



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

December 22, 2020

MEMORANDUM TO:

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SUBJECT:

SUMMARY OF THE DECEMBER 7-10, 2020, WORKSHOP ON
ADVANCED MANUFACTURING TECHNOLOGIES FOR
NUCLEAR APPLICATIONS

The U.S. Nuclear Regulatory Commission (NRC) staff from the Office of Nuclear Regulatory Research (RES) and the Office of Nuclear Reactor Regulation (NRR) held a workshop on December 7-10, 2020, on advanced manufacturing technologies (AMTs) for nuclear applications. The purpose of this workshop was to discuss ongoing activities related to AMTs including nuclear industry implementation plans, codes and standards activities, research

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findings, and regulatory approaches in other industries; to inform the public of the NRC activities and approach to approving use of AMTs; and to determine, with input from nuclear industry stakeholders and other technical organizations, areas where NRC should focus to ensure safe implementation of AMTs.

The public meeting summary, workshop agenda, Agencywide Documents Access and Management System (ADAMS) accession numbers for workshop presentations, and list of workshop participants are enclosed.

Enclosures:
As stated

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***via email**

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

Title: Workshop on Advanced Manufacturing Technologies for Nuclear Applications

Meeting Identifier: 20201326

Date of Meeting: December 7-10, 2020

Location: Webinar

Type of Meeting: Category 3

Purpose of the Meeting: The purpose of this workshop was to discuss ongoing activities related to advanced manufacturing technologies (AMTs) including nuclear industry implementation plans, codes and standards activities, research findings, and regulatory approaches in other industries; to inform the public of the Nuclear Regulatory Commission (NRC) activities and approach to approving use of AMTs; and to determine, with input from nuclear industry stakeholders and other technical organizations, areas where NRC should focus to ensure safe implementation of AMTs.

General Details: This workshop was conducted via webinar over 4 days, from 8:00am – 5:00pm (EST). Approximately 280 attendees, representing domestic and international research, academic, industry, and regulatory organizations, participated and engaged in active discussions throughout the workshop. The workshop was divided into seven sessions, which were chaired by various NRC staff members:

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

Summary of Presentations:

Session 1:

- Presentations were given by the NRC, Siemens, ENGIE, Rolls-Royce, Army Research Lab, and the US Navy.
- The topics that were presented include experience with additive manufacturing (AM) component fabrication for nuclear applications, powder metallurgy – hot isostatic pressing (PM-HIP) for nuclear applications, cold spray experience for Army applications, and AM experience for Navy applications.

Session 2:

- Presentations were given by the Nuclear Energy Institute, Electric Power Research Institute (EPRI), Exelon, Westinghouse, Framatome, and Pacific Northwest National Lab (PNNL).
- The topics that were presented include 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 process.

Session 3:

- Presentations were given by the NRC, Rolls-Royce, Naval Nuclear Lab (NNL), National Aeronautics and Space Administration (NASA), US Naval Academy, Naval Research Lab (NRL), Food and Drug Administration (FDA), EPRI, PNNL, VRC Metal Systems, Argonne National Lab (ANL), and UES, Inc.
- The topics that were presented include implementation and justification strategies for identifying and implementing candidate nuclear applications, effects of processing and post-processing variables on performance/qualification, regulatory assessment activities and approval processes, developing PM-HIP and electron beam welding (EBW) for thick section ferritic components, evaluating performance of cold spray both with and without laser glazing, past and future cold spray applications, and cold spray field implementation.

Session 4:

- Presentations were given by Westinghouse, EPRI, NNL, Federal Aviation Administration (FAA), Oak Ridge National Lab (ORNL), and PNNL.
- The topics that were presented include implementation process of the AM thimble plugging device and advanced debris filtering bottom nozzle, progress on the American Society of Mechanical Engineers (ASME) code case and data package for 316L laser powder bed fusion, inservice inspection, and accelerating quality certification of critical components with AM.

Session 5:

- Presentations were given by America Makes, National Institute of Standards and Technology (NIST), Savannah River National Lab, General Electric, EPRI, ASTM International, NASA, and NNL.
- The topics that were presented include development of consensus standards to enhance readiness of AMTs through roadmaps and centers of excellence, development of nuclear and non-nuclear standards, and the industry and regulatory needs that are driving the development.

Session 6:

- Presentations were given by the NRC, the Finnish Radiation and Nuclear Safety Authority (STUK), FDA, and FAA.
- The topics that were presented include the approaches for regulating AMTs from nuclear and non-nuclear regulators.

Session 7:

- Presentations were given by VTT, ORNL, Idaho National Lab, ANL, University of Wisconsin, NIST, and EWI.

- The topics that were presented include worldwide efforts from researchers on solutions to quality assurance and quality control issues, role of modeling and simulation in accelerating the qualification of new AMT materials, investigation of cold spray as a corrosion mitigation strategy, advances in in-situ monitoring, and an overview of the Advanced Manufacturing Consortium and its role in coordinating and funding AM research.

Key Takeaways:**Session 1:**

- Experience with AM components in low or non-safety significant nuclear and non-nuclear applications is being generated and growing.
- Use of PM-HIP with EBW for larger nuclear components looks promising, but requires larger HIP and EBW fabrication capabilities.
- Cold spray is being used increasingly for Army applications, particularly for high wear applications.

Session 2:

- AMT technologies evolve quickly, outpacing the qualification and licensing process.
- More collaboration would be beneficial for industry, Department of Energy (DOE), national labs and NRC.
- Operating experience should be utilized from other industries.

Session 3:

- Applications should be targeted to optimize unique AM characteristics.
- Current analysis tools and the digital nature of AM allows deeper understanding of causal effects.
- Regulatory authorities are exploring strategies to support accelerated safe deployment of AM components.
- PM-HIP and EBW offer possibilities for large-scale nuclear applications but are currently limited by its current capabilities.
- High velocity CS can provide several options for component surface treatment including SCC mitigation, hard-facing, or component repair.
- Strategies have been developed to achieve field application of CS for components and structures with limited accessibility.

Session 4:

- 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.

Session 5:

- Many gaps exist in technology and standards development. The American National Standards Institute is tracking these gaps (www.ansi.org/amsc).
- Standards development organizations benefits from continual communication to reduce redundant standards development.

- Collaboration with regulatory agencies would be helpful to identify codes and standards needs.

Session 6:

- The regulators share many common bases, including performance-based regulation.
- The regulators share common technical concerns for AM, e.g., powder characteristics, 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.

Session 7:

- Over the next several years, there will be significant strides in nuclear-focused AM research.
- Accelerated qualification of new AM materials is an area of interest to the community.

Next Steps:

Session 1:

- 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 benefit to the development and use in nuclear applications.

Session 2:

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

Session 3:

- Identify strategies to effectively collaborate and rapidly incorporate lessons-learned in standards and guidance.
- Expand technical basis to move beyond substitutive applications.
- Support intelligent, performance-based qualification framework.
- Continue developing technical basis for utilizing these technologies in nuclear applications.
- Identify opportunities where these technologies can simultaneously improve component performance (and safety) while reducing lifecycle asset management costs.
- Consider methods and applications where AMTs can be combined to optimize performance and increase design flexibility.

Session 4:

- Codes and Standards development to expand and continue to mature.

Session 5:

- NRC to initiate communication with other regulatory bodies on AMT topics.
- Encourage involvement in standards development.

- Encourage communication between SDOs on AMT standards development.

Session 6:

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

Session 7:

- Continue to evaluate research needs and technology gaps.

**Enclosure 2
Workshop Agenda**

Day 1 - Monday, December 7, 2020

<u>Session</u>	<u>Organization</u>	<u>Speaker</u>	<u>Title or Topic</u>	<u>Local Time (EST)</u>
Opening	NRC	Raymond Furstenuau	Opening / Introduction	8:00 – 8:10
	NRC	Matthew Hiser	Overview of Workshop	8:10 – 8:30
	Q&A / Discussion			8:30 – 8:45
Session 1 – Practical Experience Related to Implementing AMTs	Siemens	Pajazit Advovic	Siemens Gas and Power – Overview of Additive Manufacturing, Benefits and Challenges Industrial Approach for AM	8:45 – 9:15
	BREAK			9:15 – 9:25
	ENGIE	Steve Nardone / Arne Claes	Experience with AM and Related Nuclear Applications	9:25 – 10:10
	Rolls–Royce	John Sulley	Rolls–Royce's Introduction of HIP Nuclear Components	10:10 – 11:00
	BREAK			11:00 – 11:10
	Army Research Lab	Matthew Siopis	Cold Spray Technology and Experience in Army Applications	11:10 – 11:40
	US Navy	Justin Rettaliata	Additive Manufacturing Efforts in Support of the U.S. Navy Fleet	11:40 – 12:10
	General Q&A / Discussion from Session 1			12:10 – 12:30
LUNCH				12:30 – 1:15
Session 2 – Plans and Priorities for AMT Implementation in Commercial Nuclear Applications	Nuclear Energy Institute (NEI)	Hilary Lane	Industry Perspectives on AMTs	1:15 – 1:45
	Electric Power Research Institute (EPRI)	Marc Albert	Vision of AMT Use in Industry	1:45 – 2:15
	BREAK			2:15 – 2:25
	Exelon	Lee Friant	Utility Perspective on Implementing AMTs in LWRs	2:25 – 3:00
	Westinghouse	Clinton Armstrong	Westinghouse Advanced Manufacturing Development and Implementation Efforts	3:00 – 3:30
	BREAK			3:30 – 3:40
	Framatome	Christopher Wiltz	Potential Applications, Challenges and Progress of Framatome Additive Manufacturing Application	3:40 – 4:10
	Pacific Northwest National Lab (PNNL)	Robert Oelrich	AMT with Advanced Materials in Nuclear operations	4:10 – 4:40
General Q&A / Discussion from Session 2			4:40 – 5:00	

Day 2 - Tuesday, December 8, 2020

<u>Session</u>	<u>Organization</u>	<u>Speaker</u>	<u>Title or Topic</u>	<u>Local Time (EST)</u>
Session 3 – Performance Characteristics of AMT-Fabricated Components	NRC	Robert Taylor	Introductory Remarks	8:00 – 8:10
	Rolls–Royce	David Poole / William Press	Rolls–Royce's Introduction of AM Nuclear Components	8:10 – 8:55
	Naval Nuclear Lab (NNL)	Steven Attanasio	Fatigue and Mechanical Properties of Laser Powder Bed Fusion 316L Stainless Steel	8:55 – 9:25
	BREAK			9:25 – 9:40
	National Aeronautics and Space Administration (NASA)	Christopher Kantzos	Impact of Powder Supply Variation on Microstructure and Properties in Additive Manufactured Alloy 718	9:40 – 10:10
	US Naval Academy	Raymond Santucci / Elizabeth Getto	Elucidating the Effect of Feedstock Powder Spheroidization Treatment on Selective Laser Sintered Additively Manufactured 316L Stainless Steel	10:10 – 10:40
	BREAK			10:40 – 10:50
	Naval Research Lab (NRL)	David Rowenhorst	Linking 3D Microstructural Analysis of Additive Manufactured 316L to Performance and Properties	10:50 – 11:20
	NRL	Richard Fonda	The Effects of Post–Processing on Mechanical Properties and Corrosion Behavior of AM 316L Stainless Steels	11:20 – 11:50
	LUNCH			11:50 – 12:40
	Food and Drug Administration (FDA)	Daniel Porter	Process Validation for AM at the FDA	12:40 – 1:10
	NRC	Margaret Audrain	Technical Assessments of AMTs	1:10 – 1:40
	General Q&A / Discussion from Session 3 – AM			1:40 – 2:10
	BREAK			2:10 – 2:20
	Other AMTs			
	EPRI	David Gandy	PM–HIP and Electron Beam Welding Development for Nuclear Applications	2:20 – 2:50
	PNNL	Ken Ross / Jack Lareau	Cold Spray Process Details and Nuclear Applications	2:50 – 3:20
	BREAK			3:20 – 3:30
	VRC Metal Systems	Kyle Johnson	Cold Spray Mitigation and Repair for Nuclear Applications	3:30 – 4:00
	Argonne National Lab	Bogdan Alexandrenau / A.K. Rai	Laser Glazing of Cold Sprayed Coatings for the Mitigation of Stress	4:00 – 4:30

	(ANL) / UES, Inc.		Corrosion Cracking in LWR Applications	
General Q&A / Discussion from Session 3 – other AMTs				4:30 – 5:00

Day 3 – Wednesday, December 9, 2020

<u>Session</u>	<u>Organization</u>	<u>Speaker</u>	<u>Title or Topic</u>	<u>Local Time (EST)</u>
Session 4 – Approaches to Component Qualification and Aging Management	NRC	Louise Lund	Introductory Remarks	8:00 – 8:10
	Westinghouse	David Huegel	AM Thimble Plugging Device / Advanced Debris Filtering Bottom Nozzle Implementation Process	8:10 – 8:40
	Westinghouse / EPRI	Clinton Armstrong / David Gandy	Approach for 316L LPBF Code Case and Data Package	8:40 – 9:10
	BREAK			9:10 – 9:20
	NNL	Tressa White	Certification of the First Powder Bed Fusion Component in a US Naval Nuclear Propulsion Plant	9:20 – 10:00
	Federal Aviation Administration (FAA)	Michael Gorelik	On the Development of Fatigue and Damage Tolerance Framework for Metal AM Parts	10:00 – 10:30
	BREAK			10:30 – 10:40
	Oak Ridge National Lab (ORNL)	Vincent Paquit	Accelerating Quality Certification of Critical Components with Additive Manufacturing	10:40 – 11:10
	PNNL	Joel Harrison	Inservice Inspection and considerations for AMT components	11:10 – 11:40
	General Q&A / Discussion from Session 4			
LUNCH				12:00 – 12:45
	America Makes	Brandon Ribic	Overview of America Makes Activities	12:45 – 1:10
Session 5 – Codes and Standards Activities and Developments	National Institute of Standards and Technology (NIST)	Shawn Moylan	Standards Landscape for Additive Manufacturing	1:10 – 1:40
	BREAK			1:40 – 1:50
	Savannah River National Lab	George Rawls	Update on AM Activities in ASME Code	1:50 – 2:20
	General Electric / EPRI	Brian Frew / David Gandy	Approach to Codifying New Manufacturing Methods (e.g., PM–HIP, LPBF, EBW)	2:20 – 2:50
	BREAK			2:50 – 3:00
	ASTM International	Mohsen Seifi	Recent Advancements on ASTM Additive Manufacturing Research & Standardization	3:00 – 3:30
	NASA	Douglas Wells	NASA Standard for Use of AM in Crewed Spaceflight Applications (NASA–STD–6030)	3:30 – 4:00

	NNL	Jessica Coughlin	Development of AWS D20.1 standard	4:00 – 4:30
General Q&A / Discussion from Session 5				4:30 – 5:00

Day 4 – Thursday, December 10, 2020

Session	Organization	Speaker	Title or Topic	Local Time (EST)	
Session 6 – Regulatory Approaches for AMTs	NRC	Anna Bradford	Introductory Remarks	8:00 – 8:10	
	NRC	Carolyn Fairbanks	NRC Regulatory Approach for AMTs	8:10 – 8:35	
	Finnish Radiation and Nuclear Safety Authority (STUK)	Pekka Välikangas	STUK Regulatory Approach for AM	8:35 – 9:05	
	BREAK				9:05 – 9:15
	FDA	Matthew Di Prima	FDA Regulatory Approach for AM	9:15 – 9:45	
	FAA	Michael Gorelik	Regulatory Considerations for AM and "Lessons Learned" for Structural Alloys	9:45 – 10:15	
	General Q&A / Discussion from Session 6				10:15 – 10:40
BREAK				10:40 – 10:50	
Session 7 – Research and Development of AMTs	VTT	Pasi Puukko	Quality Control Tools for Metal AM and EU NUCOBAM project	10:50 – 11:20	
	ORNL	Kurt Terrani	DOE Transformational Challenge Reactor Program	11:20 – 11:50	
	LUNCH				11:50 – 12:40
	Idaho National Lab	Isabella van Rooyen	DOE–NE Advanced Manufacturing Methods Program Overview	12:40 – 1:10	
	ANL	Mark Messner	Rapid Qualification of New Materials Using Modeling and Simulation	1:10 – 1:40	
	BREAK				1:40 – 1:50
	University of Wisconsin / Kairos Power	Kumar Sridharan / George Young	Cold Spray Development for Coatings	1:50 – 2:20	
	NIST	Brandon Lane	In-situ Process Measurements for Monitoring, Control, and Simulation of AM	2:20 – 2:50	
	BREAK				2:50 – 3:00
	EWI	Mark Barfoot	Additive Manufacturing Consortium	3:00 – 3:30	
General Q&A / Discussion from Session 7				3:30 – 4:00	
Workshop Wrap-up and Conclusion				4:00 – 4:30	

Enclosure 3
ADAMS Accession Numbers for Workshop Presentations

Session 1: ML20339A649

Session 2: ML20342A032

Session 3: ML20342A371

Session 4: ML20344A010

Session 5: ML20344A111

Session 6: ML20344A421

Session 7 (and additional presentations from Sessions 3, 4, and 6): ML20345A155

Additional presentations from Sessions 3 and 5: ML20351A159

Enclosure 4
List of Workshop Participants

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Raymond Santucci	US Naval Academy
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