specific AMTs to ensure the NRC staff is prepared to review potential AMT applications efficiently and effectively. These AMTs include laser powder bed fusion (LPBF), direct energy deposition (DED), electron beam welding (EBW), powder metallurgy-hot isostatic pressing (PM-HIP), and cold spray (CS). In the future, the NRC intends to address additional specific AMTs as needed, based on industry interest and plans for implementation.

1.2 Workshop Motivation and Objectives

One activity identified in Revision 1 of the AMT AP was to organize and host a public workshop on AMTs. In November 2017, the NRC hosted a similar workshop, entitled "Additive Manufacturing for Reactor Materials and Components." A broad range of organizations participated, including those from the nuclear industry, nonnuclear industry, regulators, and international organizations. The NRC documented the workshop summary in NUREG/CP-0310, "Proceedings of the Public Meeting on Additive Manufacturing for Reactor Materials and Components," issued July 2019. This workshop provided valuable information and insights into industry interests and plans as well as the maturity and level of readiness for the inclusion of AMTs in nuclear applications.

Given the rapid pace of AMT development, the NRC determined that another workshop would be timely to receive updates on industry plans and technological developments. The staff intended the June 2020 workshop to broadly address potential industry use of AMTs, including replacement/repair of components in operating nuclear power plants and in the initial construction of small modular and advanced reactors. The NRC must be prepared to regulate and respond to industry submittals efficiently and effectively and potentially approve the use of AMTs in applications related to both operating and future plants.

The primary objectives of the workshop were to do the following:

- Discuss ongoing activities related to AMTs, including nuclear industry implementation plans, codes and standards activities, research findings, and regulatory approaches in other industries.
- Inform the public of the NRC's activities and approach to approving the use of AMTs.
- Determine, with input from nuclear industry stakeholders and other technical organizations, areas where the NRC should focus to ensure the safe implementation of AMTs.

1.3 Workshop Organization and Participants

To support the objectives of the workshop, NRC staff members organized the following session topics based on their awareness of the AMT landscape and insights from discussions with external stakeholders:

- Session 1: Practical Experience Related to Implementing AMTs
- Session 2: Plans and Priorities for AMT Implementation in Commercial Nuclear Applications
- Session 3: Performance Characteristics of AMT-Fabricated Components
- Session 4: Approaches to Component Qualification and Aging Management
- Session 5: Codes and Standards Activities and Developments
- Session 6: Regulatory Approaches for AMTs
- Session 7: Research and Development of AMTs

These sessions were intended to broadly cover the range of AMT topics, with an emphasis on practical experience and application of AMTs. The staff solicited presentations from a range of national and international organizations, including vendors, utilities, the Electric Power Research Institute (EPRI), the Nuclear Energy Institute (NEI), the U.S. Department of Defense, the U.S. Department of Energy (DOE) (including DOE laboratories), the National Institute of Standards and Technology (NIST), the National Aeronautics and Space Administration (NASA), regulatory bodies (i.e., other U.S. Government and international regulatory bodies), and universities. Table 1-1 lists the organizations that presented during the workshop, and Table 1-2 presents the final workshop agenda.

Table 1-3 indicates the presenters, their company or agency, and the general topic(s) covered by their presentation during the workshop.

Approximately 280 individuals from 80 organizations in 10 countries attended the workshop. Appendix A contains a list of participants. Attendees interacted with presenters by posing questions through the WebEx chat or by accessing a separate Microsoft Teams link following each presentation that was created to support further discussions. Chapter 2 of this report provides summaries of each presentation and each session. Appendix B contains the presentation slides for the entire workshop.

In addition to the full listing of slides in Appendix B, presentation files are publicly available in ADAMS at the following accession numbers:

- Session 1: ML20339A649
- Session 2: ML20342A032
- Session 3: ML20342A371
- Session 4: ML20344A010
- Session 5: ML20344A111
- Session 6: ML20344A421
- Session 7 (and additional slides from Sessions 3, 4, and 6): ML20345A155
- additional slides from Sessions 3 and 5: ML20351A159

Table 1-1. Participating Organizations

Organization	Country	Link
America Makes	US	https://www.americamakes.us/
ANL	US	https://www.anl.gov/
ARL	US	https://www.arl.army.mil/
ASTM International	US	https://www.astm.org/
ENGIE	France	https://www.engie.com/en
EPRI	US	https://www.epri.com/
EWI	US	https://ewi.org/
Exelon	US	https://www.exeloncorp.com/
FAA	US	https://www.faa.gov/
FDA	US	https://www.fda.gov/home
Framatome	France	https://www.framatome.com/EN/home-57/index.html
GE	US	https://www.ge.com/
INL	US	https://inl.gov/
Kairos Power	US	https://kairospower.com/
NASA	US	https://www.nasa.gov/
NEI	US	https://www.nei.org/
NIST	US	https://www.nist.gov/
NNL	US	https://navalnuclearlab.energy.gov/
NRC	US	https://www.nrc.gov/
NRL	US	https://www.nrl.navy.mil/
ORNL	US	https://www.ornl.gov/
PNNL	US	https://www.pnnl.gov/

Organization	Country	Link
Rolls-Royce	United Kingdom	https://www.rolls-royce.com/
SRNL	US	https://srnl.doe.gov/
Siemens	Germany	https://www.siemens.com/
STUK	Finland	https://www.stuk.fi/
UES Inc	US	https://www.ues.com/
University of Wisconsin	US	https://www.wisconsin.edu/
U.S. Naval Academy	US	https://www.usna.edu/homepage.php
U.S. Navy	US	https://www.navy.mil/
VRC Metal Systems	US	https://vrcmetalsystems.com/
VTT	Finland	https://www.vttresearch.com/en
Westinghouse	US	https://westinghouse.com/

Table 1-2. Workshop Agenda

Day 1 (December 7, 2020)		
Time	**Presentation Topic**	**Organization—Presenter**
8:00 AM	Opening of Workshop	NRC—R. Furstenau
8:15 AM	Q&A/Discussion	NRC—M. Hiser
Session 1: Practical Experience Related to Implementing AMTs		
8:30 AM	NRC Public Workshop on Advanced Manufacturing Technologies for Nuclear Applications	NRC—M. Hiser & M. Yoo
8:45 AM	Siemens Gas and Power—Overview of Additive Manufacturing, Benefits and Challenges Industrial Approach for AM	Siemens—P. Advovic
9:15 AM	BREAK	
9:25 AM	Experience with AM and Related Nuclear Applications	ENGIE—S. Nardone & A. Claes
10:10 AM	Rolls-Royce's Introduction of HIP Nuclear Components	Rolls-Royce—J. Sulley
11:00 AM	BREAK	
11:10 AM	Cold Spray Technology and Experience in Army Applications	ARL—M. Siopis
11:40 AM	Additive Manufacturing Efforts in Support of U.S. Navy Fleet	U.S. Navy—J. Rettaliata
12:10 PM	Q&A/Discussion	
12:30 PM	LUNCH	
Session 2: Plans and Priorities for AMT Implementation in Commercial Nuclear Applications		
1:15 PM	Industry Perspectives on AMTs	NEI—H. Lane
1:45 PM	Vision of AMT Use in the Nuclear Industry	EPRI—M. Albert
2:15 PM	BREAK	
2:25 PM	Utility Perspective on Implementing AMTs in LWRs	Exelon—L. Friant
3:00 PM	Westinghouse Advanced Manufacturing Development and Implementation Efforts	Westinghouse—C. Armstrong
3:40 PM	BREAK	
4:10 PM	Potential Applications, Challenges and Progress of Framatome Additive Manufacturing Application	Framatome—C. Wiltz
4:40 PM	AMT with Advanced Materials in Nuclear Operations	PNNL—R. Oelrich

Day 2 (December 8, 2020)		
Time	**Presentation Topic**	**Organization—Presenter**
8:00 AM	Introductory Remarks	NRC—R. Taylor
Session 3: Performance Characteristics of AMT-Fabricated Components		
8:10 AM	Rolls-Royce’s Introduction of AM Nuclear Components	Rolls-Royce—D. Poole & W. Press
8:55 AM	Fatigue and Mechanical Properties of Laser Power Bed Fusion 316L Stainless Steel	NNL—S. Attanasio
9:25 AM	BREAK	
9:40 AM	Impact of Powder Supply Variation on Microstructure and Properties in Additive Manufactured Alloy 718	NASA—C. Kantzos
10:10 AM	Elucidating the Effect of Feedstock Powder Spheroidization Treatment on Selective Laser Sintered Additively Manufactured 316L Stainless Steel	U.S. Naval Academy—R. Santucci & E. Getto
10:40 AM	BREAK	
10:50 AM	Linking 3D Microstructural Analysis of Additive Manufactured 316L to Performance and Properties	NRL—D. Rowenhorst
11:20 AM	The Effects of Post-Processing on Mechanical Properties and Corrosion Behavior of AM 316L Stainless Steel	NRL—R. Fonda
11:50 AM	LUNCH	
12:40 PM	Process Validation for AM at the FDA	FDA—D. Porter
1:10 PM	Technical Assessments of AMTs	NRC—M. Audrain
1:40 PM	Q&A/Discussion	
2:10 PM	BREAK	
2:20 PM	PM-HIP and Electron Beam Welding Development for Nuclear Applications	EPRI—D. Gandy
2:50 PM	Cold Spray Process Details and Nuclear Applications	PNNL—K. Ross and J. Lareau
3:20 PM	BREAK	
3:30 PM	Cold Spray Mitigation and Repair for Nuclear Applications	VRC Metal Systems—K. Johnson
4:00 PM	Laser Glazing of Cold Sprayed Coatings for the Mitigation of Stress Corrosion Cracking in LWR Applications	ANL & UES, Inc.—B. Alexandrenau & A.K. Rai
4:30 PM	Q&A/Discussion	

Day 3 (December 9, 2020)		
Time	**Presentation Topic**	**Organization—Presenter**
8:00 AM	Introductory Remarks	NRC—L. Lund
Session 4: Approaches to Component Qualification and Aging Management		
8:10 AM	AM Thimble Plugging Device/Advanced Debris Filtering Bottom Nozzle Implementation Process	Westinghouse—D. Huegel
8:40 AM	Approach for 316L LPBF Code Case and Data Package	Westinghouse & EPRI—C. Armstrong & D. Gandy
9:10 AM	BREAK	
9:20 AM	Certification of the First Powder Bed Fusion Component in a US Naval Nuclear Propulsion Plant	NNL—T. White
10:00 AM	On the Development of Fatigue and Damage Tolerance Framework for Metal AM Parts	FAA—M. Gorelik
10:30 AM	BREAK	
10:40 AM	Accelerating Quality Certification of Critical Components with Additive Manufacturing	ORNL—V. Paquit
11:10 AM	Inservice Inspection and Considerations for AMT Components	PNNL—J. Harrison
11:40 AM	Q&A/Discussion	
12:00 PM	LUNCH	
Session 5: Codes and Standards Activities and Developments		
12:45 PM	Overview of America Makes Activities	America Makes—B. Ribic
1:10 PM	Standards Landscape for Additive Manufacturing	NIST—S. Moylan
1:40 PM	BREAK	
1:50 PM	ASME Criteria for Powder Bed Fusion Additive Manufacturing	SRNL—G. Rawls
2:20 PM	Approach to Codifying New Manufacturing Methods	GE & EPRI—B. Frew & D. Gandy
2:50 PM	BREAK	
3:00 PM	Recent Advancements on ASTM Additive Manufacturing Research and Standardization	ASTM International—M. Seifi
3:30 PM	NASA Standard for Use of AM in Crewed Spaceflight Applications (NASA-STD-6030)	NASA—D. Wells
4:00 PM	Development of AWS D20.1 Standard	NNL—J. Coughlin
4:30 PM	Q&A/Discussion	

Day 4 (December 10, 2020)		
Time	**Presentation Topic**	**Organization—Presenter**
8:00 AM	Introductory Remarks	NRC—A. Bradford
Session 6: Regulatory Approaches for AMTs		
8:10 AM	NRC Regulatory Approach for AMTs	NRC—C. Fairbanks
8:35 AM	STUK Regulatory Approach for AMTs	STUK—P. Valikangas
9:05 AM	BREAK	
9:15 AM	FDA Regulatory Approach for AMTs	FDA—M. Di Prima
9:45 AM	Regulatory Considerations for AM and "Lessons Learned" for Structural Alloys	FAA—M. Gorelik
10:15 AM	Q&A/Discussion	
10:40 AM	BREAK	
Session 7: Research and Development of AMTs		
10:50 AM	Quality Control Tools for Metal AM and EU NUCOBAM Project	VTT—P. Puukko
11:20 AM	DOE Transformational Challenge Reactor Program	ORNL—K. Terrani
11:50 AM	LUNCH	
12:40 PM	DOE-NE Advanced Manufacturing Methods Program Overview	INL—I. van Rooyen
1:10 PM	Rapid Qualification of New Materials Using Modeling and Simulation	ANL—M. Messner
1:40 PM	BREAK	
1:50 PM	Cold Spray Development for Coatings	U. of Wisconsin & Kairos Power—K. Sridharan & G. Young
2:20 PM	In-Situ Process Measurements for Monitoring, Control, and Simulation of AM	NIST—B. Lane
2:50 PM	BREAK	
3:00 PM	Additive Manufacturing Consortium	EWI—M. Barfoot
3:30 PM	Q&A/Discussion	
4:00 PM	Workshop Wrap-Up and Conclusion	

Table 1-3. Focus Areas for AMTs by Presentation

Organization (Speaker)	LPBF	DED	CS	PM-HIP	EBW	Other AMTs	Nuclear Applications	Other Non-NPP activity	Irradiation Testing & Effects	Degradation in AMT components	AMT Qualification	Codes & Standards
Siemens (Advovic)	■							■				
ENGIE (Nardone & Claes)	■	■	■	■	■	■	■				■	
Rolls-Royce (Sulley)				■	■		■					
ARL (Siopis)			■					■		■		
U.S. Navy (Rettaliata)							■	■			■	
NEI (Lane)	■	■	■	■	■		■				■	■
EPRI (Albert)	■	■	■	■	■		■				■	■
Exelon (Friant)	■	■	■	■	■	■	■		■	■	■	■
Westinghouse (Armstrong)	■						■		■	■	■	■
Framatome (Wiltz)							■		■	■	■	■
PNNL (Oelrich)	■	■					■		■	■		
Rolls-Royce (Poole & Press)				■			■					
NNL (Attanasio)	■								■	■	■	■
NASA (Kantzos)								■				
USNA (Santucci & Getto)	■							■			■	
NRL (Rowenhorst)	■							■		■	■	■
NRL (Fonda)	■							■				
FDA (Porter)								■			■	
NRC (Audrain)	■	■	■	■	■		■				■	■
EPRI (Gandy)	■			■	■		■				■	
PNNL (Ross & Lareau)			■				■					
VRC Metal Systems (Johnson)			■				■	■		■		
ANL & UES, Inc. (Alexandrenau & Rai)			■			■	■			■		
Westinghouse (Huegel)	■						■		■	■	■	■

Organization (Speaker)	LPBF	DED	CS	PM-HIP	EBW	Other AMTs	Nuclear Applications	Other Non-NPP activity	Irradiation Testing & Effects	Degradation in AMT components	AMT Qualification	Codes & Standards
Westinghouse (Armstrong & Gandy)	■						■					■
NNL (White)	■							■	■	■	■	■
FAA (Gorelik)								■		■	■	■
ORNL (Paquit)	■	■					■		■	■	■	
PNNL (Harrison)							■				■	
America Makes (Ribic)								■				
NIST (Moylan)	■	■					■				■	■
SRNL (Rawls)	■								■	■	■	■
GE & EPRI (Frew & Gandy)	■			■	■		■	■	■	■	■	■
ASTM International (Seifi)							■	■		■		■
NASA (Wells)								■			■	
NNL (Coughlin)	■	■					■				■	■
NRC (Fairbanks)	■	■	■	■	■		■				■	■
STUK (Valikangas)	■	■	■	■	■							■
FDA (Di Prima)								■			■	
FAA (Gorelik)								■		■	■	■
VTT (Puukko)	■	■						■			■	
ORNL (Terrani)	■	■					■		■	■	■	
INL (van Rooyen)	■	■	■	■	■		■		■	■		
ANL (Messner)											■	
U. Wisconsin & Kairos (Sridharan & Young)			■									
NIST (Lane)	■										■	■
EWI (Barfoot)	■	■								■	■	■

2. Summary of Presentations

DAY 1 PRESENTATIONS

2.1 Session 1: Practical Experience Related to Implementing AMTs

2.1.1 Opening—NRC Public Workshop on Advanced Manufacturing Technologies for Nuclear Applications (Presentation B1—ML20336A004)
Presenters: *Matthew Hiser and Mark Yoo, NRC*

This presentation introduced the workshop by covering AMTs, the AMT AP, and the workshop organization. First, the presentation provided a high-level background on AMTs, including describing the five primary technologies of interest to the NRC and potential applications of each. Next, the presenters discussed the AMT AP, which includes technical and regulatory preparedness projects, as well as communication and knowledge management activities, including this workshop. Finally, the presentation gave an overview of the workshop, including motivation, approach, sessions, and logistics.

2.1.2 Siemens Gas and Power—Overview of Additive Manufacturing, Benefits and Challenges Industrial Approach for AM (Presentation B2—ML20339A650)
Presenter: *Pajazit Advovic, Siemens*

This presentation gave a synopsis of Siemens Energy's use of additive manufacturing (AM) and the implementation of additively manufactured components into the company's turbines. Siemens' early adoption of selective laser melting (SLM) and its experience developing the SLM technology and scaling its production for industrial use were detailed. This presentation included a review of SLM benefits and challenges as seen by Siemens, including an overview of Siemens' actions to prove SLM capabilities and lead AM development. The presentation concluded with a case study of a three-dimensional (3D) printed clapper and clapper holders in use at a Slovenian nuclear power plant and Siemens' perspective on the benefits this provides the nuclear community.

2.1.3 Experience with AM and Related Nuclear Applications (Presentation B3—ML20339A651)
Presenters: *Steve Nardone and Arne Claes, ENGIE*

ENGIE presented its experience with AM, and the development of its ENGIE AM Expertise Centre in late 2015, including ENGIE's actions to encourage industrialization, certify designs, improve nondestructive testing methods, and develop a greater understanding of gaps and potential solutions. It also included a discussion on Nuclear Components Based on Additive Manufacturing (NUCOBAM) Horizon 2020 Nuclear Fission and Radiation Protection Research, a project ENGIE is involved in that lasts until September 2024 to develop LPBF as a viable manufacturing method for the nuclear industry and to demonstrate its capabilities. The presentation concluded with an analysis of ENGIE's efforts to address gaps in quality assurance, reverse engineering, and certification.

2.1.4 Rolls-Royce's Introduction of HIP Nuclear Components (Presentation B4—ML20339A652)
Presenter: *John Sulley, Rolls-Royce*

This presentation covered Rolls-Royce's historical use of PM-HIP, the technique's potential use for nuclear components, and a specific example examining low-alloy steel pressure vessels.

This included the benefits of PM-HIP and Rolls-Royce's perspective on a pathway to introduce PM-HIP components into nuclear plants. The presenter also discussed an analysis of key gaps and potential risks in the process, including powder quality, can failure, cracking during quenching, and scaling limitations. Finally, the presenter explained progress in EBW and cited journal articles that contain further information.

2.1.5 Cold Spray Technology and Experience in Army Applications (Presentation B5—ML20339A653)
Presenter: *Matthew Siopis, Army Research Laboratory*

This presentation covered the Army Research Laboratory's (ARL's) development of CS and described the considerations, modeling, and certain research and development aspects investigated. The presentation described the U.S. Army's development of wear and impact protection coatings, their benefits, and their current use. The presentation concluded with a case study of CS application in Bradley turret mounts and a Letterkenny ball screw actuator, where CS enabled previously expensive repairs to be more cost effective and improve performance.

2.1.6 Additive Manufacturing Efforts in Support of the U.S. Navy Fleet (Presentation B6—ML20339A654)
Presenter: *Justin Rettaliata, U.S. Navy*

This presentation introduced the U.S. Navy's objectives for AM. It included an overview of technical documents the U.S. Navy has published to expand knowledge of AM. The presentation highlighted technical data packages, logistics integration, and the Naval Additive Manufacturing Part Identification Exercise, which are key steps to establishing integrated AM components in vessels and facilitating advanced manufacturing on board vessels.

Summary of Session 1

The topics presented include experience with AM component fabrication for nuclear applications, PM-HIP for nuclear applications, CS experience for U.S. Army applications, and AM experience for U.S. Navy applications. As additional experience on implementing AMTs accrues, those lessons learned and data should be used to justify and increase confidence in further applications of AMTs. AMTs used in other industries or applications may offer insights to benefit their development and use in nuclear applications.

Key takeaways:

- Experience with AM components in non- or low-safety-significant nuclear and nonnuclear applications is being generated and growing.
- Use of PM-HIP with EBW for larger nuclear components looks promising but requires larger hot isostatic pressing (HIP) and EBW fabrication capabilities.
- CS is being used increasingly for U.S. Army applications, particularly for high-wear applications.

Recommended next steps:

- As additional experience on implementing AMTs accrues, use those lessons learned and data to justify and increase confidence in further applications of AMTs.

- Leverage insights and knowledge from AMTs used in other industries or applications to benefit their development and use in nuclear applications.

2.2 Session 2: Plans and Priorities for AMT Implementation in Commercial Nuclear Applications

2.2.1 Industry Perspectives on AMTs (Presentation B7—ML20342A037)
Presenter: *Hilary Lane, NEI*

This presentation covered the NEI's position in the nuclear energy industry and its view on how AMTs are seen as a significant prospect. The presentation introduced the NEI's Advanced Manufacturing Task Force, which is analyzing AMTs of interest and assessing deployments of these technologies. It described AMTs for nuclear components, including PM-HIP, directed energy deposition AM (DED-AM), LPBF, and EBW.

2.2.2 Vision of AMT Use in the Nuclear Industry (Presentation B8—ML20342A035)
Presenter: *Marc Albert, EPRI*

This presentation outlined EPRI roadmaps for the development of AMTs and AMs. Roadmaps covered suggested AMTs for nuclear components, including PM-HIP, DED-AM, LPBF, advanced cladding processes, and EBW. Additionally, the presentation discussed EPRI's activities addressing AM to support spare and replacement parts.

2.2.3 Utility Perspective on Implementing AMTs in LWRs (Presentation B9—ML20342A036)
Presenter: *Lee Friant, Exelon*

This presentation covered Exelon's view on AM, indicating the utility's perspective on the three most compelling benefits: cost savings, obsolete part replacement, and component improvement. In addition to potential benefits, the presentation discussed the more significant barriers, including the lack of familiarity with AMTs, lack of standards, and the absence of a regulatory framework. The presentation concluded with Exelon's main takeaways for utilities, including the setting of realistic timelines and challenges with first-time AMT applications.

2.2.4 Westinghouse Advanced Manufacturing Development and Implementation Efforts (Presentation B10—ML20342A034)
Presenter: *Clinton Armstrong, Westinghouse*

This presentation covered the objectives of Westinghouse's Advanced Manufacturing Program and multiple AM projects, including the company's thimble plugging device, fuel debris filtering bottom nozzle, and fuel spacer grid. Additionally, the presentation discussed the additional efforts for innovation projects and replacement part identification that are geared towards developing AM processes for nuclear components. The presentation concluded with a brief overview of HIP and advanced welding development efforts.

2.2.5 Potential Applications, Challenges and Progress of Framatome Additive Manufacturing Application (Presentation B11—ML20342A033)
Presenter: *Christopher Wiltz, Framatome*

This presentation provided an overview of AMTs from Framatome's perspective and comments about how the industry sees AMTs being integrated into the nuclear industry. The presentation then focused on Framatome's nuclear fuel-related activities and progress, including a case study on Framatome's channel fastener manufactured with 316L stainless steel using the LPBF technique. Framatome's channel fastener has been designed, evaluated, and will be installed at the Browns Ferry Nuclear Power Plant, Unit 2, where it will be in operation for three cycles and then analyzed. The presentation concluded with Framatome's perspective on the path forward for AM applications.

2.2.6 AMT with Advanced Materials in Nuclear Operations (Presentation B12—ML20342A038)
Presenter: *Robert Oelrich, PNNL*

This presentation began with the state of advanced manufacturing in the nuclear industry and the current efforts being made to test AMT components in operating light-water reactors (LWRs). This was followed by how AMTs can enable innovation in the field of advanced materials, allowing for more rapid grading, use of nontraditional materials in current reactors, and the development of components for new advanced reactors. Additionally, the presentation discussed the number of variables that require control and understanding in AM. It included further comments on how AM continues to evolve and how this may impact licensing processes and standards. The presentation concluded with a case study on Pacific Northwest National Laboratory's (PNNL's) coating/cladding developments related to accident tolerant fuel.

Summary of Session 2

This session covered the identification of candidate components and uses of AMT, AMT parts in service or soon to be in service, uses of AMTs in fuel hardware components, and AMT development and qualification processes.

Key takeaways:

- AMT technologies evolve quickly, outpacing the qualification and licensing processes.
- More collaboration would benefit industry, the DOE, national laboratories, and the NRC.
- Operating experience from other industries should be used for nuclear applications.

Recommended next steps:

- Continue to develop standards and increase collaboration among all nuclear stakeholders as well as other industries.
- Focus collaboration to increase knowledge and confidence in the industry for AMTs.
- Share lessons learned from experience with AMTs.
- Seek input and feedback from nonnuclear regulators and industry organizations.
- Consider performing shorter (i.e., 1-day) workshops on specific AMTs.

DAY 2 PRESENTATIONS

2.3 Session 3: Performance Characteristics of AMT-Fabricated Components

2.3.1 Rolls-Royce's Introduction of AM Nuclear Components (Presentation B13—ML20351A160)
Presenters: *David Poole and William Press, Rolls-Royce*

This presentation covered Rolls-Royce's implementation strategy, a case study on its primary circuit manual globe valve, and its strategies going forward. The presenters discussed their development of the manual globe valve, made from 316 stainless steel through LPBF, which is a safety-critical, high-production-volume component located on a pressure boundary. The presenters evaluated the strategy used to justify design, centering on a multifaceted system that thoroughly details requirements for sampling trials, testing, failure analysis, and inspection.

2.3.2 Fatigue and Mechanical Properties of Laser-Powder Bed Fusion 316L Stainless Steel (Presentation B14—ML20342A373)
Presenter: *Steven Attanasio, NNL*

This presentation covered the U.S. Naval Nuclear Laboratory's (NNL's) interests in metal AM and the potential benefits that naval nuclear operations could experience by using AMTs. The presentation focused on the microstructures of 316L stainless steel builds manufactured using AM and HIP. It included the results of thorough testing and review, comparing the differences between the standards for 316L stainless steel and the AM builds. Results summarized at the end of the presentation indicate that AM components can meet the current standards despite typical negative attributes, such as orientation effects.

2.3.3 Impact of Powder Supply Variation on Microstructure and Properties in Additive Manufactured Alloy 718 (Presentation B15—ML20342A374)
Presenter: *Christopher Kantzos, NASA*

This presentation covered NASA's view on AM and its motivations to use AM in its operations. It focused on the NASA project to understand feedstock effects on SLM Alloy 718 using 16 different powder stocks from 8 different suppliers. The aim of this effort was to understand how manufacturing environments affected the final powder and its buildability, and also to document how reuse of these powders differed. The presentation reviewed the extensive tests and results, and each section concluded with significant findings and potential points for the standardization of feedstock powders.

2.3.4 Elucidating the Effect of Feedstock Powder Spheroidization Treatment on Selective Laser Sintered Additively Manufactured 316L Stainless Steel (Presentation B16—ML20351A161)
Presenters: *Raymond Santucci and Elizabeth Getto, U.S. Naval Academy*

This presentation covered the U.S. Naval Academy's efforts to better understand powder morphology and its effects on AM builds. Plasma-treated powders were theorized to result in better builds by improving spheroidization of the powder, thereby improving layer recoating, powder packing, and final properties. Testing two different powders, untreated and plasma treated, showed that there are significant differences in build properties, especially in porosity.

2.3.5 Linking 3D Microstructural Analysis of Additive Manufactured 316L to Performance and Properties (Presentation B17—ML20342A375)
Presenter: *David Rowenhorst, NRL*

This presentation covered the U.S. Naval Research Laboratory's (NRL's) efforts to catalog AM microstructures of 316L stainless steel using NRL's robotic serial sectioning system. Significant data were provided related to the serial sectioning process. The presenter gave a further overview of pore data and grain formations reproduced in 3D. The presentation concluded that the production of these 3D structures is useful for modeling and simulation and will be an essential factor in modeling verification. The modeling of 316L stainless steel showed that the grains of 316L stainless steel made using LPBF are larger and more complex than those of typically manufactured 316L stainless steel.

2.3.6 The Effects of Post-Processing on Mechanical Properties and Corrosion Behavior of AM 316L Stainless Steels (Presentation B18—ML20342A381)
Presenter: *Richard Fonda, NRL*

This presentation covered the results of indepth NRL tests to determine microstructure, corrosion behavior, and mechanical properties of AM 316L stainless steel in as-built and postprocessed conditions. One significant finding was that 316L AM stainless steel tends not to exhibit passivity, especially at the surface. The passivity improves up until roughly 380 micrometers depth. The loss of passivity is attributed to significant porosity in the as-built condition. Comparatively, the postprocessed builds exhibited changes in microhardness and cell structures. Significantly, HIP processed builds reduced porosity by about two-thirds and effectively increased passivity in these samples. Overall, all AM structures exceeded 316L stainless steel specifications for yield strength, ultimate tensile strength, and elongation.

2.3.7 Process Validation for AM at the FDA (Presentation B19—ML20342A376)
Presenter: *Daniel Porter, FDA*

From the perspective of the U.S. Food and Drug Administration (FDA), submissions using AM have increased, dominated by LPBF technologies. This presentation demonstrated the FDA's method to validate samples using the U.S. FDA AM guidance document. Significant factors that the FDA requires to validate samples include position and orientation to build plate, feedstock control, and postprocessing parameters. In conclusion, the presentation offered a perspective on how nuclear regulation could be more flexible and inclusive.

2.3.8 Technical Assessments of AMTs (Presentation B20—ML20339A385)
Presenter: *Margaret Audrain, NRC*

This presentation covered the NRC's current technical perspective on LPBF and the NRC AMT Action Plan. It discussed a ranking of significant factors and gaps present in the LPBF process, including process control and management, witness specimens, residual stress, powder quality, and postprocessing. It provided further ranking for specific issues related to 316L stainless steel, including differences in mechanical properties, weldability, and long-term effects. The presentation concluded with gaps in codes and standards, including criteria for powder recycling and sieving, heterogeneity, witness specimens, and weld integrity.

2.3.9 PM-HIP and Electron Beam Welding Development for Nuclear Applications (Presentation B21 – ML20342A377)
Presenter: *David Gandy, EPRI*

This presentation covered EPRI's projects involving PM-HIP and EBW and how these projects benefit EPRI's larger Small Modular Reactor Advanced Manufacturing Project. The presentation focused on the process of building the typically complex and expensively forged reactor head, which was completely manufactured using PM-HIP and EBW. Citing this specific case study, EPRI presented the benefits of these two techniques, including the ease of inspection and shorter lead times of PM-HIP and the rapid and repeatable electron beam welds. The presentation also gave an overview of EPRI's efforts to establish the capability for EBW in the United States with the modular in-chamber EBW apparatus used for the project and its potential application to current reactors.

2.3.10 Cold Spray Process Details and Nuclear Applications (Presentation B22—ML20342A378)
Presenters: *Ken Ross and Jack Lareau, PNNL*

This presentation summarized the CS process and reasons why this could be useful to the nuclear industry, including a detailed mechanistic description of CS application and important factors that affect the quality of a CS application, including high pressure, helium usage, surface preparation, powder processing, and material choice. It covered case studies to describe the quantitative benefits currently seen in CS applications, including in chlorine-induced stress-corrosion cracking (SCC) repairs and Westinghouse LWR fuel cladding. The presentation further described the potential to use CS for monitoring purposes and online tracking of preexisting cracks since nickel CS coatings are magnetostrictive. The presentation concluded with comments on code considerations, regulatory implications, and technical justifications.

2.3.11 Cold Spray Mitigation and Repair for Nuclear Applications (Presentation B23—ML20342A379)
Presenter: *Kyle Johnson, VRC Metal Systems*

This presentation covered VRC Metal Systems' use of CS to mitigate seawater corrosion issues in military and industrial applications and how its experience in this area can inform the handling of nuclear corrosion issues with CS applications. The presenter cited CS corrosion mitigation techniques as a solution due to the ability to apply CS at low temperatures (as low as 400 degrees Celsius), its high density and high adherence, its crack retardation properties, and its rapid application. The presentation showed the company's efforts to develop a highly mobile unit to apply CS to tight spaces and described a successful case study on a commercial vertical canister system, where application is uniform and efficient using robots.

2.3.12 Laser Glazing of Cold Sprayed Coatings for the Mitigation of Stress Corrosion Cracking in LWR Applications (Presentation B24—ML20345A163)
Presenters: *Bogdan Alexandrenau and A.K. Rai, ANL and UES, Inc.*

This presentation covered work by Argonne National Laboratory (ANL) and UES to mitigate SCC of Alloy 600 and Alloy 182 weldment with a hybrid CS and laser glazing process. Samples of SCC-prone and SCC-resistant material are coated using CS and then treated with laser glazing to improve corrosion protection and repair cracks in the substrate. Results found that laser glazing improved adhesion in samples where the surface was initially grit blasted; however, adhesion strength was nearly the same in samples that were not laser glazed. The study concluded that, under optimal conditions, the hybrid treatment was able to seal to the crack and reduced crack growth rate in Alloy 600 and Alloy 182.

Summary of Session 3

This session covered a wide range of topics, including implementation and justification strategies for identifying and undertaking candidate nuclear applications, effects of processing and postprocessing variables on performance/qualification, regulatory assessment activities and approval processes, development of PM-HIP and EBW for thick-section ferritic components, effects of laser glazing on CS performance, past and future CS applications, and CS field implementation.

Key takeaways:

- Applications should be identified that optimize unique characteristics for the chosen AMT.
- Current analysis tools and the digital nature of AM allow for a deeper understanding of causal effects on performance than for conventionally manufactured materials.
- Regulatory authorities are exploring strategies to support the accelerated deployment of AM components, while still meeting safety requirements.
- PM-HIP and EBW offer possibilities for large-scale nuclear applications but are currently limited by existing manufacturing capabilities; upcoming work is focused on expanding these capabilities.
- High-velocity CS can provide several options for component surface treatment, including SCC mitigation, hard-facing, and component repair.
- Strategies have been developed to achieve field application of CS for components and structures with limited accessibility.

Recommended next steps:

- Continue developing the technical basis for using these technologies in nuclear applications.
- Identify strategies to effectively collaborate and rapidly incorporate lessons learned in standards and guidance.
- Expand the technical basis to move beyond substitutive applications to realize optimal benefit of AMTs.
- Develop an intelligent, performance-based qualification framework to allow more rapid implementation.
- Identify opportunities for these technologies to simultaneously improve component performance (and safety) while reducing lifecycle asset management costs.
- Consider methods and applications for which AMTs can be combined to optimize performance and increase design flexibility.

DAY 3 PRESENTATIONS

2.4 Session 4: Approaches to Component Qualification and Aging Management

2.4.1 AM Thimble Plugging Device/Advanced Debris Filtering Bottom Nozzle Implementation Process (Presentation B25—ML20344A013)
Presenter: *David Huegel, Westinghouse*

This presentation covered the Westinghouse process of qualifying its two AM components currently in use. The presentation provided a detailed timeline of Westinghouse's AM testing and analyses of the components until they were qualified and installed into the unit. It gave a more detailed overview of the testing performed, including irradiated and unirradiated mechanical testing, microstructure evaluation, and dye penetration testing. The presentation concluded with a brief explanation on the process under Title 10 of the *Code of Federal Regulations* (10 CFR) 50.59, "Changes, tests and experiments," and the role of AM testing in the implementation of AM components.

2.4.2 Approach for 316L LPBF Code Case and Data Package (Presentation B26—ML20344A011)
Presenters: *Clinton Armstrong and David Gandy, Westinghouse and EPRI*

This presentation detailed the importance of the relevant code case and data package development in furthering the manufacturing of 316L stainless steel using LPBF. The presentation then focused on the current standards for 316L stainless steel components, how AM components compare, and how standards for such components may appear based on the experience of Westinghouse and EPRI. The presentation showed graphs and tables of current data on 316L stainless steel manufactured using LPBF. It concluded with discussion of a draft code case and important next steps in the standardization process.

2.4.3 Certification of the First Powder Bed Fusion Component in a US Naval Nuclear Propulsion Plant (Presentation B27—ML20344A012)
Presenter: *Tressa White, NNL*

This presentation described NNL's efforts to manufacture AM hardware suitable as a pressure boundary component for submarine propulsion plant operation. It described the criterion for acceptance testing in the project and mechanical test data. The project was successful in generating components and witness specimens that were within standards. The presentation concluded by highlighting the success of this project, ending in the recent approval and installation of components.

2.4.4 On the Development of Fatigue and Damage Tolerance Framework for Metal AM Parts (Presentation B28—ML20344A052)
Presenter: *Michael Gorelik, FAA*

This presentation introduced the U.S. Federal Aviation Administration (FAA's) view on fatigue in AM materials, highlighting four major factors that affect fatigue life: metal-related defects, machining-induced defects, porosity, and nonmetallic inclusions. It detailed the importance of characterization methods for these defects and of developing nondestructive methods of testing, especially for AMT components. The presentation concluded with selected research and development data and results for fatigue and damage tolerance, emphasizing the importance of collaboration among industries to further AM development.

2.4.5 Accelerating Quality Certification of Critical Components with Additive Manufacturing (Presentation B29—ML20345A164)
Presenter: *Vincent Paquit, ORNL*

This presentation described the Transformational Challenge Reactor (TCR) program and its use of AMTs. It detailed the certification pathways used for these components, "smart manufacturing" approaches taken by the Oak Ridge National Laboratory (ORNL) in AMTs, and the development of a digital platform for manufacturing in the AM space. The presentation also covered augmented intelligence for AM, emphasizing that a benefit of AM components is the possibility for integrated augmented intelligence for in situ evaluation. This was further explained in anomaly detection examples and property predictions. The presentation concluded by highlighting ORNL's collaborative effort to install 3D-printed fuel assembly channel fasteners in a commercial reactor.

2.4.6 Inservice Inspection and Considerations for AMT Components (Presentation B30—ML20344A014)
Presenter: *Joel Harrison, PNNL*

This presentation addressed potential inservice inspection requirements for AMT components in the nuclear industry, highlighting that the lack of attention this has received is detrimental to widespread AMT component use in the nuclear energy industry. It presented specific sections of current inservice inspection examination requirements and detailed the potential incorporation of AMTs.

Summary of Session 4

This session covered the implementation process for the AM thimble plugging device and advanced debris filtering bottom nozzle, progress on an American Society of Mechanical Engineers (ASME) code case and data package for 316L stainless steel manufactured using LPBF, inservice inspection, and accelerating quality certification of critical components with AM.

Key takeaways:

- AMTs are being incorporated, with more implementation planned.
- Codes and standards development should aim to keep pace with AMT advances.
- Much work remains for inservice inspection, including the Performance Demonstration Initiative.

Recommended next steps:

- Expand and continue to mature codes and standards development.

2.5 Session 5: Codes and Standards Activities and Developments

2.5.1 Standards Landscape for Additive Manufacturing (Presentation B31—ML20344A116)
Presenter: *Shawn Moylan, NIST*

This presentation described NIST's influence on AM standards and the role AM standards will have in the AMT space. It further detailed NIST's efforts to supply measurement science research for developing AM standards and the formation of the Additive Manufacturing Standards Collaborative, which is intended to coordinate and accelerate the creation of AM standards and to facilitate growth in the AM industry. The presentation also explained additional committees, such as ASTM International's (ASTM's) Committee F42 and ISO Technical Committee 261. The presentation concluded with ASME efforts and NIST's perspectives on AM standards.

2.5.2 ASME Criteria for Powder Bed Fusion Additive Manufacturing (Presentation B32—ML20344A117)
Presenter: *George Rawls, SRNL*

This presentation described current ASME criteria for LPBF manufacturing and highlighted the production of a final draft on criteria for pressure-retaining metallic components using AM. The presentation further explained the details of these criteria, emphasizing requirements and limitations and how LPBF compares to non-AM techniques. The presentation concluded with an outlook on the path forward and how these criteria should be treated as a baseline for future development efforts.

2.5.3 Approach to Codifying New Manufacturing Methods (Presentation B33—ML20344A113)
Presenters: *Brian Frew and David Gandy, GE and EPRI*

This presentation described the current gaps in requirements in the ASME B&PV Code and specific alloys that need qualification for manufacturing using PM-HIP, CS, LPBF, and EBW techniques. For each manufacturing technique, the presentation outlined significant code cases across industries and important alloys that should be reviewed for that technique. Overall, it concluded that the nuclear industry's acceptance of AMTs is still low, and increased data for specific materials will be helpful in mobilizing the nuclear industry and standardization.

2.5.4 Overview of America Makes Activities (Presentation B34—ML20344A115)
Presenter: *Brandon Ribic, America Makes*

This presentation described America Makes and its role in the AM space. Its role is centered around three core activities: development of AM technology, acceleration of human capital development, and maintenance of a collaborative ecosystem. The presentation explained how this is done through operations, technology, and communications across stakeholders, government, and communities. It further detailed the merits of AM for nuclear applications and presented different factors affecting the effective scaling of AM technology for nuclear applications. The presentation concluded with the current regulation and standards landscape and future opportunities present for development.

2.5.5 Recent Advancements on ASTM Additive Manufacturing Research and Standardization (Presentation B35—ML20351A216)
Presenter: *Mohsen Seifi, ASTM*

This presentation described ASTM's current actions to develop codes and standards and address gaps. This included a description of the ASTM AM Center of Excellence, founded in 2018 to accelerate ASTM standardization activities. The presentation further detailed the F42 Subcommittee on Applications for AM. This was followed by detailed examples of current research and development efforts ASTM is collaborating on to develop data for AM.

2.5.6 NASA Standard for Use of AM in Crewed Spaceflight Applications (NASA-STD-6030) (Presentation B36—ML20344A114)
Presenter: *Douglas Wells, NASA*

This presentation described NASA's standardization activities and its efforts to support standards development organizations, such as ASTM and the FAA. The presentation further detailed NASA-STD-6030 and the techniques and materials covered within that standards document. It then gave a classification tree within NASA-STD-6030 and important factors considered as NASA tailored its qualification process. The presenter reflected on NASA's near-term challenges with risk management of high-criticality parts with limited postbuild structural integrity verification, and how managing risk as the AM field develops is critical for the aerospace industry.

2.5.7 Development of AWS D20.1 Standard (Presentation B37—ML20344A112)
Presenter: *Jessica Coughlin, NNL*

This presentation introduced American Welding Society (AWS) D20.1/D20.1M:2019, "Specification for Fabrication of Metal Components Using Additive Manufacturing," which provides extensive design, qualification, manufacture, and inspection requirements for LPBF and DED. The presentation highlighted that extensive testing and evaluation requirements are needed to ensure acceptable and repeatable properties, due to the inherent variability present in AM processes. Standardized testing can also provide consistent means for detecting quality concerns and sources of variation.

Summary of Session 5

This session covered roadmaps, centers of excellence, development of nuclear and nonnuclear consensus standards, and the industry and regulatory needs driving the development and readiness of AMTs.

Key takeaways:

- Many gaps exist in technology and standards development. The American National Standards Institute is tracking these gaps (www.ansi.org/amsc).
- Standards development organizations benefit from continual communication to reduce the development of redundant standards.
- Collaboration with regulatory agencies would be helpful to identify needs related to codes and standards.

Recommended next steps:

- Initiate NRC communication with other regulatory bodies on AMT topics.
- Encourage industry and regulatory involvement in standards development.
- Encourage communication among standards development organizations on AMT standards development.

DAY 4 PRESENTATIONS

2.6 Session 6: Regulatory Approaches for AMTs

2.6.1 NRC Regulatory Approach for AMTs (Presentation B38—ML20344A422)
Presenter: *Carolyn Fairbanks, NRC*

This presentation described regulatory preparedness activities taken under the NRC AMT Action Plan. It gave an overview of the 10 CFR 50.59 process and summarized the assessment of regulatory guidance. The rest of the presentation largely focused on the development of an AMT guidelines framework and the two regulatory pathways for incorporating AMTs: the equivalency approach and the design modification approach. The NRC provided a sample application guidance flow chart to demonstrate the potential regulatory pathway.

2.6.2 STUK Regulatory Approach for AM (Presentation B39—ML20345A165)
Presenter: *Pekka Valikangas, STUK*

This presentation provided an overview of the regulation of AM components in Finnish nuclear facilities. It began with a brief overview of Finnish nuclear facilities for context, including a general snapshot of Finnish nuclear legislation and safety requirements. The presenter gave details on Finnish regulatory oversight of AM, highlighting the importance of overseeing the reliability of the process and quality of the builds, including the consideration of international research and standardization. The presentation further elaborated on conventional standards and how the transition to including AM produces multiple questions on how to codify the procedure.

2.6.3 FDA Regulatory Approach for AM (Presentation B40—ML20344A423)
Presenter: *Matthew Di Prima, FDA*

This presentation described the FDA's typical pathway for medical device regulation and how this has been applied to AM. The classification of medical devices is covered under Federal codes and also indicates the degree of regulation based on the degree of risk. The presentation covered the information required in submissions, which can be reduced or increased based on the device classification. Generally, the FDA does not intend to regulate the manufacturing process as long as the resulting device meets requirements. This allows the FDA smoother acceptance of AM products.

2.6.4 Regulatory Considerations for AM and "Lessons Learned" for Structural Alloys (Presentation B41—ML20344A424)
Presenter: *Michael Gorelik, FAA*

This presentation highlighted the potential for performance-based standards for the FAA's regulation of AM, stating that although the rules should not change, specific factors of the AM process may require regulation. The presenter discussed relevant technologies and highlighted the specific regulatory processes. The presentation concluded with the FAA's lessons learned with powder metallurgy and structural castings, and how the historical experience and relevant regulatory techniques may apply to AM.

Summary of Session 6
This session discussed approaches for regulating AMTs from nuclear and nonnuclear regulators. The regulatory organizations in this session identified numerous commonalities.

Key takeaways:

- Regulators share many common bases, including performance-based regulation.
- Regulators share common technical concerns for AM, such as powder characteristics and the use of witness coupon testing to represent manufactured parts.
- Regulators could consider greater coordination and information exchange, particularly on AM, which is being implemented in many industries now for the first time.

Recommended next steps:

- Consider enhanced coordination between the NRC and other U.S. regulators to benefit from lessons learned on approaches for integrating AMTs into current regulatory frameworks.
- Coordinate among international nuclear regulators to provide broader perspectives and ensure common approaches, consistent with different national regulatory needs.

2.7 Session 7: Research and Development of AMTs

2.7.1 Quality Control Tools for Metal AM and EU NUCOBAM Project (Presentation B42—ML20345A156)
Presenter: *Pasi Puukko, VTT*

This presentation described the general approach for AM qualification in three parts: process qualification (including machine, powder, operator), component qualification, and individual part quality control. The presenter also elaborated that AM component quality will be monitored by both destructive and nondestructive testing and in-process monitoring. They described the European Union’s (EU’s) NUCOBAM Project, detailing its role in the qualification process and responsibility for providing the evaluation of inservice behavior allowing AM for nuclear integration. The presentation described multiple work packages, detailing multiple collaborative efforts, including the Finnish Technical Research Centre’s (VTT’s) AM process qualification work package. It then described the current state of qualification methods used for LPBF and the problems being addressed in developing a general LPBF qualification scheme.

2.7.2 DOE Transformational Challenge Reactor Program (Presentation B43—ML20345A157)
Presenter: *Kurt Terrani, formerly ORNL*

This presentation gave an in-depth review on the TCR and its efforts in the AM and augmented intelligence spaces. It highlighted specific efforts, including ORNL’s effort to codify metal AM and the incorporation of sensors into AM builds for operational data harvesting. The presentation then reviewed AM 316L stainless steel used for the TCR and its microstructures before irradiation and how such material compares to conventional 316L stainless steel and the performance expected in the TCR.

2.7.3 DOE-NE Advanced Manufacturing Methods Program Overview (Presentation B44—ML20345A158)
Presenter: *Isabella van Rooyen, INL*

This presentation explained the actions the DOE Office of Nuclear Energy (DOE-NE) has pursued and its objectives and priorities for fiscal year 2021, including increasing stakeholder participation, leveraging research, identifying gaps and needs, increasing collaboration, and establishing projects. The presentation then focused on highlighting significant awarded projects and commented on the current state of Idaho National Laboratory's (INL's) work, including projects relating to LPBF, nondestructive testing, and CS.

2.7.4 Rapid Qualification of New Materials Using Modeling and Simulation (Presentation B45—ML20345A159)
Presenter: *Mark Messner, ANL*

This presentation described the premier challenges in qualifying AM materials, especially for high-temperature applications, including potentially significant variability between AM builds, and the importance of long-term and time-dependent properties that lack conclusive short-term testing such as creep and thermal aging characteristics. The presentation then elaborated on ANL's efforts to design modeling tools capable of predicting these important factors and accelerating qualification, highlighting three separate qualification tools: physically based models, staggered qualification approaches, and uncertainty quantification through Bayesian inference. The presentation then concluded with potential collaborative use of these tools in a qualification pathway and a summary of key gaps present in the current modeling space.

2.7.5 Cold Spray Development for Coatings (Presentation B46—ML20345A160)
Presenters: *Kumar Sridharan, University of Wisconsin, and George Young, Kairos Power*

This presentation focused on CS and related recent studies, concluding that the technology would be advantageous in the nuclear industry for repair and coating applications. The presenters then explained specific case studies of successful CS application, including mitigating and repairing stainless steel canisters used for dry cask storage and corrosion and tritium diffusion barrier coatings for fluoride salt-cooled high-temperature reactors using nickel and tungsten.

2.7.6 In-Situ Process Measurements for Monitoring, Control, and Simulation of AM (Presentation B47—ML20345A161)
Presenter: *Brandon Lane, NIST*

This presentation described NIST's efforts to develop in situ process monitoring of AM, including a thermography system that tracks the melt pool and can provide significant information relative to component properties and microstructure based on the radiance temperature and cooling rate. The presentation then elaborated on how a monitoring method can inform controls based on machine learning. The presentation concluded with NIST's in situ data and dissemination framework.

2.7.7 Additive Manufacturing Consortium (Presentation B48—ML20345A162)
Presenter: *Mark Barfoot, EWI*

This presentation introduced EWI (formerly the Edison Welding Institute) and explained its role in the materials industry and how it contributes to AM development by evaluating new processes, developing material property data, enabling clients to adopt the technology, and founding the Additive Manufacturing Consortium (AMC) in 2009. The presenter then explained the benefits of the AMC and the collaborators within the AMC, including General Electric Company (GE) and NASA. The presentation concluded with projects the AMC has sponsored and how interested parties can take part in AMC activities.

Summary of Session 7

This session covered worldwide efforts by researchers on solutions to quality assurance and quality control issues, the role of modeling and simulation in accelerating the qualification of new AMT materials, the investigation of CS as a corrosion mitigation strategy, advances in in situ monitoring, and an overview of the AMC and its role in coordinating and funding AM research. Participants agreed that it is important to continue to evaluate research needs and technology gaps.

Key takeaways:

- Over the next several years, nuclear-focused AM research will make significant strides.
- The nuclear community is interested in the accelerated qualification of new AM materials.

Recommended next steps:

- Continue to evaluate research needs and technology gaps.

3. Summary and Conclusion

The staff had the following primary objectives for the NRC's public workshop on AMTs for nuclear applications:

- Discuss ongoing activities related to AMTs, including nuclear industry implementation plans, codes and standards activities, research findings, and regulatory approaches in other industries.

- Inform the public of the NRC's activities and approach to approving the use of AMTs.

- Determine, with input from nuclear industry stakeholders and other technical organizations, areas where the NRC should focus to ensure the safe implementation of AMTs.

The workshop provided an opportunity to share information among international counterparts on approaches to using AMTs. Participants agreed that to support near- and medium-term use of AMTs in nuclear applications, industry and researchers should focus on developing data to support the qualification of AM materials. These data can be used to support codes and standards development and provide a technical basis to support implementation. Initial use of AMTs in non- or low-safety-significant components will provide a path to use for components of higher safety significance by building experience and confidence in the performance and properties of AMT components in representative environments. Combining this approach with innovative plans for in-service inspections and post-service destructive evaluation can further improve confidence in the performance of AMTs.

The NRC staff intends to consider an array of insights from the workshop (largely identified in the session summaries in Section 2) in future activities related to AMTs. These include strong engagement through codes and standards bodies, improved coordination with other regulators, and novel approaches to accelerate qualification that take advantage of the digital nature of AM and advanced modeling and simulation tools.

Appendix A Workshop Attendees and Presenter Bios

Name	Organization
Sunil Acharya	ANSYS
Marc Albert	EPRI
Stephen Alexander	ISL, Inc.
Bogdan Alexandreanu	ANL
Brian Allik	NRC
Lydiana Alvarado	NRC
Isaac Anchondo-Lopez	NRC
Jordan Anderson	Ontario Power Generation
Clinton Armstrong	Westinghouse
Steven Attanasio	NNL
Lee Aucott	UKAEA
Meg Audrain	NRC
Pajazit Avdovic	Siemens Energy
Dustin Avery	U. Alabama
Marsha Bala	INL
Mark Barfoot	EWI
David Beaulieu	NRC
Paul Beer	Curtiss Wright
Jay Bennett	NASA
Michael Benson	NRC
Iñigo Bolado	
Dawn Bosco	BPMI
Anna Bradford	NRC
Jonathan Braisted	NRC
Nicole Brown	U.S. Navy
Hayden Brundage	NRC
Frederick Brust	EMC^2
Mike Burke	EPRI
Dirk Cairns-Gallimore	DOE
Bob Caldwell	NRC
Thomas Capobianco	
James Carr	CNL
Harold Carter	NNL
Yiren Chen	ANL
Minghui Chen	U. New Mexico
Alex Chereskin	NRC
Andrew Chern	BWXT
Ganesh Cheruvenki	NRC
Jason Christensen	INL

Name	Organization
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Arne Claes	ENGIE
William Cleary	WEC
Alyson Coates	ORNL
Keith Consani	NIST
Sam Cordner	NASA
Nicolas Correa	UKAEA
Jessica Coughlin	NNL
Ted Coulter	TVA
Ted Dahne	Toshiba
Jens Darsell	PNNL
Robert Davis	NRC
Mike Di Lisi	Ontario Power Generation
Matthew Di Prima	FDA
Mark Dietrich	Dassault Systemes
David Dijamco	NRC
Paul Donavin	
Alkan Donmez	NIST
Daniel Drazkowski	NNL
Darrell Dunn	NRC
Bassem El-Dasher	TerraPower
Laila El-Guebaly	U. Wisconsin
James Eliou	NNL
Jonathan Emery	
Giovanni Facco	NRC
Carolyn Fairbanks	NRC
Adam Falcone	Naval Reactors
Shaw Feng	NIST
William Ferrell	AMS Corporation
Kevin Field	U. Michigan
Eric Focht	NRC
Richard Fonda	NRL
Steve Frankl	NRC
Kathryn Franks	BPMI
Brian Frew	GE
Lee Friant	Exelon
Travis Fritts	BWXT
Raymond Furstenau	NRC
Daniel Galicki	BWXT
David Gandy	EPRI
Adam Garofalo	U.S. Navy
Michael Gilbert	Ontario Power Generation

Name	Organization
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David Glenn	BWXT
William Golumbfskie	NSWC, Carderock
Hipo Gonzalez	NRC
Paul Goodwin	UKAEA
Michael Gorelik	FAA
Carlo Grassucci	BPMI
David Gross	Dominion Engineering, Inc.
Mark Guthrie	Curtiss-Wright EMD
Jonah Haefner	U.S. Navy
Evan Handler	U.S. Navy
Joel Harrison	PNNL
Alex Hashemian	AMS Corporation
Matt Hauser	NNL
Shawn Heath	Framatome
Greg Hersak	CNL
David Herzog	NNL
Takehisa Hino	Toshiba
Matthew Hiser	NRC
Allen Hiser	NRC
Keith Hoffman	NRC
Michael Holmes	WEC
Marc Horner	Ansys
Christopher Hovanec	DOE
Susan Hovanec	U.S. Navy
David Huegel	WEC
Richard Huff	ASTM International
Shane Hughes	Toshiba
Amy Hull	NRC
Alex Huning	ORNL
Brian Hunt	Precision Custom Components, LLC
Keith Hustosky	BPMI
Michael Ickes	Westinghouse
Raj Iyengar	NRC
Richard Jacob	PNNL
Mahdi Jamshidinia	ASTM International
Amanda Jenks	Dominion Engineering, Inc.
Francis Johns	Emirates Nuclear Energy Corporation
Kyle Johnson	VRC Metal Systems
Al Jones	NIST
Colin Judge	INL
Tom Jungling	BPMI

Name	Organization
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Moritz Kaess	U. Stuttgart
Rajib Kalsar	PNNL
Junya Kaneda	Hitachi GE Nuclear Energy
Christopher Kantzos	NASA
Y Kata	Toshiba
Hyunwoong Ko	NIST
Tatsuro Kobayashi	TEPCO
Mageshwari Komarasamy	PNNL
Patrick Korzeniowski	U.S. Navy
Michael Kottman	ASTM International
Markus Kotzanek	Framatome GmbH
Michelle Koul	US Naval Academy
Jason Lambin	Crane Nuclear
Hilary Lane	NEI
John Lane	NRC
John Lareau	PNNL
Steven Lawler	Frazer-Nash Consultancy
Doris Lewis	NRC
Meimei Li	ANL
Shengyen Li	SWRI
Bruce Lin	NRC
Jennene Littlejohn	NRC
Nathan Livesey	NAVSEA
Christopher Lohse	SIA
Shanlai Lu	NRC
Yan Lu	NIST
Sarah Luna	NASA
Louise Lund	NRC
Tim Lupold	NRC
Shah Malik	NRC
Mohammad Masoomi	ANSYS Inc.
Uwe Mayer	MPA U. of Stuttgart
Lauralyn McDaniel	ASME
Brian McDermott	TVA
Travis McFalls	BWXT
Matthew McMahon	U.S. Navy
Mike McMurtrey	INL
Bob McReynolds	Kairos Power
James Medoff	NRC
Teresa Melfi	Lincoln Electric
Nate Mentzer	NRC

Name	Organization
Mark Messner	ANL
Michael Miller	ANSYS
Paul Miller	ANSYS
Frank Mischler	Hitachi America, Ltd.
Tesfaye Moges	NIST
Robert Montgomery	PNNL
Shawn Moylan	NIST
Aaron Nardi	VRC Metal Systems
Steve Nardone	ENGIE
Alderson Neira	Proto Precision Additive LLC
Scott Nelson	UT-Battelle
Charles Nguyen	U.S. Navy
Wallace Norris	PNNL
Carol Nove	NRC
Richard Novotnak	BPMI
Scott Novotny	NAVSEA
Mark Nutt	PNNL
Robert Oelrich	PNNL
Tara O'Neil	PNNL
Ichiro Ono	TEPCO
Jeff Otterstetter	PPI
George Pabis	NovaTech
Yiming Pan	SWRI
Vincent Paquit	ORNL
Dong Park	NRC
Arash Parsi	WEC
Eternity Perry	AMS
Cecile Petesch	CEA
John Pfabe	WEC
Ed Pheil	Elysium Industries USA
Jeff Poehler	NRC
Dave Poole	Rolls-Royce
Steven Pope	ISL, Inc.
Daniel Porter	FDA
Jim Powers	TAES
Bill Press	Rolls-Royce
Iouri Prokofiev	
Matt Prowant	PNNL
Patrick Purtscher	NRC
Pasi Puukko	VTT
J. Quinn	TAES
Amarendra Rai	UES Inc
Antonio Ramirez	The Ohio State U.
George Rawls	SRNL

Name	Organization
Scott Read	CNL
Eric Reichelt	NRC
Justin Rettaliata	NAVSEA
Gustavo Reyes	INL- BEA
Stephen Rhyne	NuGen
Brandon Ribic	America Makes
Jacob Rindler	The Ohio State U.
Allen Roach	INL
Jennifer Robinson	NNL
Ken Ross	PNNL
David Rowenhorst	NRL
David Rudland	NRC
Ryann Rupp	INL
Michael Russell	ORNL
Hideaki Sadamatsu	Hitachi-GE Nuclear Energy, Ltd.
Sujit Samaddar	USNRC
Eric Sansoucy	CNL
Raymond Santucci	US Naval Academy
Alyssa Schneider	NRC
Mohsen Seifi	ASTM
Jennifer Semple	U.S. Navy
Iymari Sepulveda	NRC
Sam Sham	ANL
Jeff Simmons	TAES
Matthew Siopis	ARL
Gregory Smith	NRL
Laura Smith	NRC
Kumar Sridharan	U. Wisconsin
George Stopyak	NNL
James Stouch	Precision Custom Components, LLC
Amanda Stutzman	Penn State U.
John Sulley	Rolls-Royce
Ben Sutton	EPRI
Yusuke Suzuki	TAES
Nicole Tailleart	NRL
Norihiko Tanaka	Toshiba Energy Systems & Solutions Corporation
Robert Taylor	NRC
Kurt Terrani	ORNL
Kim Tran	NSWCCD
Austin Travis	General Atomics
Robert Tregoning	NRC
Elissa Trueman	NSWC Carderock
John Tsao	NRC

Name	Organization
Caroline Vail	NSWC Carderock
Brian Van Luik	Curtiss Wright-EMD
Isabella van Rooyen	INL
Luisa Vener	NNL
Matthew Verrier	DOE
Jan-Albert Viljoen	NRG
Jillian Vlah	BPMI
Jay Wallace	NRC
Yanli Wang	ORNL
Albert Wavering	NIST
Chris Wax	EPRI
Johannes Weiser	Evobeam GmbH
Doug Wells	NASA
Martin Werz	MPA Stuttgart
Brian West	NASA
Tressa White	NNL
Dan Widrevitz	NRC
Chris Wiltz	Framatome
Paul Witherell	NIST
Brian Wittick	NRC
Udi Woy	Nuclear AMRC
Matt Yagodich	BPMI
James Yang	ANSYS
Mark Yoo	NRC
Austin Young	NRC
James Zess	MCHX Technology
Xuan Zhang	ANL

Presenter Bio's (alphabetically)

Marc Albert is a Senior Technical Leader in the Advanced Nuclear Technology Department (ANT) at EPRI. Marc manages and overseas the research related to Advanced Manufacturing and Materials within the nuclear industry. Prior to joining EPRI, Marc spent the first 10 years of his career as a Design Engineer with a nuclear steam supply system (NSSS) vendor including onsite support for new plant construction. Marc received his bachelor's degree in Mechanical Engineering at the University of Pittsburgh and is a licensed professional engineer.

Bogdan Alexandreanu is a Principal Nuclear Materials Engineer in the Nuclear Science and Engineering Division at Argonne National Laboratory. Research interests center on Environmentally Assisted Cracking (EAC) in aqueous reactor environments, particularly on environmental effects on fatigue crack initiation and growth, stress corrosion cracking (SCC) of nickel alloys and weldments, including the effect of the welding parameters on nickel-base weld SCC susceptibility. Prior research includes the examination and evaluation of SCC susceptibility of materials from nuclear power plants that experienced SCC, such as nozzles and weldments from Davis-Besse plant (2002 and 2010) and weldments from V. C. Summer plant (2000). Bogdan received MSc and PhD degrees in Nuclear Engineering and Radiological Sciences from The University of Michigan at Ann Arbor.

Clint Armstrong is the Advanced Manufacturing SME at Westinghouse Electric Company LLC. Clint's technology development efforts cover a broad range of advanced manufacturing technologies including AM, hot isostatic pressing, advanced welding, and machining within Westinghouse's Global Technology Office. Clint has a Bachelor of Science in Industrial and Manufacturing Engineering from The Pennsylvania State University and a Bachelor of Science in Physics from Slippery Rock University of Pennsylvania.

Steve Attanasio has a Ph.D. in Metallurgy from MIT, and has been at Naval Nuclear Laboratory for 25 years where he has worked on core, plant, and steam generator materials corrosion and performance. Steve currently works on applications, material properties, and microstructure studies of additively manufactured metals.

Meg Audrain joined the NRC in July 2008 as a materials engineer. She began her career as a technical reviewer in NRR in the subject areas of Alloy 600 stress corrosion cracking, degradation of nuclear metals, and HDPE. She currently works in the Office of RES as the technical lead for PWSCC crack growth rate studies and AMTs.

Pajazit Avdovic is the Innovation Manager for Additive Manufacturing and Senior Key Expert in Manufacturing at Siemens Energy AB Sweden. Pajazit has a Doctor of Philosophy of Engineering from the Lund University-Sweden. He gained his 30-year professional experiences in international organizations in Serbia and Siemens Energy, Sweden. Today Pajazit possesses a wide network of cooperation with many Swedish Universities, Research Institutes, and companies in the area of AM. He is author and co-author for several published articles and an owner of several patents in Subtractive and Additive Manufacturing. He is Chairman for Siemens Energy yearly conference "Additive Next" and part of the steering committee for AM related forums in Sweden. In 2017, Dr Avdovic was Project Manager for the project "PERUN- Nuclear Power Plant replacement part" which was "HIGHLY COMMENDED" for the Industrial Product Design TCT Award 2017.

Mark Barfoot oversees EWI's growing AM initiatives and helps EWI develop new AM technology opportunities. He directs the

Additive Manufacturing Consortium (AMC), a national consortium of industry, government, academic and non-profit research organizations operated by EWI. He also manages EWI's interest in the ASTM AM Center of Excellence (CoE), which involves supervision of the industry consortia focused on AM standards development, ASTM direct-funded projects, education and training, and project bids that leverage the ASTM CoE brand.

Arne Claes is responsible for managing the equipment qualification (EQ) & obsolescence program at ENGIE Nuclear Corporate. He graduated from the university of Leuven with a Master of Science in Electro-Mechanical Engineering. Arne was selected for the ENGIE nuclear trainee program and started his career in the instrumentation and control (I&C) maintenance division at the Doel Nuclear Power Plant. He successfully completed his traineeship and became responsible for developing and improving maintenance strategies on critical I&C equipment and managing critical I&C suppliers. Since 2017, he started working in the component engineering department and became responsible for developing and implementing an effective obsolescence program at the Doel Nuclear Power Plant. As of 2020 he became responsible for the EQ & Obsolescence program at corporate level.

Jessica Coughlin is an Advisor Engineer with the Naval Nuclear Laboratory (NNL), where she has spent the past fifteen years focusing on welding engineering and AM topics. Her recent work has involved fundamental research supporting the creation of quality standards for metal AM technologies. In her position as vice-chair of the American Welding Society D20 committee on AM, she played a pivotal role in the creation of the AWS D20.1 standard. Jessica is currently serving as chair of the AWS D20 committee.

Matthew Di Prima is a Materials Scientist in the FDA's Office of Science and Engineering Laboratories, housed in the Center for Devices and Radiological Health. His areas of research are investigating how the AM process can alter material properties, the interplay between corrosion and durability testing, and explant analysis. Along with his research duties, he is the head of the AM Working Group which is spearheading efforts across the Agency to address how this technology affects medical devices and other regulated medical products.

Carolyn Fairbanks is a senior materials engineer at the NRC in the Vessels and Internals Branch in the Office of Nuclear Reactor Regulation, where the focus of her work involves the study of the neutron embrittlement of reactor pressure vessel materials and the fracture toughness of steels used in the fabrication of various nuclear components. Ms. Fairbanks has held positions in the NRC's Office of Nuclear Regulatory Research and former Division of New Reactors, addressing materials degradation mechanisms and aging issues. Prior to the NRC, Ms. Fairbanks was a Materials Engineer at NIST.

Richard Fonda has worked at the U.S. Naval Research Laboratory for more than 25 years on a variety of topics including high strength steels, joining technologies, three-dimensional microstructures, and AM. In 2014, he also became a program officer for the Manufacturing Science programs at the Office of Naval Research, where he supports fundamental research on manufacturing technologies of interest to the Navy.

Brian Frew has been in the nuclear industry for more than 25 years and has been responsible for materials selection and fabrication requirements for reactor vessel and internal components. He has served as vice-chair and is a current member of the

ASME subgroup for Materials, Fabrication and Examination. His current role is the Consulting Engineer for Materials and Chemistry for GE Hitachi Nuclear Energy.

Lee Friant is a Sr. Staff Engineer at Exelon Nuclear Generation. Lee is responsible for governance, oversight and implementation of Fleet Steam Generator Program Engineering functions at Exelon PWR sites. Lee also serves as Subject Matter Expert (SME) in Selective Leaching, failure analysis, metallurgy and NDE for Reactor Coolant System and Balance of Plant Materials Degradation issues at Exelon's Nuclear plants.

David Gandy is a Senior Technical Executive in EPRI's Nuclear Materials area where he is responsible for technical oversight of major projects on powder metallurgy, advanced welding, AM, GEN IV alloys, and next-generation erosion/wear resistant alloys. Mr. Gandy has 36+ years of demonstrated leadership and excellence in materials and welding technologies supporting the power industry in the development and implementation of advanced life prediction methodologies of boiler, steam & gas turbine, reactor pressure vessels, and heat recovery steam generators. Mr. Gandy is recognized as an ASM International Fellow. He currently holds 13 U.S. Patents and has authored over 230 journal articles and technical reports.

Elizabeth Getto is an assistant professor of mechanical engineering at United States Naval Academy. She has a PhD from the University of Michigan in nuclear engineering and is a microstructure characterization specialist.

Michael Gorelik is the Chief Scientist for Fatigue and Damage Tolerance at the Federal Aviation Administration (FAA). He has over 25 years of experience in the areas of fracture mechanics, fatigue, damage tolerance, AM, characterization and modeling of material behavior and probabilistic methods. At the FAA, Dr. Gorelik supports various certification programs, development of advisory materials and rulemaking activities across the Agency, training of FAA personnel, and research and evaluation of new technologies such as AM. He represented the FAA on America Makes Governance Board, serves as an advisor for the ANSI / America Makes AMSC and ASTM AM COE, and is the Chair of the ASME / IGTI Structures and Dynamics Committee. He authored / co-authored over 60 journal papers and conference presentations, including many invited presentations and keynotes.

Joel Harrison is a research analyst and ASNT NDE Level III at PNNL. Prior to joining the PNNL team in 2019 he spent 39 years performing and supervising ASME Section XI inservice inspection and NDE examinations in the commercial nuclear power industry in the United States, Europe and Southeast Asia. He has extensive experience in writing and implementing ASME Section XI NDE certification programs and requirements. He holds four ASME Section XI, Appendix VIII (PDI) piping qualifications and was the first person to qualify an ultrasound imaging system for the detection of IGSCC at EPRI in 1983. He currently serves as Secretary for the ASME Section XI Working Group on Procedure Qualification and Volumetric Examination and a member of the Section XI Subgroup NDE as well as several related Task Groups.

Matthew Hiser is a materials engineer in the Corrosion and Metallurgy Branch in the Office of Nuclear Regulatory Research at the NRC. He joined the NRC in 2011 and has worked primarily on irradiation-assisted degradation of reactor internals, degradation of neutron absorber materials, spent fuel canister degradation, and AMTs.

David Huegel is a fellow engineer at Westinghouse and currently involved in Westinghouse's efforts in the area of AM and specifically laser powder bed fusion to produce fuel related components. His background includes approximately 20 years in safety analyses and the last 13 years in fuel assembly design. Mr. Huegel was directly involved in Westinghouse's efforts to install an additively manufactured thimble plugging device in Byron Unit 1 in the spring 2020 outage.

Kyle Johnson is the Director of Engineering for VRC Metal Systems. VRC Metal Systems is the largest US manufacturer of high pressure, hand-held, and portable cold spray equipment. Mr. Johnson leads several projects funded by the US DOE for applying cold spray in nuclear applications. Mr. Johnson will talk today about cold spray applications in the nuclear industry.

Christopher Kantzos recently graduated from Carnegie Mellon University in 2019 completing his PhD in the Materials Science and Engineering department. His thesis work focused on machine learning approaches to surface roughness analysis. He now works at the NASA Glenn Research Center (in Cleveland, Ohio) working in the High Temperature and Smart Alloys branch working on alloy development and Additive Manufacturing.

Brandon Lane is a mechanical engineer in the Intelligent Systems Division at NIST in Gaithersburg, MD. He leads the Metrology for Real-time Monitoring of Additive Manufacturing project, co-leads developments of the AM Metrology Testbed (AMMT), and is on the organizing committee for the AM Benchmark Test Series (AM-Bench).

Hilary Lane serves as the Director of Fuel and Radiation Safety at the NEI. She has over 10 years of experience in the nuclear field, including holding positions with the National Nuclear Security Administration (NNSA) in Washington, DC and Lawrence Livermore National Laboratory (LLNL) – where she supported the U.S. nuclear deterrent life extension programs. She has also worked at the NRC on fuel cycle regulatory matters. Ms. Lane holds a B.S. in Materials Science and Engineering from the University of Maryland, College Park and a Project Management Certification from George Washington University.

Mark Messner is a member of ANL's technical staff. His research focused on developing materials, design methods, and systems for high temperature concentrating solar power, nuclear, and aerospace applications. He is a member of the ASME Boiler & Pressure Vessel Code, Section III Committee Subgroup on High Temperature Reactors, and serves on and chairs several relevant ASME working groups covering high temperature reactor materials, design, and construction.

Shawn Moylan is a mechanical engineer and project leader in the Engineering Laboratory at NIST. He leads the Qualification for Additive Manufacturing Feedstocks, Machines, and Processes project. Shawn is also a member of the advisory committee for the ANSI/America Makes Additive Manufacturing Standardization Collaborative, the vice chair of ASTM F42.01 on Test Methods for Additive Manufacturing, and a member-at-large of ASME's Council on Standards and Certification.

Steve Nardone is responsible for the ENGIE Thematic Lab Advanced Materials Technologies, which includes the AM activities and the ENGIE fleet of laser powder bed fusion equipment. He graduated from the University of Mons with a Master in Materials Science. Steve became an expert in the field of materials for conventional power plants with 14-years of experience in metallography, root cause analysis, remaining life assessment and creep damage evaluation of power generation equipment. He has also acquired relevant experience in Quality Assurance and technical audits during production and repair of strategic spare parts. In his present position, he manages transversal and multidisciplinary projects in various fields of advanced materials for the energy sector, including the qualification of AM processes.

Robert Oelrich leads the Fuels & Materials Performance team within PNNL's National Security Directorate. Prior to joining PNNL, Robert led Westinghouse's Accident Tolerant Fuel (ATF) program during which several new ATF technologies, such as chromium-coated cladding and uranium silicide, fuel were taken from concept to reactor insertion in just over 2 years. Prior to that, Robert's team supported the initial development of the 3D-printed thimble plug at the Columbia Fuel Fabrication Facility, which has now been inserted into Byron Unit 1.

Vincent Paquit is a senior research scientist and lead for the Energy Systems Analytics group in the Electrification and Energy Infrastructures Division at ORNL supporting two core missions of the Department of Energy: Energy sustainability and National Security. His research interests are in the fields of Artificial Intelligence, Computer Vision, and Image Processing, with a predilection for high performance image processing algorithms development. Dr. Paquit is also the Data Analytics lead for the ORNL Manufacturing Demonstration Facility (MDF) where his team is developing a Data Analytics Framework for Advanced Manufacturing. This extensive digital platform aims at better understanding manufacturing processes for the purpose of part qualification and certification, and process control and correction. His vision, currently supported by DOE Advanced Manufacturing Office (AMO), has impacted multiple projects and programs at ORNL; in particular, the Transformational Challenge Reactor (TCR), a program aiming at 3D printing high quality components for nuclear applications. For TCR, he is overseeing the digital, manufacturing, and characterization activities to support the development of the framework and associated data driven techniques that will accelerate the certification and validation of these components.

Dave Poole is a Chartered Engineer at Rolls-Royce Plc where he holds the position of Manufacturing Engineering Manager for AM in the Nuclear and Defense Sector. He began working in AM in 2007 and setup the first metal AM facility in Rolls-Royce in 2009. Since then he has developed the technology through a number of material alloy and application programs, and now leads a dedicated AM division with multiple teams, facilities and capabilities.

Daniel Porter currently is a Regulatory Scientist at the U.S. FDA's Division of Applied Mechanics researching the properties of AM lattice structures and AM facemask sealing efficacy. Dr. Porter also has experience as a Lead Reviewer in the Office of Orthopedic Devices (OHT6) within the Center of Devices and Radiological Health at the U.S. FDA. He holds a Bachelor and Master of Science in Mechanical Engineering from the University of Louisville (UofL). He completed nearly two years of internships at Sandia National Laboratories in New Mexico where he researched gas chromatography technologies for national security applications. Dr. Porter received his Ph.D. in Mechanical Engineering from UofL where he studied vibrational energy harvesting, MEMS technology, and AM. He completed his postdoctoral position at Southern Methodist University (SMU) in Dallas, Texas where he studied AM of ultraviolet industrial silicone and thermally curable medical grade silicone.

Bill Press is a Technical Specialist in component design within Rolls Royce Submarines. He has led technical projects across a broad range of safety critical components and vessels, supporting their design, safety justification, manufacture and operation. Most recently, Bill has applied his specialist technical knowledge to drive forward the introduction of the Additive Manufacture Technology within the business in order to deliver important quality, cost and program benefits.

Pasi Puuko is the Research Team Leader in Advanced manufacturing technologies at VTT Technical Research Centre of Finland. He has twenty years' experience working in the field of research and has carried out various projects at national and international level as project manager or as work package leader, mainly related to digital fabrication and AM, especially for laser-beam powder bed fusion. His ambition is to promote and thus increase the usage of digital manufacturing technologies. He is a board member of Finish Rapid Prototyping Association.

Amarendra K. Rai has been with UES Inc. since 1981 and is currently a Principal Research Scientist. For the last few years, he is involved in the development of materials damage restoration technologies including directed energy deposition and cold spray. Dr. Rai has worked extensively on the development of coatings utilizing various techniques including physical vapor deposition and thermal spray for a variety of applications.

George Rawls has over 35 years of experience in the design, analysis, and testing of systems, structures, and components, including extensive experience in the application of codes and standards to pressure vessels and piping systems. He is currently a Fellow for the American Society of Mechanical Engineers and a Chairman for the ASME Special Committee on Use of Additive Manufacturing for Pressure Retaining Equipment.

Justin Rettaliata has 19 years in industry and the federal government, working in mechanical engineering, systems engineering, and program management. Justin is currently the Technical Warrant holder for additive manufacturing (AM) in charge of the development of specifications and standards for how the Naval Sea Systems Command (NAVSEA) adopts/utilizes AM and serves as the technical lead for AM for NAVSEA. Justin holds a B.S. in Mechanical Engineering from Lehigh University, a Master's in Business Administration from the College of William and Mary, and a Ph.D. in Systems Engineering from the George Washington University.

Brandon Ribic was named Technology Director of America Makes in October 2019. Driven by the National Center for Defense Manufacturing and Machining (NCDMM), America Makes is the national accelerator for AM and the first of nine Manufacturing Innovation Institutes (MIIs) established and managed by the U.S. Department of Defense (DoD) as public-private partnerships. Prior to joining NCDMM, Dr. Ribic was a joining processes and AM materials specialist at Rolls-Royce Corporation. He led the Materials Technology Center efforts in AM process modeling and in-situ process monitoring. His research focused on welding and AM processes for various titanium and nickel superalloy gas turbine engine components. One of his most notable achievements is successfully developing, qualifying, and productionizing (TRL 7) the first ever CMSX-4 AM repair for Rolls-Royce.

Ken Ross is a Materials Research Engineer in the Energy Processes & Materials Group at PNNL. Ken is an expert in solid phase processes, such as cold spray and friction stir welding. Ken currently conducts research in nuclear, hydropower, defense, and automotive sectors for government and private stakeholders. After retiring from 40+ years in private industry, Mr. Lareau joined the PNNL on a part time basis working in the field on nondestructive testing development and qualification. In this capacity, he supports the research efforts of various branches of the NRC, primarily Research, Nuclear Reactor Regulation and Nuclear Material Safety.

David Rowenhorst received his Ph.D. from Northwestern University in 2004 in Materials Science and Engineering and joined the NRL as a NRL Postdoctoral Associateship and in 2006 continuing on as a staff scientist in the Phase Transformations and Joining Section. His work concentrates on the 3D characterization of materials, concentrating on automated electron backscatter diffraction (EBSD serial-sectioning and X-ray tomography to analyze the evolution of grain boundary networks in polycrystalline materials and phase transformations in high strength steels and AM.

Raymond Santucci is an assistant research professor in the mechanical engineering department at the US Naval Academy. He completed his doctoral studies at the University of Virginia in Material Science and Engineering, specializing in corrosion and electrochemistry.

Mohsen Seifi is the global director of AM programs at ASTM International, responsible for AM center of excellence (CoE) and various AM programs while leading a team of technical experts in the field. In his role, he brings technical leadership to accelerate standardization activities across all ASTM AM related technical committees and building new partnerships/initiatives as well as development of new AM standards related programs within diverse ASTM portfolios. He has 10+ years of managing and prioritizing multiple programs/projects in research/business environments with strong academic/business development background. He has also appointment as an adjunct faculty at Case Western Reserve University in OH, USA. Part of his PhD work focused on rapid qualification methods for metal AM processes. He has co-authored 40+ peer reviewed publications that are cited 1800+ times and has presented 60+ invited and keynote lectures at various technical meetings, industries and government agencies while also receiving various technical society honors and awards.

Matt Siopis is a materials research engineer and technical lead for the Army Research Laboratory (ARL) cold spray effort. Matt is responsible for the development of materials, process conditions, equipment, implementation and transition of cold spray technology. Matt is author to several cold spray patents related to nozzle design and hybrid manufacturing.

Kumar Sridharan is Professor in the Departments of Nuclear Engineering and Materials Science & Engineering at the University of Wisconsin, Madison. His expertise spans a broad spectrum of areas in materials science, including nuclear reactor materials, corrosion, cold spray technology, characterization and testing of materials, interfaces of materials and manufacturing, and industrial applications. Prof. Sridharan has made leading contributions in the areas of materials compatibility for Molten Salt Reactors (MSRs) and ATF cladding development and is Fellow of American Society for Materials, Fellow of American Nuclear Society, and Fellow of Institute of Materials (UK).

John Sulley is a European Registered Engineer and UK Chartered Engineer, and a Fellow of the UK Institution of Mechanical Engineers. He has 36 years of design, manufacturing development, and justification experience of nuclear plant components working for Rolls-Royce Submarines. He has held positions of Chief Engineer, Chief Design Engineer, Chief of Engineering Capability, and Valves Internal Authority, and is currently a Rolls-Royce Associate Fellow. John is a member of two

ASME Section III design code committees – valves and pumps. He has been heavily involved in instigating and implementing advanced manufacturing techniques such as hot isostatic pressing and AM.

Kurt Terrani is a Senior Staff Scientist at ORNL and the Director of the Transformational Challenge Reactor (TCR) program for the DOE Office of Nuclear Energy. He joined the laboratory as a Weinberg Fellow in the Nuclear Fuel Materials Group in 2010 after completing his Ph.D. in nuclear engineering at University of California, Berkeley. His research focused on fundamental aspects of nuclear fuel and materials manufacturing, radiation effects, and behavior.

Isabella van Rooyen holds a Ph.D. in physics, M.Sc. in metallurgy, and an MBA. She is the National Technical Director: Advanced Methods for Manufacturing Program for the US Department of Energy. She is also a distinguished staff scientist at INL where she has led the advanced electron microscopy and micro-analysis examinations for the Advanced Gas Reactor TRISO fuel development program since 2011. In addition, she is the principal investigator of a variety of research projects for nuclear applications that focus on areas including TRISO coated particles, AM qualification reviews and AMM.

Douglas Wells is a structural materials engineer in the Materials and Processes Laboratory at the NASA Marshall Space Flight Center. Doug has twenty-five years of experience in fatigue, damage tolerance, and fracture control of flight structures. For the past seven years, he has focused on developing methodologies for the qualification and certification of additively manufactured spaceflight hardware, including the development of the first NASA standard to establish requirements for incorporating additively manufactured hardware into flight vehicles for NASA and its commercial partners. In addition to standards development for NASA, Doug is actively engaged with the broader international standards community working in AM, including ASTM and SAE. Currently, much of his time is spent on the interpretation of certification requirements for additively manufactured hardware on a variety of NASA missions. Doug came to NASA following his Bachelor of Science degree in Aerospace Engineering at Virginia Tech and also holds a Master of Science in Mechanical Engineering from Stanford University.

Christopher Wiltz has nearly 30 years in the nuclear fuel assembly research & development, design, manufacturing and licensing. Wiltz is based in Richland, Washington and currently functions as the worldwide manager of Framatome's design to cost and design to manufacture activities, which includes implementation and industrialization of new products and technologies both internal and external to Framatome.

Tressa White has been a research engineer at the Naval Nuclear Laboratory in New York for the last 15 years investigating both core and plant structural materials performance. Most recently, she's delved into justifying AM techniques, specifically laser-powder bed fusion, to be a qualified production method for the nuclear Navy. Today, Tressa will share how NNL certified the first metal additive hardware to go in service in a submarine propulsion plant and how that action, more so than the part, is critical to their AM vision.

Mark Yoo is a materials engineer in the Component Integrity Branch in the Office of Nuclear Regulatory Research at the NRC, where he is primarily focused on AMTs and advanced non-light water reactors. He joined the NRC in 2010 in the Office of Nuclear Reactor Regulation where he focused on license renewal and materials degradation mechanisms and aging of the reactor vessel and vessel internals.