Enclosure 1

United States Nuclear Regulatory Commission
Action Plan for Advanced Manufacturing Technologies (AMTs), Revision 1

1. Background and Objectives

The initial draft advanced manufacturing technologies action plan (initial AMT AP) [1] dated January 28, 2019, addressed the needs for assessments of guidance updates and other activities to ensure NRC staff preparedness to review AMT applications from the nuclear industry. This document revises and updates the initial AMT AP to identify the accomplishments to date, provide the status of on-going tasks, and establish additional tasks which have been identified through the activities to date and completion of earlier tasks. The initial AMT AP and the Revision 1 AMT AP were developed based on the state-of-knowledge at the time each was drafted. The initial AMT AP assumed that the application of a single AMT component in a U.S. nuclear reactor would occur in the Spring of 2019, therefore tasks were grouped as either near-term needs or continuing needs. Since development of the initial AMT AP, the candidate AMT component has been identified by industry as a thimble plugging device (TPD). The Revision 1 AMT AP takes this and other developments into consideration and has re-structured the tasks by topic area. This revision includes tasks from the initial AMT AP that are carried over since they have not yet been completed, follow-on tasks based on work completed under the initial AMT AP, and new tasks that have become identified through the level of development by industry and evolution of AMTs over the past year.

AMTs have the potential to produce high quality components faster and at lower costs, while enhancing the performance of current operating plants and advanced reactors. In addition, AMTs have the potential to provide replacement parts for obsolete components relatively quickly and to reduce warehouse inventories. Several companies are pursuing AMTs in order to fabricate components for use in nuclear power plants [2-5]. The NRC recognizes that the nuclear industry is likely to use AMTs in applications that require regulatory oversight. The initial AMT AP and this revision focus on the development of appropriate regulatory guidance and requirements through a risk-informed and performance-based approach to regulatory decision-making. This will emphasize measurable (or calculable) parameters and objective criteria to assess performance that are established based on risk insights, deterministic analyses and/or performance history.

Traditionally, structural materials and manufacturing methods for safety-related nuclear components[1] are controlled and managed through consensus codes and standards that are endorsed through regulatory guides or incorporated into the NRC regulations. Safety-related components that are not produced using an NRC-endorsed code or standard can be approved as an alternative in accordance with 10 CFR 50.55a(z). At this point, the staff has not identified and does not anticipate that rule changes will be necessary for licensees to utilize AMTs; however, guidance may be needed for both staff and licensees to ensure efficient and effective safety review of applications that include AMTs.

The AMT AP reflects the dynamic nature of the fast-paced evolution of these technologies. As

[1] The term “component” is broadly meant to include new and replacement components, repair activities of existing components, and specific fabrication elements (i.e., welds, coatings, etc.) of a component.

such, the NRC anticipates periodic revisions of the AMT AP to reflect the evolving state of knowledge and potential industry utilization of AMT. Figure 1 provides a holistic illustration of the inter-related nature of the AMT AP tasks. As tasks progress and are completed, the information will be used to inform other tasks.

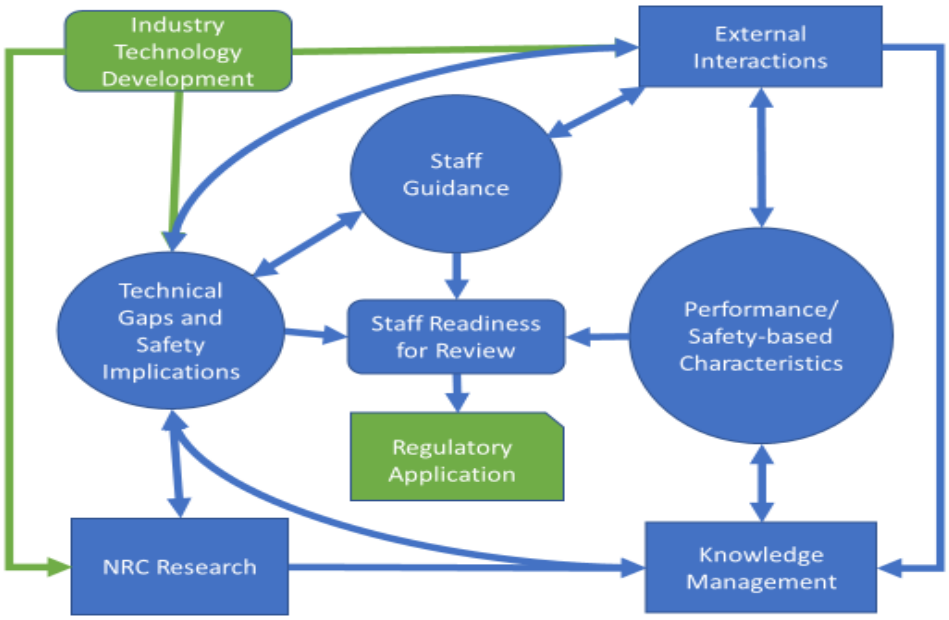

Figure 1: Interactive Nature of AMT AP Tasks

The objectives of the revised AP are to:

- Continue to assess the safety significant differences between AMTs and traditional manufacturing processes, from a performance-based perspective. The initial focus of these assessments are AMTs already identified as most likely to be used in the near-term for nuclear components that may require NRC approval (i.e., Additive Manufacturing (AM) - Laser Powder Bed Fusion (L-PBF), Directed Energy Deposition (DED); Powder Metallurgy – Hot Isostatic Pressing (PM-HIP); and Electron Beam (EB) Welding, and Cold Spray). Assessments of other AMTs will be considered, as appropriate, based on their potential application by industry [2].
- Prepare the NRC staff to address, as appropriate, industry implementation of components manufactured using AMTs through the 10 CFR 50.59 process.
- Identify and address AMT characteristics pertinent to safety, from a risk-informed and performance-based perspective, that are not managed or addressed by codes, standards, regulations, etc.
- Provide guidance and tools for review consistency, communication, and knowledge management for the efforts associated with AMT reviews.
- Provide transparency to stakeholders on the process for AMT approvals.

The deliverables and schedule associated with the revised AMT AP are provided in Table 1 (Enclosure 2). The staff plans revise this action plan on approximately 9-month to 12-month intervals. This interval may be extended if the staff determines the technology development has not progressed enough to warrant a change.

2. Summary of Accomplishments from the Initial AMT AP

The status of each task in the initial AMT AP and schedules for continued and new tasks are provided in the attached Table 2 (Enclosure 3). ADAMS accession numbers and dates are provided for completed tasks. Tasks which were not completed, will be continued with this revision. New tasks and follow-on tasks to completed tasks are included as well. The following list identifies the accomplishments under the initial AMT AP.

Task 1 Near-Term Needs:

- A public meeting on the initial AMT AP was held on February 7, 2019 (ADAMS Accession No. ML19035A043) – Task 1.1.
- A list of short-term interactions is listed in ADAMS Accession No. ML19108A024 – Task 1.2.
- A memorandum describing the candidate AMT method and timeframe was distributed to NRC Division Directors on April 18, 2019 – Task 1.3.
- Staff held discussions between headquarters (HQ) and Regional staff, and developed presentation materials on AMTs, particularly additive manufacturing, and the 10 CFR 50.59 process. This presentation was given at the NRC non-destructive evaluation (NDE) technical advisory group (TAG) meeting held during August 20-22, 2019 and was repeated via Skype for additional HQ and regional staff on September 23, 2019 – Task 1.6.

Task 2 Continuing Needs:

- An external interaction plan (ADAMS Accession No. ML19101A052) was completed – Task 2.1.
- Staff interacted with a variety of external organizations, including codes and standards committees, other government organizations (both regulatory and non-regulatory), industry (collective groups such as EPRI, Nuclear Steam Supply System (NSSS) vendors, and manufacturers), and international organizations. Information was disseminated to internal stakeholders and used to inform NRC activities related to AMTs – Task 2.2.
- A memorandum of understanding (MOU) Addenda with EPRI for Advanced Manufacturing was developed (ADAMS Accession No. ML19099A039) which facilitates technical communication and coordination – Task 2.2.
- Contracts have been placed with ORNL, PNNL, and ANL to support the development of a technical knowledge basis and provide gap analyses – Task 2.4.

Task 4 Knowledge Management:

- Staff participated in a Massachusetts Institute of Technology (MIT) course on AMT (2.5 months online course covering broad span of technologies) – Task 4.1.
- RES developed a SharePoint site (https://usnrc.sharepoint.com/teams/AMT_WG) – Task 4.1.

3. Tasks, Schedule and Deliverables

Section 2 above and the attached Table 2 (Enclosure 3) identify tasks from the initial AMT AP that have been completed. Those tasks from the initial AMT plan that were not completed and will be continued, and new/follow-on tasks to this revised AP are identified in this section and Table 2. Tasks were grouped as near-term and continuing need in the initial AMT AP. This revision groups tasks by topic, with cross-references to tasks from the initial AMT AP as appropriate.

Task 1: Technical Preparedness

Task 1 focuses on developing the technical information, knowledge, and tools to prepare the staff to review AMTs. There are three subtasks supporting this task, which are described in greater detail below.

Subtask 1A: AMT Processes under Consideration
(continuation of Task 1.5 of the initial AMT AP)

There are five AMT processes currently identified for NRC consideration based on industry interest and potential application within the next 3 –5 years: AM (L-PBF, and DED), PM-HIP, EB welding, and Cold Spray. Assessments of additional AMTs will be considered as appropriate based on their potential application by industry. Using the information gathered under the initial AMT AP, as well as additional staff training, site visits, contractor support, and the data gathered from earlier efforts, the staff will develop documents for each process to describe: (1) the differences between the proposed initial AMT-produced component relative to traditional manufacturing, (2) the safety significance of the identified differences, and (3) the aspects of the technology not addressed by codes and standards or regulations for each of the AMT processes currently under consideration. These documents will focus on performance-based considerations between components made using AMT and traditional manufacturing. These documents will be scheduled as indicated in Table 1 (Enclosure 2).

Subtask 1B: Inspection and NDE

The staff must have adequate information in order to identify whether inspection and non-destructive examination (NDE) techniques are sufficient to assess the condition of AMT-fabricated components, in particular for the types of defects that can compromise the safe performance of the component and can accelerate degradation of the component during service. Staff will generate a report to assess the state of technologies in the testing and examination of parts made using AMTs. The assessment will focus on testing and/or methods that can be used to inspect AMT parts, and the advantages/disadvantages of and limitations associated with the various methods.

This report will be completed by November 2020 and will be used to inform an evaluation of the capabilities and limitations of the state-of-the-art NDE methods. This assessment will inform early staff decisions related to NDE on AMT-fabricated components as well as future research activities related to qualifications and inspections.

Subtask 1C: Modeling and Simulation of Microstructure and Properties

An important aspect of understanding the differences between AMT and traditionally-manufactured components lies in understanding the differences in the associated microstructures, and how these microstructural differences can affect the performance of the AMT component. This understanding will improve the staff's ability to address these differences when performing regulatory reviews. The material's microstructure can provide insight into the material behavior in the environment. By understanding the microstructure, one can possibly predict material properties and performance and minimize the need for expensive experiments. This approach is being considered by ASME for demonstrating acceptable performance in high temperature applications using additive manufacturing. This task will focus primarily on flaw characteristics and

distributions. Some technical issues, such as creep mechanisms for high temperature-specific modeling concerns may not be sufficiently developed for inclusion at this time.

This task will investigate the state-of-the-art in predicting microstructure and properties in AMT materials, which may aid in the development of qualification needs and potentially provide a path for validation of the acceptability of individual AMT components similar to the use of witness specimens and lot testing. Modeling and simulation tools are being developed to predict potential problem areas that otherwise may not be detectable by conventional NDE methods. Many organizations are currently comparing modeling and simulation results to the actual performance of AMT-fabricated components.

Staff will prepare two complementary reports for this task. The first report will evaluate modeling and simulation tools used to predict the initial microstructure of AMT components and identify existing gaps and challenges that are unique to AMT compared to conventional manufacturing processes. The report will address all the AMTs identified, other than cold spray, and may be supplemented later as other AMTs are identified for potential use. The report will be completed by December 2020 as indicated in Table 1 (Enclosure 2).

The second report will evaluate modeling and simulation tools used to predict the material properties and component integrity for AMT components based on their microstructure and identify existing gaps and challenges that are unique to AMT compared to conventional manufacturing processes. The report will be completed by December 2020 as indicated in Table 1 (Enclosure 2).

Task 2: Regulatory Preparedness

Task 2 focuses on developing the regulatory guidance and tools to prepare staff for efficient and effective review of AMT-fabricated components submitted to the NRC for review and approval. There are three subtasks supporting this task, which are described in greater detail below.

Subtask 2A: Implementation using the 10 CFR 50.59 Process
(follow-on to Task 1.6 of initial AMT AP)

Incorporate feedback from the Regional staff into the draft briefing document, "Implementation of 10 CFR 50.59 for Components Produced using Advanced Manufacturing Technologies – AMT Action Plan Subtask 1.6." Additional support to the Regions will be provided when requested by the Regional staff. These briefing materials will be updated as other AMTs are proposed. The final document will be completed by May 2020 as indicated in Table 1 (Enclosure 2).

Subtask 2B: Assessment of Regulatory Guidance
(continuation of Task 3 of the initial AMT AP)

The staff will assess whether any regulatory guidance (e.g., regulatory guides, standard review plan [SRP] sections) needs to be updated or created to clarify the process and procedure for reviewing submittals with AMT components. The need for revision will be based on the information gathered through this action plan and experience obtained through review of AMT component submittals.

An initial survey of NRC guidance has focused on NUREG-0800, "Standard Review Plan

for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition" (SRP). This document was selected because it represents a singularly important portion of NRC guidance pertinent to AMT review. While other guidance and regulations exist in the form of 10 CFR sections, regulatory guides, branch technical positions, etc., the SRP was deemed to be the most applicable, significant, high-value, and practical to update.

The staff will communicate their findings to the division directors by May 2020. This work will be discussed at the public meeting described under Task 2C.

Subtask 2C: AMT Guidance Document
(continuation of Task 2.7 in the initial AMT AP)

Using the information and knowledge gathered, the staff will develop a report which describes the generic technical information to be addressed in AMT submissions. The report will be discussed at public meeting(s) and modified accordingly. The report will build on the general characteristics discussed in Section 2 (*Performance-based AMT Application Characteristics*) of the initial AMT AP and will identify broad areas where AMT technology deviates from traditional manufacturing from safety, risk-informed and performance-based perspectives. The report will address the current state-of-knowledge and current anticipated AMT approaches; it is expected to require revision and updating based on lessons learned, the evolving state of knowledge and potential industry utilization of AMT. Industry-developed technical data packages for early AMTs may help inform the report. The report will serve as a resource for staff reviewers of AMT submittals.

The report will address these four generic topics, as one approach to organize generic guidance, and to improve the consistency and efficiency of staff reviews:

- Design and Performance Requirements
- Materials and Processes
- Demonstration Data
- In-Service Inspection and Aging Management

The four topics above are consistent with the discussion in Section 2 of the initial AMT AP and will provide guidance to reviewers pertaining to review of these topics.

The development of this document will be scheduled as indicated in Table 1 (Enclosure 2). A public meeting to present the concept / framework will be held in July 2020 and will also include discussion of the work completed under Task 2A and 2B. A second public meeting will likely be held in September 2020 once a complete draft document has been developed.

Task 3: Communications and Knowledge Management

Task 3 focuses on the integration of information from external organizations, including research regulatory, industry, codes and standards, and international bodies, into the NRC staff knowledge base for informed regulatory decision-making. This task coordinates external interactions, disseminates information from these interactions to the appropriate staff and supports technical training and workshops to improve staff knowledge of AMTs. The specific activities to accomplish this general task are described in five subtasks described in greater detail below.

Subtask 3A: Internal Interactions
(continuation of Task 2.6 of the initial AMT AP)

Staff will continue internal interactions to ensure all the information gathered is available and communicated to all Offices. There is wide potential for the application of AMT in the nuclear industry which would involve staff from across the agency. NRR/DSS will continue to perform its activities under the Accident Tolerant Fuel (ATF) project plan, but there may be greater need for interactions regarding advanced manufacturing related to fuel assembly components, such as spacer grids. In NMSS, AMTs are expected to have applications as mitigation/repair methods for potential degradation of dry storage canisters. Staff involved with vendor inspections will need to evaluate and monitor processes specific to the various types and applications of AMTs that licensees may incorporate.

Advanced reactor vendors have also expressed interest in the use of AMTs. The NRC anticipates that the design process for advanced reactors will involve an iterative process of assessments and decisions to manage risks, control costs, and resolve technical issues and regulatory concerns. Therefore, the interactions between the NRC staff and advanced reactor community, including individual vendors, will be somewhat different than more traditional interactions with an operating reactor or equipment supplier wishing to employ AMTs. Based on advanced reactor vendor feedback and technical needs, the NRC's NRR Division of Advanced Reactors and Non-Power Production and Utilization Facilities (DANU) will determine additional actions that need to be taken specifically on AMTs for advanced reactors.

Staff points of contact (POCs) in the fuels, dry storage, and advanced reactor areas will be identified and used to ensure technical and regulatory consistency and coordination. The AMT working group will meet with these POCs on a quarterly basis to discuss progress and emergent information, and to coordinate communication among affected technical staff and management within the agency.

Subtask 3B: External Interactions
(continuation of Task 2.1, 2.2, 2.4, and 2.5 of the initial AMT AP)

Staff will continue communications with external organizations as described in the external interaction plan. Staff will engage with external organizations as appropriate to gain an improved understanding on the use and performance of AMT parts. Descriptions and identification of several of these organizations are provided in Appendix C of the initial AMT AP. Staff will also continue to participate in ASTM and ASME Codes and Standards committees. Staff will monitor and then identify and pursue resolution of issues in the development of a new ASME code case currently in development, "*ASME Requirements for Pressure Retaining Equipment Using Powder Bed Fusion Additive Manufacturing*," and associated efforts. After each participation in an event, the NRC POC will draft a report which summarizes the interaction and information exchange, potential technical and regulatory impacts, and follow-on actions and next steps. Documentation will be completed and distributed within two weeks of the conclusion of the meeting and discussed, as appropriate, by the AMT working group. Staff will also remain engaged in ASTM/ISO standards development, in particular for AMTs that may take require additional evaluation because of the unique nuclear design requirements.

The external interaction plan will be expanded to identify specific meeting dates, as appropriate, through at least December 2020, with external POCs and staff POCs listed for each interaction. In addition, the external interaction plan may be revised based on prioritization and updated with additional interactions/organizations as appropriate. The next revision of the updated external interaction plan will be completed by May2020 as indicated in Table 1 (Enclosure 2).

Subtask 3C: Knowledge Management
(continuation of Task 4 of the initial AMT AP)

Information gathered, generated, and provided to the staff on the AMTs of interest should be effectively archived so future staff unfamiliar with AMT processes can readily access the information. This is particularly important for information used in review of an AMT-related submission. Knowledge management (KM) will be handled through a living KM plan, and the documents and information generated will be updated on a periodic basis. For each KM activity, this plan will identify the lead staff organization (RES, NRR, etc.), provide details of the KM approach, and provide a detailed schedule and an estimate of resources. Activities in the KM plan will include:

- AMT seminars – Seminars (with either internal or external presenters) on AMT technical or regulatory approaches, including discussion of aspects related to the NRC evaluation areas on an as needed basis.
- Additional NRC public meeting(s) for focused technical issues related to AMTs for reactor materials and components.
- AMT Training – External and internal training opportunities and workshops will be pursued as appropriate to provide the necessary technical information to relevant NRC staff.
- SharePoint – Maintaining and regularly updating the SharePoint site for relevant AMT information (https://usnrc.sharepoint.com/teams/AMT_WG).

Further staff development may include:

- Rotational assignments to improve cooperation and communication with other organizations actively working on relevant AMTs (e.g., Office of Nuclear Energy (NE) at the Department of Energy (DOE), National Institute of Standards and Technology (NIST), National Aeronautics and Space Administration (NASA), Department of Defense (DOD), Federal Aviation Administration (FAA)).
  - RES is planning to send two staff to perform rotations at Oak Ridge National Laboratory to improve firsthand knowledge of AMTs.
- Temporary assignment of personnel between agencies within the Federal Government, colleges and universities, federally funded research and development centers, and other eligible organizations, in accordance with the Intergovernmental Personnel Act (IPA) Mobility Program or similar programs

A draft of the Knowledge Management Plan will be completed in April 2020 and finalized in June 2020 as indicated in Table 1 (Enclosure 2).

Subtask 3D: Public Workshop
Staff will hold a public workshop on AMTs as a follow-on to the *Workshop on Additive Manufacturing for Reactor Materials & Components [5] which* was held November 28-29,

2017, at NRC Headquarters and documented in NUREG/CP-0310. In addition to discussing tasks completed and underway on the action plan, workshop topic areas will address assessments of AMTs, and may include: (1) state-of-the-art of AMT development, (2) industry activities and priorities, (3) testing to assess irradiation and aqueous environment effects on performance of AMTs, (4) qualification, (5) codes and standards, (6) NDE, (7) computer modeling, (8) applications for new and advanced reactors, (9) dry storage mitigation and repair, and (10) regulatory perspectives. The workshop will be held at a date to be determined, based upon availability of invited speakers and scheduling factors. These workshop topic areas will have a clear regulatory connection. A tentative target date for the workshop is December 2020, depending on speaker availability.

Subtask 3E: AMT Materials Information Course

A training course on AMT material information will be developed by appropriate subject matter experts to address knowledge management related information and other content identified by the inter-agency AMT team. The training materials will cover:

- Overview of AMT techniques, initially focusing on L-PBF, PM-HIP, EB welding, Cold Spray, and DED. Additional technologies may be added as they mature and become a nearer-term interest for industry application.
- A detailed consideration of unique aspects about an AMT relative to the conventional processes used to make the component, from a safety perspective with risk-informed and performance-based considerations.

These training materials will assist staff performing reviews or assessments for a wide range of potential AMT applications. Staff must understand the material and processing aspects of AMTs, and how material qualifications are developed through codes and standards. Training materials will be developed, and a training course will be held by November 2020, as indicated in Table 1 (Enclosure 2)

References:

[1] United States Nuclear Regulatory Commission DRAFT Action Plan for Advanced Manufacturing Technologies (AMTs), ADAMS Accession No. ML19029B355, January 25, 2019 (Publicly Available).

[2] NEI Report, *Roadmap for Regulatory Acceptance of Advanced Manufacturing Methods in the Nuclear Energy Industry*, May 13, 2019.

[3] Kinsey, S. and Jessup, W. United States Nuclear Manufacturing Infrastructure Assessment, prepared for DOE-NE, MPR 1660-0001-RPT-001, Rev 1, December 19, 2018.

[4] Thomas, B.T., *Short Summary of Work Completed for RAR NRO-2017-008,* "*Evaluation of Additive Manufacturing (3-D Printing) of Metallic Parts by Direct Metal Laser Melting (DMLM),"* (ADAMS Accession No. ML19011A105), January 31, 2019.

[5] NUREG/CP-0310, Proceedings of the Public Workshop on Additive Manufacturing for Reactor Materials and Components, ADAMS Accession No. ML19214A205, July 2019.