David Rudland NRC	**NRC Activities in Advanced Manufacturing Technologies** As the nuclear industry progresses toward the use of AMT-built reactor components, it is critical that the inspection capabilities needed to qualify and monitor the integrity of these components are effective and reliable. There are multiple regulatory pathways that could lead to the use of such technologies and inspection of such components in safety related applications in nuclear plants. In continuation of previous efforts, the NRC is planning research to assess the feasibility of NDE methods for the inservice inspection of AMT components.
William Chuirazzi Idaho National Laboratory **Robert Montgomery** Pacific Northwest National Laboratory **Amir Ziabari** Oak Ridge National Laboratory	**DOE AMMT Efforts on Non-Destructive Evaluation for Additively Manufactured Nuclear Components** This talk focuses on non-destructive evaluation (NDE) efforts for additively manufactured (AM) nuclear components under the DOE office of Nuclear Energy Advanced Materials and Manufacturing Technologies (AMMT) program. The talk will cover 1) recent developments of AI-based X-ray CT reconstruction algorithms which allow for rapid and high-quality characterization of hundreds of parts, 2) investigations of correlations between neutron and X-ray CT imaging of AM components, and 3) investigations of ultrasonic techniques to characterize bulk material properties and as a means for inspection when component access is limited. We discuss the distinct capabilities of these techniques and highlight the synergies between them. Our plan is to leverage these techniques to qualify and certify AM components.
Joseph Turner University of Nebraska-Lincoln	**Ultrasonic NDE for Metal Additive Manufacturing: Impact of Microstructure** Ultrasonic nondestructive evaluation is important for inspection of metal samples created by additive manufacturing (AM). Currently, challenges remain with respect to the uniformity of microstructures in metal AM parts. In this presentation, these microstructures and their impact on defect detection will be discussed using several examples. Prospects for future research will then be presented.
Christopher Kube Pennsylvania State University	**In-process and Post-build NDE of Powder Bed Fusion Gr-91 Stainless Steel** An EOS M280 powder bed fusion system was integrated with several ultrasound sensors to monitor multiple parts simultaneously. The goal of the study was to use NDE during the process to discern slight difference in part microstructure. The in process measurements will be highlighted in addition to post-build resonant ultrasound spectroscopy. Discussion of all of the results, lessons learned, and outlook to be given.
Jesse Waller New Mexico State University	**NDE Inspection Needs for Additively Manufactured Components: A Technology and Standardization Gap Analysis** Version 3.0 of the ANSI/America Makes Standardization Roadmap for Additive Manufacturing is currently in public review. Key gaps related to the nondestructive evaluation (NDE) and qualification and certification approaches used by the aerospace industry are discussed. Common challenges faced by the aerospace industry and fracture critical spaceflight hardware and the nuclear industry and safety critical hardware are addressed. For example, a new NDE gap in the Roadmap has been introduced that encompasses in-service inspection of safety-critical components meeting the quality and performance requirements of the nuclear industry and regulatory authorities throughout the components' lifetime.

David G. Moore **Ciji L. Nerson** **Caleb A. Schauble** **Matthew J. Dennis** Sandia National Laboratories	**Characterization of Additively Manufactured Samples with Mechanical Testing and Nondestructive Inspection Techniques: A Path Forward for Qualification** Additively manufactured (AM) components contain discontinuities, indications, and defects which can change the component's mechanical performance during qualification or while the part is in-service. The inspection uncertainty and misidentification of discontinuities created during the AM build limits the use of this manufacturing process for aerospace applications. Current research at Sandia National Laboratories is addressing these concerns by focusing on mechanical characteristics, metallurgical techniques, and nondestructive inspection methods to assess uniaxial tensile specimens, which in turn will optimize the AM machine set-up parameters. This presentation focuses on a direct metal laser sintering (DMLS) powder bed fusion machine that is being prepared for production use. A background on Sandia National Laboratories' research efforts and how nondestructive evaluation assists design teams will be described. Four case studies will be summarized. Computed tomography, eddy current, and ultrasonic test methods will inspect AM specimens, and the advantages and disadvantages of each inspection method will be presented. The use of material strength testing, microstructural analysis, and nondestructive inspection techniques will be described, along with a roadmap for identifying limits for the qualification of AM materials.
Alexander Heifetz Argonne National Laboratory	**Detection of Microscopic Subsurface Defects in Metals with Unsupervised Learning of Pulsed Infrared Thermography Images** Pulsed infrared thermography (PIT) is a nondestructive method for imaging of internal defects in solids using heat transfer. Advantages of PIT include non-contact and one-sided material examination using compact instrumentation. PIT involves deposition of heat pulse on material surface with a flash lamp. As heat is diffusing from the surface into material bulk, material surface temperature is monitored with fast-frame Infrared (IR) camera via measuring blackbody radiation. Presence of internal defects is detected via appearance of transient temperature "hot spots" on material surface due to local thermal resistance of defects. Limitations of imaging resolution with PIT include blurring due to heat diffusion, detection sensitivity of IR camera, and uneven heating of the specimen. We investigated experimental limits of PIT detection of subsurface defects in high strength corrosion resistant stainless steel 316 alloy. Metallic specimens with calibrated microscopic flat bottom hole defects, with diameters in the range from 200μm to 75μm, were produced using electro discharge machining (EDM) drilling. PIT images were processed with the unsupervised learning (UL) based spatial-temporal blind source separation (STBSS) algorithm to enhance visibility of defects. While the raw PIT data did not show any material defects, using STBSS algorithm to process PIT reveals defects as small as 100μm in diameter. To the best of our knowledge, this is the smallest reported size of defect in a metal imaged with PIT.
Pingsha Dong University of Michigan	**Effects of Distributed Defects and Interactions on Fatigue Behavior of AM Components and a Zone-based NDE Methodology** Recent investigations have shown that fatigue behavior of metal AM components exhibits a significant difference from that typically seen in wrought materials. This can be attributed mainly to the presence of distributed geometric discontinuities and their interactions, particularly at stress riser locations. In this talk, some of the recent important findings are presented on effects of distributed defects and their interactions on fatigue behaviors of AM parts, particularly on test specimens containing stress raisers. The results suggests that a zone-based NDE inspection procedure should be a key enabler for ensuring both fitness-for- service of AM components and cost-effective deployment of AM technologies in safety-critical applications.

Steve Mahaut CEA-LIST	**NDE and Monitoring for AM Parts and Process** In this talk, several studies carried out at CEA will be presented, related to industrial and collaborative projects including various AM processes: powder bed fusion, wire arc additive manufacturing, direct energy deposition. Both NDE on built parts and online monitoring tools have been investigated, aiming at ensuring the quality of AM parts. Different NDE techniques (RT and CT, UT, ET) as well as specific NDE data analysis and correlation (with AM settings and building parameters) will be discussed.
Udisien Woy Nuclear Advanced Manufacturing Research Centre	**A Systemic Perspective on Developing Non-destructive Evaluation (NDE) Strategies for Additive Manufacturing (AM) Applications in Nuclear** Non-destructive evaluation (NDE) is an involving and encompassing endeavor that supports important decisions concerning the appropriateness of critical industrial structures, including those fabricated via additive manufacturing (AM). However, the potential advantages of these advanced manufacturing technologies, such as the ability to simplify the fabrication of complex geometries, are presently constrained by limited understanding of the resulting risk profile. Correspondingly, systemic factors influencing discreet AM technologies and procedures are explored, to accentuate the efficacy of different NDE methods for accurately and reliably informing validation requirements.
Ron Aman EWI	**Considerations and Experience Applying NDE to AM Materials and Components** EWI has been developing and applying NDE techniques to additive manufacturing materials for nearly 20 years. Special considerations need to be observed with AM materials due to complex geometry produced and unique microstructures observed in these materials. The application of NDE methodologies to large-scale Directed Energy Deposition (DED) aero structures, standard qualification builds and a new approach to use zone criticality and process observations to inform NDE processing will be discussed.
George Connolly, EPRI, Inc. **John Shingledecker**, EPRI, Inc. **Anand Kulkarni**, Siemens Corp. **Jeff Crandall,** CCAT, Inc. **Bruce Greer**, EPRI, Inc. **Stephen Tate,** EPRI, Inc.	**UT and FMC/TFM for Additively-Manufactured Components: Recent Experiences** We present a summary of recent UT scanning results, from both conventional UT and Full Matrix Capture/Total Focusing Method (FMC/TFM), and observations therefrom upon a series of AM coupons and reference standards. The components, designed in-house at EPRI, are printed using laser-based powder bed fusion (LPBF). The UT results are correlated against RT results and visual microstructural characterization. A procedure to quantify UT sensitivity to various reflectors is presented. We also comment upon UT performance in application to AM coupons composed of more than one metal.

Andrew Gavens Naval Nuclear Laboratory **Benjamin Palmer** Naval Nuclear Laboratory **James Eliou** Naval Nuclear Laboratory **Eric Biedermann** Vibrant Corporation **Garret Gatewood** Vibrant Corporation	**Using Process Compensated Resonance Testing to Differentiate Laser Powder Bed Fusion Additively Manufactured Witness Coupons Produced with Varying Process Parameters** Production of high quality additively manufactured (AM) components requires a consistent manufacturing process. Variability between builds, AM equipment manufacturers, and AM facilities using laser powder bed fusion (L-PBF) systems is currently a concern. Production of small witness coupons placed throughout a build volume provides material for evaluation upon completion of a build. 316L stainless steel witness coupons were built using a variety of L-PBF build conditions. These coupons were then evaluated with process compensated resonance testing (PCRT). PCRT is a fast, quantitative nondestructive evaluation and process control method that analyzes the resonance frequencies of a component. It was demonstrated that PCRT could differentiate coupons manufactured with default conditions from those produced with ±5% or greater variation in laser power or velocity. Using PCRT to nondestructively evaluate witness coupons produced alongside a component confirms that the equipment is operating correctly and can manufacture high quality material. This increases confidence that the AM build was performed under the desired process conditions and supports the overall component qualification.
Adam Wick **James Eliou** **Nicholas Cosentino** **Andrew Turnbull** Naval Nuclear Laboratory	**Embedding Surface-connected Cracks in 316L Stainless Steel Laser Powder Bed Fusion Manufactured Pipe Specimens for Qualification of Phased Array Ultrasonic Testing Inspection Techniques** This talk presents details and best practices for designing and fabricating cracked pipe specimens for qualification of phased array ultrasonic testing (PAUT) techniques using metal additive manufacturing. Conventionally, specimens like this are made by implanting electro-discharge machined (EDM) notches in pre-built pipes or by contract with a flawed specimen vendor that will implant more realistic cracks using proprietary processes. Fabricating PAUT qualification specimens using additive manufacturing allows for more realistic cracks (including realistic inter-granular stress corrosion cracking) placed and sized more accurately at a lower cost and a shorter turnaround time. Computed tomography has been used to image existing cracks to inform design of new ones and to verify proper placement and size of additively manufactured cracks.
Peter Collins Iowa State University	**On the Process-Structure-Property-Performance for Additively Manufactured Titanium Alloys** An Integrated Computational Materials Engineering (ICME) framework has been developed and applied for multiple variants of large-area additive manufacturing of the aerospace alloy Ti-6Al-4V. The approach permits the integration of (i) mesoscopic models of heat-transfer and a moving energy source with (ii) kinetic and thermodynamic models for the prediction of key aspects of the materials state and the subsequent (iii) uniaxial tensile properties and (iv) statistical methods of developing so-called “design allowable curves”. This previous effort has demonstrated which aspects of the materials state seem to matter for this particular alloy, as well as correlated features that could be measured. This work indicates the need to develop methods to measure materials state and materials composition, both of which can be controlled through the process. The control of the state, including NDE impact, will be presented. Of particular interest is the need to measure texture, defects, and composition. Insights into emergent work, as well as what is likely to be possible, will be presented.

Reza Zoughi **Peter Collins** Center for Nondestructive Evaluation, Iowa State University	**A Vision for Comprehensively Bringing Additive Manufacturing (AM) and Nondestructive Evaluation (NDE) Together in a National Testbed** We aim to establish a *unique* and *comprehensive national testbed facility* where engineers and scientist can collaborate to achieve one primary objective: Enable Next-Generation Additive Manufacturing (AM), where *in-process* and *post-manufacture* Nondestructive Evaluation (NDE) techniques are integrally implemented. The collaborating scientists and engineers will achieve this by adopting a holistic view of AM, and intentionally integrating individual research and development (R&D) activities into a larger framework which simultaneously considers: the AM processes; the materials involved; the build quality; the geometry/topology; and the desired properties and performance as defined by an end-user. These aspects are understood to be both hierarchical and potentially hybrid in nature (e.g., multiple AM processes for a given part, multiple materials, hierarchical topologies, etc.). *Quality assurance* underpins all of these efforts. Thus, this proposed Facility uniquely emphasizes the importance of integrating nondestructive evaluation (NDE) techniques directly into the AM paradigm and the emergent economy. Our collaborating scientists and engineers will conduct their activities while optimizing existing nondestructive evaluation (NDE) techniques and developing new and innovative methods for the sole purposes of *in-process* and *post-manufacture* inspection of the AM processes and products. This presentation outlines these objectives and discuss a roadmap for achieving them.