ADVANCED METHODS OF MANUFACTURING AND CONSTRUCTION FOR NUCLEAR ENERGY PROJECTS

A Report for the
U.S. Senate Committee on Environment and Public Works and the
U.S. House of Representatives Committee on Energy and Commerce

U.S. Nuclear Regulatory Commission
January 2025

TABLE OF CONTENTS

INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) developed this report as required by Section 401 of the Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act of 2024 (ADVANCE Act). Specifically, Section 401(a) of the ADVANCE Act requires the NRC to "submit to the appropriate committees of Congress a report... on manufacturing and construction for nuclear energy projects." Section 401(b) further requires the NRC to seek input from specified stakeholders. Section 401(c) includes specific requirements for the content of this report; the NRC has addressed each of these. As specified in Section 401 of the ADVANCE Act, this report focuses on "nuclear energy projects," including those that meet the definition of an advanced nuclear reactor in Section 3 of the Nuclear Energy Innovation and Modernization Act (NEIMA). This includes new light-water reactors (LWRs), non-LWRs, and fusion machines.

Implementing the ADVANCE Act is a key priority for the agency, and the NRC is continuing to work to provide regulatory clarity and predictability with respect to advanced manufacturing and construction for nuclear energy projects. In developing this report, the NRC considered actions it has taken to address the topics specified in Section 401 of the ADVANCE Act, such as the Advanced Manufacturing Technology action plan issued in 2020, which reflected the agency's commitment to readiness and understanding of this evolving field at the time (Ref. 1). The report builds on the actions taken and ongoing actions, to further identify potential future actions to address these topics. These actions are outlined in Enclosure 1 of this report. Depending on NRC regulatory needs, technology development, and stakeholder interest—and subject to resource availability and prioritization—potential future actions (Enclosure 1, Table 3) will be explored.

The NRC values public input and feedback on its implementation of the ADVANCE Act. As part of its efforts to respond to the requirements in Section 401(b) of the ADVANCE Act, the NRC held public meetings to seek input from a broad range of external stakeholders. The NRC also received correspondence from stakeholders related to Section 401 of the ADVANCE Act. Enclosure 2 contains details of those public meetings and a list of the incoming correspondence. The NRC considered the feedback in preparing this report.

EXAMINATION OF UNIQUE LICENSING ISSUES OR REQUIREMENTS (SECTION 401(c)(1)(A) OF THE ADVANCE ACT)

ADVANCED MANUFACTURING PROCESSES

Advanced manufacturing processes use one or more innovative advanced manufacturing technologies (AMTs) to manufacture existing products in new ways or to manufacture new products. These processes are more efficient than traditional manufacturing. Advanced manufacturing processes can include new ways to make or join hardware, surface treatments, or other novel manufacturing techniques. Examples of specific AMTs include additive manufacturing (3D printing), friction stir welding, and laser peening.

In the NRC's regulatory framework for fission designs, regulations in Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.55a, "Codes and Standards," provide two paths for NRC approval of AMTs for LWRs. The first path is through the NRC's incorporation by reference of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code Rules of Construction into 10 CFR 50.55a. Incorporation by reference provides clarity and reliability to applicants and licensees regarding regulatory requirements. The NRC has a long history of relying on the voluntary consensus standards process to develop requirements for

new technologies. The second path, under Section 50.55a(z), allows NRC applicants and licensees to obtain NRC approval for alternatives to the standards incorporated by reference.

In terms of unique licensing issues or requirements, advanced manufacturing processes are largely not covered by NRC-approved codes and standards. Where an advanced manufacturing process is not covered by codes and standards, the standards development process or a plant-specific approach would need to be used for applicants and licensees to pursue use of the advanced manufacturing process in a nuclear energy project. Development of standards and incorporation into the NRC's regulations, particularly for nuclear components, is technically complex and requires significant time and resource expenditures by both the NRC and external organizations. For a plant-specific approach, the applicant or licensee would need to provide a justification for the request for NRC approval that explains why the material is appropriate (i.e., safe) for the intended use. Further, the applicant or licensee would need a qualification program that can verify that specific items manufactured through the advanced manufacturing process will meet the specifications for the planned use. For example, a carbon steel reactor pressure vessel head could be manufactured using powder metallurgy hot isostatic pressing. Use of carbon steel manufactured using this advanced manufacturing process is not currently covered by the code. Therefore, an applicant or licensee would need to have a qualification program developed and provide a justification to support the request for NRC approval to demonstrate it is safe for its intended use.

The NRC does not have regulatory guidance that describes what information would be sufficient to support a request for NRC approval for use of advanced manufacturing processes not covered by codes and standards. The NRC has identified developing such guidance (DD3 in Enclosure 1, Table 3) as a potential future action to provide regulatory clarity to applicants and licensees and efficiency in the NRC review process. This action, if further pursued, is expected to be completed by quarter 4 (Q4) of fiscal year (FY) 2026. Additionally, a specific topic identified by stakeholders as an area for potential innovation is accelerated material qualification. The qualification of new materials for long-term elevated temperature applications in non-LWRs is a lengthy process. National laboratories, nongovernmental organizations, and universities are exploring innovative approaches to accelerate the deployment of new materials. Examples of such innovations being investigated include material microstructural modeling, machine learning, and stochastic data analytics, as well as novel integral effects experimentation and use of supplemental ion irradiation data. Development of novel performance-based condition monitoring and materials surveillance technologies is also being explored to assess the integrity of new materials qualified by these accelerated approaches during operation. The NRC has identified the development of additional guidance on how to perform accelerated qualification of new materials consistent with applicable NRC requirements (DD4 in Enclosure 1, Table 3) as a potential future action to provide greater clarity in this area. This action, if further pursued, is expected to be completed by Q1 of FY 2028.

ADVANCED CONSTRUCTION TECHNIQUES

Advanced construction techniques are innovative methods of construction, including the use of the latest technology and novel materials to streamline the building process, and often result in increased efficiency, sustainability, and cost-effectiveness. Examples of such methods include prefabrication, modular construction, 3D printing, and use of robotics. These advanced construction techniques are rapidly evolving and warrant examining licensing and oversight programs for adjustments appropriate for the new techniques.

The unique licensing issues and applicable requirements for advanced construction techniques are similar to advanced manufacturing processes because many advanced construction techniques are not covered by NRC approved codes and standards. The NRC has recent experience approving advanced construction techniques that are not currently covered by codes and standards. For example, the NRC staff approved a GE-Hitachi Nuclear Energy Americas, LLC (GEH) topical report for steel-plate composite structures (Ref. 2). GEH is considering revising this topical report as it updates its methods for construction. The NRC is participating in pre-application engagement with GEH to support an efficient review of the potential revision to the topical report (DE2 in Enclosure 1, Table 2). This ongoing action is expected to be completed by Q4 of FY 2026. NRC approval of topical reports involving advanced construction techniques streamlines the application of those techniques by approving technical approaches for their use and reduces burden for future applicants and licensees who can then reference the approved topical report to provide a technical justification for using the construction technique.

The NRC does not have regulatory guidance specifically focused on advanced construction techniques. The NRC has identified the development of regulatory guidance for the structural monitoring of designs using advanced construction techniques (DE1 in Enclosure 1, Table 3) as a potential future action to provide clarification to applicants and licensees and enhance the review process for submittals involving these techniques. This action, if further pursued, is expected to be completed by Q1 of FY 2027.

Another unique issue related to advanced construction techniques is the agency's readiness to provide oversight with respect to these techniques. The NRC staff is currently developing the risk-informed, performance-based, technology-inclusive, and scalable Advanced Reactor Construction Oversight Program (ARCOP) (Ref. 3) (DI1 in Enclosure 1, Table 2). This ongoing action is expected to be completed by Q1 of FY 2026. The ARCOP is a flexible inspection program that can adjust to the shorter construction timeframes, dynamic schedules, and offsite and modular construction methods of advanced reactor construction. The NRC staff sought public input on advanced construction methods through public sessions at the 2023 and 2024 Regulatory Information Conferences, as well as through four public workshops on the ARCOP held in 2024. In developing the ARCOP, the NRC staff also incorporated lessons learned from recent construction at Vogtle Electric Generating Plant, Units 3 and 4, and Virgil C. Summer Nuclear Station, Units 2 and 3 (Ref. 4).

RAPID IMPROVEMENT OR ITERATIVE INNOVATION PROCESSES

Rapid improvement or iterative manufacturing processes refer to systematic approaches where manufacturing processes are continuously refined and improved by repeating cycles of analysis, implementation, evaluation, and feedback, allowing for gradual adjustments based on data and results to achieve optimal production efficiency and quality over time.

For rapid improvement or iterative innovation processes, the unique licensing issues pertain to the applicant's or licensee's ability to make changes in design or construction techniques based on these processes within the NRC's current regulatory structure. The NRC currently has two licensing processes for fission power reactors: contained in 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities" (Part 50), and 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Part 52). Part 50 permits substantial flexibility during construction, with review of the final design occurring during or after construction as part of the operating license application review.

The NRC's regulations for combined licenses and design certifications under Part 52 are designed to promote standardization. Part 52 is best employed to maximize regulatory stability and the finality of agency safety decisions in the context of mature technologies that will normally not require significant changes during construction. All current design certification rules include controls on changes to the design depending on whether the information is designated as "Tier 1" or "Tier 2," with a portion of those as "Tier 2*." On November 20, 2024, the Commission directed the NRC staff (Ref. 5) to evaluate options for providing regulatory flexibility in Part 52 during construction and operational phases, including change process for Tier 1 and Tier 2* information and adjustment of Tier designations (DD7 in Enclosure 1, Table 2). This ongoing action is expected to be completed by Q2 of FY 2025.

In addition, applicants and licensees would benefit from additional guidance being developed to clarify pathways to incorporate rapid improvement or iterative innovation processes within the NRC's regulated activities. The NRC staff is currently developing design review lessons learned to improve the NRC's review process and guidance on rapid development and iterative innovation (DD6 in Enclosure 1, Table 2). This ongoing action is expected to be completed by Q4 of FY 2025.

EXAMINATION OF CERTAIN REQUIREMENTS AND OPPORTUNITIES (SECTION 401(c)(1)(B) OF THE ADVANCE ACT)

REQUIREMENTS FOR NUCLEAR-GRADE COMPONENTS IN MANUFACTURING AND CONSTRUCTION FOR NUCLEAR ENERGY PROJECTS

The requirements for nuclear-grade components in manufacturing and construction for nuclear energy projects vary for fission reactors and fusion machines. For fission reactors, 10 CFR 50.55a provides the regulations for codes and standards relative to the design, construction, operation, inspection, and testing of all relevant systems and components in a nuclear power plant. For nuclear-grade components, ASME BPV Code provisions are incorporated by reference in 10 CFR 50.55a. In addition, Institute of Electrical and Electronics Engineers (IEEE) standards are incorporated by reference in 10 CFR 50.55a for electrical and instrumentation and controls. 10 CFR Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," identifies requirements for quality assurance programs for structures, systems, and components with safety-related functions. The requirements of Appendix B are generally met by following ASME NQA-1, "Quality Assurance Requirements for Nuclear Facility Applications," which is incorporated by reference into 10 CFR 50.55a for LWRs and endorsed by NRC guidance.

For non-LWR designs, 10 CFR 50.55a has limited applicability, as most portions of the regulation are specific to LWRs. Currently, the most efficient way to determine acceptable nuclear-grade components is through the endorsement of non-LWR codes and standards via regulatory guides (RGs). For example, the NRC endorsed ASME BPV Code, Section III, Division 5, "High Temperature Reactors," in RG 1.87, Revision 2, "Acceptability of ASME Code, Section III, Division 5, 'High Temperature Reactors,'" January 2023 (Ref. 6), with exceptions and limitations. ASME BPV Code, Section III, Division 5 covers material, fabrication, design, testing, and installation requirements for both metals and nonmetals at elevated temperatures. The primary regulatory requirements related to quality assurance for manufacturing and construction of mechanical components for non-LWRs are in Appendix B to 10 CFR Part 50 and the principal design criteria, which are customized based on the reactor design. For electrical and instrumentation and controls, 10 CFR 50.55a(a)(2)(iii) incorporates by reference standard IEEE 603-1991, "IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations," which applies to new nuclear power reactors of all types.

Commercial fusion technology is currently in the initial development phase. The Commission directed that fusion machines be licensed and regulated under the byproduct material framework contained in 10 CFR Part 30 or adequate and compatible Agreement State regulations. The nuclear-grade requirements contained in 10 CFR 50.55a do not apply under this regulatory framework.

OPPORTUNITIES TO USE STANDARD MATERIALS, PARTS, OR COMPONENTS IN MANUFACTURING AND CONSTRUCTION FOR NUCLEAR ENERGY PROJECTS

Generally, the existing opportunities to use standard (i.e., commercial- or non-nuclear-grade) materials, parts, or components in manufacturing and construction differ based on the power reactor technology type. In addition, for all nuclear power plants, NRC regulations include a process, called commercial-grade dedication, through which licensees can evaluate commercially available items to demonstrate whether they are of sufficient quality to meet safety requirements, if applicable. This process is most frequently used for non-safety-related components and thus does not require NRC approval. If dedication is not possible for a particular part (e.g., if adequate quality cannot be demonstrated without destructive testing), then licensees and applicants may have to procure/manufacture the parts to nuclear-grade quality standards.

For LWRs, the NRC requires the use of specific ASME standards for the construction and repair of some systems, structures, and components based on their function and safety classification. However, licensees and applicants can request approval from the NRC to not use those standards. For non-LWRs, the NRC does not require the use of standards for construction or repair, and, as a result, applicants and licensees are able to use standard materials, components or parts without special approval whenever they can demonstrate those parts are adequate to perform their safety function. Like non-LWRs, the NRC does not require the use of standards for fusion machines.

The NRC is also monitoring ASME's development of code provisions for non-LWRs that aim to lower construction costs of nuclear components by leveraging nonnuclear construction practices that are commensurate with the component's safety and risk significance. The NRC is prepared to review these code provisions to determine if they are acceptable for demonstrating compliance with NRC requirements. As an example, the NRC is preparing for stakeholder interest in the use of standard materials, parts, or components in nuclear applications, such as by exploring the technical viability of using ASME BPV Code, Section VIII, "Rules for Construction of Pressure Vessels."

While there are many opportunities under existing regulations for NRC applicants and licensees to use standard materials and parts, the NRC recognizes that voluntary consensus standards, even if not required, may provide useful references to applicants and licensees in selecting appropriate parts and materials for use in facilities. The NRC is an active participant in the development of nuclear standards and will continue to follow the development of standards relevant to NRC-regulated activities, whether specific to nuclear industry or not.

In addition, approving the use of nonnuclear codes and standards would allow applicants and licensees to use standard materials manufactured for use in other industries.

The NRC is continuing to review opportunities to expand the ways that applicants and licensees may be able to make use of standard materials and parts for uses that require nuclear-grade materials. The NRC has initiated an effort to compare nuclear and nonnuclear codes and standards for pressure vessels and to identify safety and quality differences between these

codes and standards. As part of implementing the NRC action plan on enhancing the NRC codes and standards program for future reactors (Items 3.1 and 3.5 in Ref. 7), the NRC staff is working to identify available nonnuclear codes and standards (including those standards developed by the American Petroleum Institute and the International Organization for Standardization Standard 9001, "Quality management systems—Requirements"), as well as standard materials that have the potential for nuclear applications. The NRC staff then plans to assess the technical and quality differences between the selected nonnuclear and the applicable nuclear codes and standards to identify the aspects of the nonnuclear codes and standards, and standard materials, that could be applicable to nuclear components. The NRC has identified the development of risk-informed and performance-based component review guidance (DD2 in Enclosure 1, Table 3) as a potential future action to increase efficiency when assessing the proposed use of nonnuclear codes and standards in mechanical and structural integrity applications. This action, if further pursued, is expected to be completed by Q1 of FY 2026.

OPPORTUNITIES TO USE STANDARD MATERIALS THAT ARE IN COMPLIANCE WITH EXISTING CODES AND STANDARDS TO PROVIDE ACCEPTABLE APPROACHES TO SUPPORT OR ENCAPSULATE NEW MATERIALS THAT DO NOT YET HAVE APPLICABLE CODES AND STANDARDS

Following the process for qualification of nuclear or standard materials from existing codes and standards, as described in the "Advanced Manufacturing Processes" section above, provides an acceptable approach to support or encapsulate new materials that are not covered by codes and standards, such as some new high temperature alloy materials. The NRC is actively engaged with codes and standards organizations on these activities. The NRC has identified the development of guidance on the use of new materials that are not currently covered by codes and standards (DD3 in Enclosure 1, Table 3) as a potential future action to enhance efficiency with respect to qualifying new materials for existing LWRs, as well as new LWRs and non-LWRs. This action would expand on work conducted as part of the AMT action plan that focuses on qualification of non-code approved material (Ref. 1). This action, if further pursued, is expected to be completed by Q4 of FY 2026.

REQUIREMENTS RELATING TO THE TRANSPORT OF A FUELED ADVANCED NUCLEAR REACTOR CORE FROM A MANUFACTURING LICENSEE TO A LICENSEE THAT HOLDS A LICENSE TO CONSTRUCT AND OPERATE A FACILITY AT A PARTICULAR SITE

This section describes requirements relating to the transport of a fueled advanced nuclear reactor core and, consistent with the Senate Report, (S. Rep. 118-182) issued to address the ADVANCE Act, provides an update on work related to factory production of micro-reactors, including the utilization of manufacturing licenses, licensing considerations for initial fuel loading of reactor modules in a factory setting, and the transfer of fueled reactor modules between licensees. The NRC staff has provided options to the Commission for its consideration of policy issues related to micro-reactors that would be manufactured and fueled at factories and then transported to sites for power operation (Ref. 8). In one of the proposed options, a micro-reactor loaded with fuel would not be considered "in operation," provided that mechanisms are in place to prevent criticality, which would allow the use of existing NRC and U.S. Department of Transportation regulations, although exemptions from one or more regulatory requirements may be required (Ref. 9). The NRC also included similar provisions in the proposed rule for 10 CFR Part 53, "Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors"; those proposed provisions would consider a factory-fueled reactor to not be "in operation,"

provided that mechanisms are in place to prevent criticality. The NRC also plans to consider this topic in more detail as part of implementation of Section 208 of the ADVANCE Act.

With regard to transportation packages for micro-reactors,[1] the regulations in 10 CFR Part 71 provide flexibility for new technologies. For example, in May 2021, the NRC staff approved a transportation package involving a novel AMT friction stir welding manufacturing process for fabrication of the basket component (Ref. 10). The NRC has identified the development of additional guidance for the use of new or nonnuclear technologies and incorporation of greater manufacturing flexibility (i.e., iterative innovation) into transportation package designs (N1 in Enclosure 1, Table 3) as a potential future action to further enhance the agency's preparedness to review submittals associated with advanced manufacturing and construction. This action, if further pursued, is expected to be completed by Q1 of FY 2028.

IDENTIFICATION OF SAFETY ASPECTS OF ADVANCED MANUFACTURING PROCESSES AND ADVANCED CONSTRUCTION TECHNIQUES THAT ARE NOT ADDRESSED BY EXISTING CODES AND STANDARDS (SECTION 401(C)(1)(c) OF THE ADVANCE ACT)

This section highlights safety aspects of advanced manufacturing processes and advanced construction techniques that are not addressed by existing codes and standards, with a focus on whether guidance may be established or updated. For advanced manufacturing processes, a focus area for the NRC is to provide the ability to inspect advanced manufactured components for manufacturing defects that may threaten structural integrity. The NRC is engaging with the national laboratories to determine whether current nondestructive examination technologies can identify defects that may impact the function of advanced manufactured components. The NRC has identified the development of general guidance on the examination of novel materials to support structural integrity (DD5 in Enclosure 1, Table 3) as a potential future action to provide additional clarity in this area. This action, if further pursued, is expected to be completed by Q1 of FY 2028.

With respect to advanced construction techniques, the NRC staff is aware of several technologies that reactor designers are considering that are not addressed by existing codes and standards. However, the NRC is well-prepared to address these kinds of evolving technologies. The NRC has already reviewed and approved designs involving advanced construction techniques. For example, the AP1000 reactor design employed modular construction.

Additionally, the NRC is supporting the development of codes to address the safety aspects of advanced manufacturing and construction. For example, in RG 1.243, Revision 0, "Safety-Related Steel Structures and Steel-Plate Composite Walls for Other Than Reactor Vessels and Containments" (Ref. 11), the NRC endorsed, with exceptions and clarifications, the 2018 edition of American National Standards Institute/American Institute of Steel Construction code N690, "Specification for Safety-Related Steel Structures for Nuclear Facilities," which applies to the modular steel-plate composite design proposed by several reactor applicants. The NRC is also working to develop guidance on seismic isolators, which several advanced reactor applicants plan to use in novel ways, and on seismic design methodologies for advanced reactors (DE3 in Enclosure 1, Table 2). This ongoing action is expected to be completed by Q1 of FY 2028.

[1] A certified transportation package comprises the radioactive contents and the packaging hardware, such as the container, radiation shielding, criticality control elements, and shock-absorbing devices. See 10 CFR 71.4, "Definitions."

IDENTIFICATION OF OPTIONS FOR ADDRESSING THE ISSUES, REQUIREMENTS, AND OPPORTUNITIES (SECTION 401(c)(1)(D) OF THE ADVANCE ACT)

This section and Enclosure 1 summarize the completed, ongoing, and potential future actions that the NRC has identified for addressing issues, requirements, and opportunities examined in the report.

Table 2 in Enclosure 1 includes four ongoing NRC activities: (1) design review lessons learned to improve the review process and guidance on rapid development and iterative innovation; (2) ARCOP; (3) guidance on seismic design of advanced reactors; and (4) pre-application engagement on a potential revision to an approved topical report for steel-plate composite structures (DD6, DI1, DE2, and DE3 in Enclosure 1, Table 2, respectively). Table 3 in Enclosure 1 includes additional actions that the NRC will explore within the existing regulatory framework if warranted based on NRC regulatory needs, technology development, and stakeholder interest, and subject to resource availability and prioritization.

These potential future actions include guidance development for risk-informed, performance-based component review; new materials that do not yet have applicable codes and standards; examination of novel materials; incorporation of manufacturing flexibilities in transportation package designs; accelerated material qualification; and structural monitoring of designs using advanced construction techniques (DD2, DD3, DD4, DD5, N1, and DE1, in Enclosure 1, Table 3, respectively).

The NRC has not identified any actions that would require rulemaking at this time. After the NRC establishes the regulatory framework required by NEIMA as part of the 10 CFR Part 53 rulemaking, the NRC may consider whether further rulemaking related to the topics in ADVANCE Act, Section 401 would be appropriate and justifiable based on lessons learned from 10 CFR Part 53. For example, the future use of standard materials, parts, or components may benefit from the development of a new alternative performance-based codes and standards regulation, offering additional flexibility and regulatory efficiency for future LWR and non-LWR designs. The NRC staff would propose this approach to the Commission if developing such a regulation appeared both feasible and justifiable.

This report does not present any new actions focused on fusion machines, as the NRC is currently conducting a limited-scope rulemaking and developing guidance for fusion machines separately, consistent with NEIMA and the amendments made by Section 205 of the ADVANCE Act.

IMPACT ON OPPORTUNITIES FOR DOMESTIC NUCLEAR MANUFACTURING AND CONSTRUCTION DEVELOPERS (SECTION 401(c)(1)(E) OF THE ADVANCE ACT)

Advanced manufacturing and construction techniques result in many first-of-a-kind costs considerations for vendors and construction applicants. The scope and depth of justification needed for applications of new materials and technologies pose challenging questions for vendors and applicants. If manufacturing and construction were restricted to specific nuclear codes and standards, that would likely impact vendors by resulting in a smaller customer community across which to amortize compliance costs, potentially acting as a barrier to entry and in turn restricting purchasers to a smaller vendor community. Such restrictions would also create constraints for international vendors that may be working under different nuclear codes and standards.

Several of the actions identified in this report could clarify or expand the opportunities for more vendors to engage in nuclear energy projects. Nonnuclear vendors may gain additional clarity on potential opportunities in nuclear energy projects if additional guidance is developed regarding the expectations for new technologies and acceptable uses of codes and standards beyond those traditionally used. Providing guidance for applicants supports higher quality applications, which could facilitate more efficiency in application reviews. Additionally, clarifying where novel technologies, codes and standards, and flexibility in design can be leveraged would provide applicants with greater regulatory predictability as they seek to innovate and engage an expanded vendor community.

DESCRIPTION OF THE EXTENT TO WHICH COMMISSION ACTION IS NEEDED FOR IMPLEMENTATION (SECTION 401(c)(1)(F) OF THE ADVANCE ACT)

This report identifies potential future NRC actions that could improve clarity and efficiency associated with the use of advanced methods of manufacturing and construction. In some cases, Commission direction would be needed to budget for those actions and to review and approve policy or rulemaking proposals provided by the NRC staff. The NRC does not anticipate that Commission direction is needed to complete any of the ongoing actions identified in the report.

COST ESTIMATES, PROPOSED BUDGETS, AND PROPOSED TIMEFRAMES (SECTION 401(c)(2) OF THE ADVANCE ACT)

Enclosure 1, Table 3 shows the cost estimates, proposed budgets, and proposed timeframes by fiscal year for implementation of risk-informed and performance-based regulatory guidance for advanced manufacturing and construction for nuclear energy projects. The full-time equivalents represent NRC staff resources, and the dollar amount represents contractor support. The low and high range costs represent potential changes in final project scope, as refined following a decision to initiate the actions.

CONCLUSION

The NRC has several initiatives underway that will improve its agility and preparedness to efficiently review submittals associated with advanced manufacturing and construction for nuclear energy projects. The NRC staff solicited input from stakeholders in accordance with Section 401(b) of the ADVANCE Act and will continue to engage stakeholders in the future as other novel manufacturing techniques emerge in these rapidly evolving areas. The NRC will continue to seek innovative ways to address the use of advanced manufacturing processes, advanced construction techniques, and rapid improvement or iterative innovation processes for nuclear energy projects.

ACRONYMS

10 CFR	Title 10 of the *Code of Federal Regulations*
ADAMS	Agencywide Documents Access and Management System
ADVANCE Act	Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act of 2024
AMT	Advanced Manufacturing Technologies
ARCOP	Advanced Reactor Construction Oversight Program
ASME	American Society of Mechanical Engineers
BPV	Boiler and Pressure Vessel
CFR	*Code of Federal Regulations*
FY	Fiscal Year
GEH	GE-Hitachi Nuclear Energy Americas, LLC
IEEE	Institute of Electrical and Electronics Engineers
LWR	Light-Water Reactors
NEIMA	Nuclear Energy Innovation and Modernization Act
NRC	U.S. Nuclear Regulatory Commission
NQA	Nuclear Quality Assurance
Q	Quarter
RG	Regulatory Guide

REFERENCES

1. "United States Nuclear Regulatory Commission Action Plan for Advanced Manufacturing Technologies (AMTs)," Revision 1, June 22, 2020 (NRC's Agencywide Documents Access and Management System (ADAMS) ML19333B980).
2. Final Safety Evaluation for GE-Hitachi Licensing Topical Report NEDO-33926/NEDC-33926P, Revision 2, "BWRX-300 Steel-Plate Composite Containment Vessel and Reactor Building Structural Design" (Docket No. 99900003) (package at ML24220A014).
3. SECY-23-0048, "Vision for the Nuclear Regulatory Commission's Advanced Reactor Construction Oversight Program," June 6, 2023 (ML23061A086).
4. "10 CFR Part 52 Construction Lessons-Learned Report," January 16, 2024 (ML23325A202).
5. "Staff Requirements – SECY-22-0052 – Proposed Rule: Alignment of Licensing Processes and Lessons Learned from New Reactor Licensing (RIN 3150-Al66)," November 20, 2024 (ML24326A003).
6. RG 1.87, Revision 2, "Acceptability of ASME Code, Section III, Division 5, 'High Temperature Reactors,'" January 2023 (ML22101A263).
7. "Action Plan for Enhancing U.S. Nuclear Regulatory Commission's Codes and Standards Program for Future Reactors," August 22, 2024 (ML24234A013).
8. SECY-24-0008, "Micro-Reactor Licensing and Deployment Considerations: Fuel Loading and Operational Testing at a Factory," January 24, 2024 (ML23207A250).
9. "U.S. Nuclear Regulatory Commission Review of the Risk Assessment Approach for Transportation Package Approval of the Project Pele Transportable Nuclear Power Plant for Domestic Highway Shipment," August 5, 2024 (ML23321A132).
10. "Certificate of Compliance No. 9381, Revision No. 0, for the Model No. HI-STAR 180L Package," May 5, 2021 (ML21124A143).

11. RG 1.243, Revision 0, “Safety-Related Steel Structures and Steel-Plate Composite Walls for Other Than Reactor Vessels and Containments,” August 2021 (ML21089A032).

ENCLOSURE 1

COMPLETED, ONGOING, AND POTENTIAL NEW ACTIONS RELATED TO THE ACCELERATING DEPLOYMENT OF VERSATILE, ADVANCED NUCLEAR FOR CLEAN ENERGY ACT OF 2024 (ADVANCE ACT) SECTION 401

Actions described in this Enclosure include completed, ongoing, and potential new actions related to Section 401 of the ADVANCE Act. These tables are not exhaustive but highlight actions of particular relevance to this report. The term “external entities” as used in the “Impact” column in the tables refers to the nuclear energy industry, nuclear and manufacturing technology developers, manufacturing and construction industries (including manufacturing and construction companies with operating facilities in the United States), and other public stakeholders expected to be directly affected by these actions.

Table 1 – Completed NRC Program Actions Related to ADVANCE Act Section 401

Action	Primary ADVANCE Act Section 401 Provision	Impact	Status/Timeframe
Issue Action Plan for Advanced Manufacturing Technologies	401(a)	Substantial impact to the NRC and external entities in facilitating enhanced readiness to review applications relying on advanced manufacturing processes.	Completed issuance of action plan; activities pursuant to action plan completed
Issue Action Plan for Enhancing U.S. Nuclear Regulatory Commission (NRC) Codes and Standards Program for Future Reactors	401(a)	Substantial impact to the NRC and external entities in supporting prioritization and facilitating enhanced readiness to review, for potential endorsement, codes and standards for use by future light-water reactor (LWR) and non-LWR applicants.	Completed issuance of action plan; activities pursuant to action plan ongoing
Approve GE-Hitachi Nuclear Energy Topical Report on BWRX-300 Steel-Plate Composite Containment Vessel and Reactor Building Structural Design	401(a)	Moderate impact to the NRC and external entities by documenting NRC approval of an advanced construction methodology and demonstrating the NRC's readiness to review advanced construction techniques for nuclear energy projects.	Completed

Table 2 – Ongoing NRC Program Actions Responsive to ADVANCE Act Section 401

Action	ADVANCE Act Section 401 Provision	Impact	Estimated Completion Timeframe
Provide a paper to the Commission evaluating options for providing regulatory flexibility in 10 CFR Part 52 during construction and operational phases (DD7)	401(c)(1)(A)	Regulatory flexibility in 10 CFR Part 52 during construction and operational phases, including with respect to the change process for Tier 1 and Tier 2* and adjustment of Tier designations is expected to yield moderate efficiency gains to the NRC and external entities.	Q2 fiscal year (FY) 2025
Develop design review lessons learned to improve the review process and guidance on rapid development and iterative innovation (DD6)	401(c)(1)(A)(iii)	Continued improvements and communication of the review process and guidance to support improved pre-application interactions, review planning, and reviews are expected to yield moderate efficiency gains for both the NRC and external entities.	Q4 FY 2025
Develop the Advanced Reactor Construction Oversight Program (DI1)	401(c)(1)(A)(ii)	Reframe and optimize inspection procedures and resource intensity for advanced reactor construction projects. Improved construction oversight is expected to yield substantial efficiency gains to the NRC and external entities.	Q1 FY 2026
Pre-application engagement on revision to approved topical report for steel-plate composite structures (DE2)	401(c)(1)(A)(ii)	Pre-application engagement supporting an efficient review of a revision, if submitted, to an approved GEH topical report on an advanced construction technique. Initial topical report previously approved. Revised topical report, if submitted and approved, would yield substantial efficiency gains to the NRC and applicants who reference the GEH topical report during design review.	Q4 FY 2026

Action	ADVANCE Act Section 401 Provision	Impact	Estimated Completion Timeframe
Develop guidance on seismic design of advanced reactors (DE3)	401(c)(1)(C)	Improve NRC efficiency and consistency of reviews focused on advanced reactor considerations. Improved application quality, established review criteria, and improved consistency of review are expected to yield moderate efficiency gains to the NRC and external entities.	Q1 FY 2028

Table 3 – Potential New NRC Program Actions Related to ADVANCE Act Section 401[2]

Action	ADVANCE Act Section 401 Provision(s)	Resources		Impact	Timeframe
		Cost Range (Low/High)	Currently Funded?		
Develop risk-informed and performance-based guidance on structural and mechanical review of components (DD2)	401(c)(1)(B)(ii)	1.50 – 2.00 full-time equivalent (FTE) $400 – $500K	Partially	Improvements in application quality, established review criteria, and consistency of review are expected to yield moderate efficiency gains to the NRC and external entities	Q2 FY 2025 – Q1 FY 2026
Develop guidance on new materials that do not yet have applicable codes and standards (DD3)	401(c)(1)(A) & (c)(1)(B)(iii)	1.25 – 1.75 FTE $125 – $175K	Partially	Improvements in application quality, established review criteria, and consistency of review are expected to yield moderate efficiency gains to the NRC and external entities	Q2 FY 2025 – Q4 FY 2026
Develop guidance on accelerated material qualification (DD4)	401(c)(1)(A)(iii)	1.50 – 2.00 FTE $400 – $500K	No	Improvements in application quality, established review criteria, and consistency of review are expected to yield moderate efficiency gains to the NRC and external entities	Q2 FY 2025 – Q1 FY 2028
Develop guidance on examination of novel materials (DD5)	401(c)(1)(C)	1.50 – 2.00 FTE $400 – $500K	No	Improvements in application quality, established review criteria, and consistency of review are expected to yield moderate efficiency gains to the NRC and external entities	Q2 FY 2025 – Q1 FY 2028

[2] These potential future actions will be undertaken depending on NRC regulatory needs, technology development, and stakeholder interest, and subject to resource availability and prioritization.

Action	ADVANCE Act Section 401 Provision(s)	Resources		Impact	Timeframe
		Cost Range (Low/High)	Currently Funded?		
Develop transport guidance for the use of new or nonnuclear technologies to provide greater manufacturing flexibility in package designs (N1)	401(c)(1)(B)(iv)	1.50 – 2.00 FTE $400 – $500K	No	Improvements in application quality, established review criteria, and iterative manufacturing flexibility are expected to yield moderate efficiency gains to the NRC and external entities	Q2 FY 2025 – Q1 FY 2028
Develop guidance for structural monitoring of designs using advanced construction techniques (DE1)	401(c)(1)(A)(ii)	1.50 – 2.00 FTE $400 – $500K	No	Improvements in application quality, established review criteria, and consistency of review are expected to yield moderate efficiency gains to the NRC and external entities	Q2 FY 2025 – Q1 FY 2027

ENCLOSURE 2

STAKEHOLDER ENGAGEMENT

Public Meetings

In the preparation of this report, the U.S. Nuclear Regulatory Commission (NRC) solicited input from a broad range of external stakeholders, consistent with the requirements in Section 401(b) of the ADVANCE Act. Specifically, the NRC sought input from the U.S. Department of Energy, the nuclear energy industry, national laboratories, institutions of higher education, nuclear and manufacturing technology developers, manufacturing and construction industries, standards development organizations, labor unions, nongovernmental organizations, and other public stakeholders. The NRC held the following public meetings to seek input from external stakeholders on advanced methods of manufacturing and construction for nuclear energy projects:

- 2024 NRC Standards Forum (September 25, 2024)

  The Standards Forum is an annual meeting that facilitates strategic discussions on codes and standards needs and priorities across standards development organizations (NRC's Agencywide Documents Access and Management System (ADAMS) ML24298A246). Discussions at the forum enhance coordination in the development of codes and standards and explore opportunities to accelerate the NRC's review and potential endorsement of these codes and standards. This forum included an afternoon session on advanced manufacturing and construction for nuclear energy projects and a focused session led by the NRC to gather public input in response to Section 401 of the ADVANCE Act.

- Advanced Methods of Manufacturing and Construction—ADVANCE Act—Section 401 (September 30, 2024)

  The NRC held this public meeting to solicit input from external stakeholders on advanced methods of manufacturing and construction for nuclear energy projects (ML24291A083). The public meeting covered each of the topics specified in Section 401 of the ADVANCE Act.

- Periodic Advanced Reactor Stakeholder Meeting (October 30, 2024)

  The NRC conducts periodic meetings to share information and discuss topics related to the licensing and regulation of advanced reactors with the nuclear industry and other stakeholders. The NRC solicited public input related to Section 401 of the ADVANCE Act during the October 30, 2024, periodic advanced reactor stakeholder meeting (ML24355A157).

Correspondence

Table 1 below lists the groups who submitted written correspondence to the NRC related to Section 401 of the ADVANCE Act.

Table 1: Incoming Correspondence Related to ADVANCE Act Section 401

Incoming Correspondence	ADAMS Identifier
October 2, 2024, letter from the Breakthrough Institute to Mike King, Special Assistant for ADVANCE Act Implementation— "Sec. 401. Report on Advanced Methods of Manufacturing and Construction for Nuclear Energy Projects"	ML24276A206
October 14, 2024, comments from the Breakthrough Institute via "Contact Us" form on NRC ADVANCE Act public webpage	ML24295A113
November 11, 2024, letter from Andrew Mauer, Sr. Director, Regulatory Affairs, Nuclear Energy Institute, to Mike King, Special Assistant for ADVANCE Act Implementation——"NEI Input on Advanced Methods of Manufacturing and Construction for Nuclear Energy Projects"	ML24317A080