U.S.NRC
United States Nuclear Regulatory Commission
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Important Aspects in Nondestructive Examination for Advanced Manufacturing Technologies and Novel Materials

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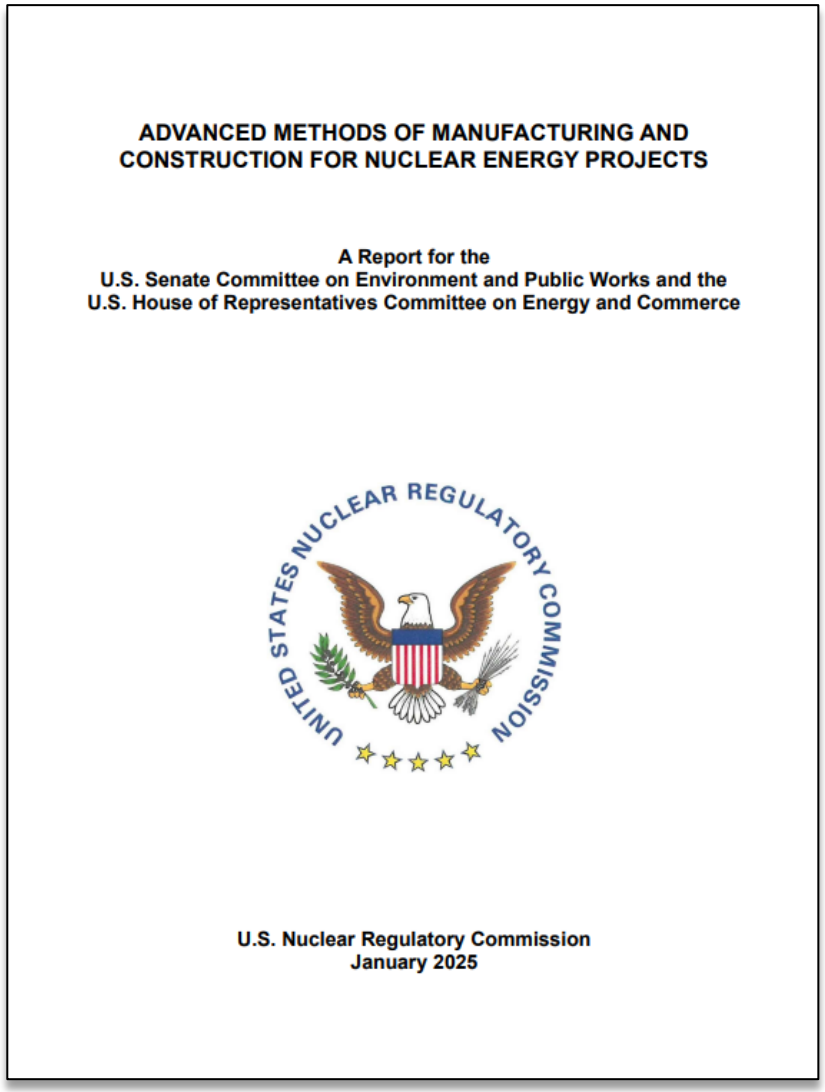
2026 Industry/NRC NDE Technical Information Exchange Public Meeting

Outline

- Describe Goals for ADVANCE Act DD5
- Applying Lessons-Learned to New Methods and Materials
- What to do at Different Stages in deploying NDE
  - Fabrication Flaws
  - Service-induced degradation
- Graded Approach to NDE Rigor

ADVANCE Act, Section 401

- Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act of 2024
  - the **Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act of 2024** (ADVANCE Act) Section 401 and the staff report (ML24320A077).
- *Table 3 Action DD5*
  - Develop guidance on NDE of new/novel materials with an initial focus on materials and components manufactured using advanced manufacturing technologies (AMT)[1]
- This meeting is to gather stakeholder input on the future of NRC's work on the NDE of AMT and novel materials



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
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Development of DD5

- Nuclear components made by advanced manufacturing processes pose new and unique challenges due to the novel microstructures and defects that develop during the manufacturing process
- The effectiveness and reliability of nondestructive examination technologies need to be established with respect to these microstructures and relevant defects
- Instead of focusing on individual AMTs or materials, the NRC is considering provide general information for developing NDE of AMT and novel materials

Application Quality Boosts Review Efficiency

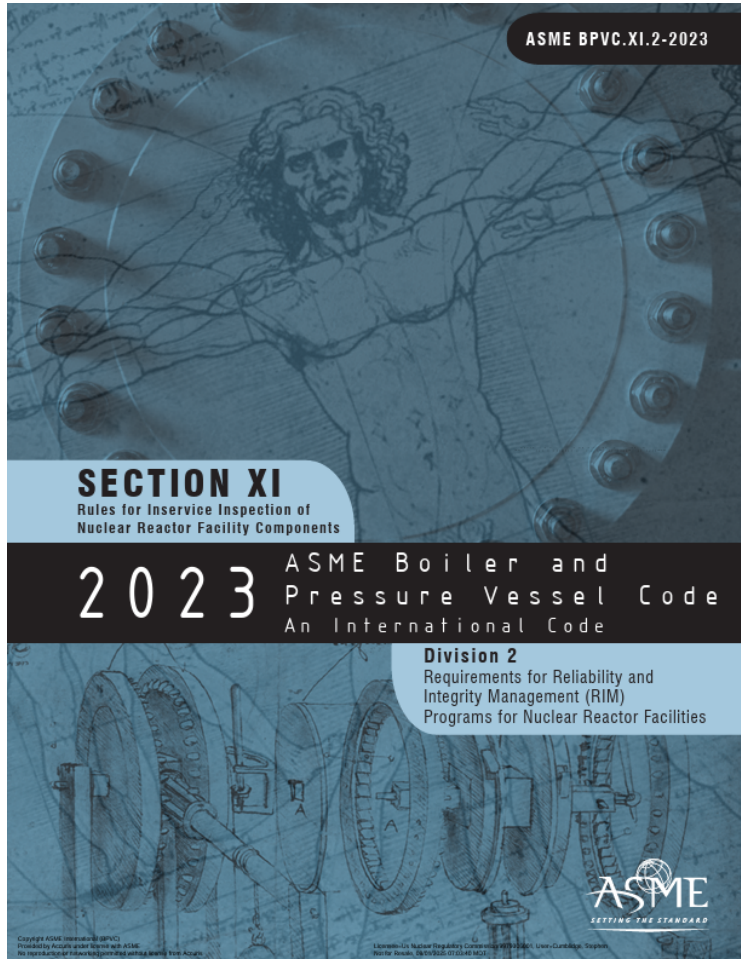
- With AMT, we can expect applications from applicants new to nuclear power and the NRC process
- The NRC is working to complete reviews in an expedited timeframe for a wide range of licensing actions
- Technical readiness is a key to an efficient review
- Understanding the types of information that the NRC has seen in successful applications will help the licensing actions and determinations

Applying Hard-Won Experience to New Applications

- The nuclear industry and the NRC have learned a lot about how to run certification and qualification programs
- Getting something out of the lab and onto a construction site has many challenges
- The use of these AMTs and materials can be streamlined to fit into a functional system if the developers are aware of the steps taken in the past

DD5 Program and RIM

- Many of the concepts described in this presentation can be found in ASME Code Section XI Division 2 Requirements For Reliability And Integrity Management (RIM) Programs For Nuclear Reactor Facilities
- A complete program designed using RIM will likely hit most or all the areas of interest



Making NDE Matter

- NDE Programs should be done with clear goals
  - Ensure components will perform as expected
  - Optimize safety factors
- NDE Programs need clear acceptance criteria
  - Clear acceptance standards prevent ambiguous situations
- NDE for the sake of performing NDE can be counterproductive
  - There have been many times when someone has added NDE to a process with no clear understanding of what to do with the information
  - This can cause issues that are challenging to resolve

What to Consider at Each Phase

- Mitigating Fabrication Flaws
  - Development Phase
  - Implementation Phase
- Mitigating Service-Induced Degradation
  - Development Phase
  - Implementation Phase
- Graded Approach Based on Consequence of Component Failure

Mitigating Fabrication Flaws

Development Phase

- Define the important parameters for the component construction
- Determine typical fabrication flaws for the material/method
- Determine acceptance criteria for fabrication flaws
- Find or develop an NDE method/procedure capable of reliably detecting and sizing fabrication flaws
- Determine alternate approach if NDE is not possible

Mitigating Fabrication Flaws

Implementation Phase

- Develop a Certification/Qualification for component production
- Develop a Certification/Qualification for the NDE
- Develop a technical basis document

Mitigating Service-Induced Degradation

- Development Phase
  - Determine the expected degradation mechanisms for the components under reactor conditions
  - Calculate the unacceptable flaw sizes or critical extent of degradation that would threaten the reliability of the component
  - Find or develop an NDE method/procedure or online monitoring capable of detecting and sizing service-induced degradation lower than the critical size/extent
  - Develop program to handle materials and configurations resistant to NDE (if any)
  - Develop a technical basis document

Mitigating Service-Induced Degradation

- Implementation Phase
  - For known and active degradation, develop an inspection or monitoring plan for each affected component timed to catch the degradation before reaching unacceptable levels
  - For Components with no known degradation mechanism, develop a sampling plan that provides reasonable assurance that any unexpected degradation in the components would be found before reaching unacceptable levels
  - Develop a Certification/Qualification for the NDE personnel, equipment, and procedure

Component Fabrication

Mitigating Fabrication Flaws

- Define the important parameters for the component construction
  - A given AMT method can produce a range of results, depending on the specifics
  - Variables such as the exact materials, heat input, time at temperature, and final heat treatments will all affect the microstructure of metals and possible fabrication flaws
  - Important information includes the allowed range of each of these variables and the final expected material properties using the proposed method

Determine possible or expected fabrication flaws for the material/method

- Once the exact fabrication method has been determined, it is important to determine what can go wrong during fabrication
- Each novel material and AMT will have their own set of fabrication flaws, which will be influenced by the parameters used to construct the component
- Determine the common flaws introduced by normal variations in the construction method and errors in the manufacture of the component

Determine acceptance criteria for fabrication flaws

- It is very important to define what constitutes an unacceptable flaw
- Workmanship Quality Based Standards:
  - “A well-made component made using this technique should have no flaws larger or more numerous than X”
  - Can produce components with consistent properties
  - Can result in excess repairs or rejected parts if too strict
- Structural Analysis Based Standards
  - Flaw size or quantity is based on the size of flaw that would compromise component reliability
  - Flaws need to be documented and tracked

Find or Develop Appropriate NDE Method

- Now that the materials and unacceptable flaws have been determined, one can choose an NDE technique and procedure
- The NDE procedure should be able to detect flaws that are smaller or less dense than the unacceptable flaw size

What if NDE Does Not Work?

- Some materials or component geometries may not allow for reliable detection of unacceptable flaws
- This has been handled in the past via a combination of controls and destructive testing
  - Show via destructive testing that components made following the allowed construction do not contain unacceptable flaws before beginning production
  - During production, a sample of components are destructively tested for quality assurance
- This would be more challenging for safety-significant components

Develop a Certification/Qualification for component production

- Once everything for the procedure has been determined, formally define the requirements for component production
  - What is the exact procedure to make the components, including essential variables and tolerances
  - What level of training and/or experience is required for personnel?
  - What makes and models of equipment can be used for the fabrication?

Develop a Certification/Qualification for NDE

- What is the exact procedure to perform the NDE, including essential variables and tolerances
- What level of training and/or experience is required for personnel?
- What makes and models of equipment can be used for the NDE?

Service-Induced Degradation

Determine the expected degradation mechanisms for the components in the field

- Components should be evaluated to determine if they will be subject to service-induced degradation
- Levels of Degradation
  - Active degradation
  - Postulated degradation
  - No known degradation
- This expected degradation rate should be based on the operating materials and operating conditions and possible cycling of the component in service

Calculate Unacceptable Degradation Levels

- A vitally important part of any NDE program is knowing how much degradation challenges the reliability and integrity of the component
- Develop pre-determined levels of degradation and actions when these levels are reached
- The critical degradation levels should be based on structural analysis
- The degradation rates should be considered in the critical degradation levels

Find or Develop an Appropriate NDE Method

- The NDE method should be able to detect degradation levels significantly smaller than the critical degradation level
- Periodic NDE
  - Easy to accommodate
  - Some level of design for inspectability required
  - Can increase outage lengths
  - No information between examinations
- Online Monitoring
  - Provides continuous information on the status of components
  - Should be incorporated into the design of the plant

Managing Active Degradation

- Active degradation sometimes cannot be avoided or comes as a surprise
- Mitigation or repair/replacement are the ideal solutions to active degradation
- Managing through NDE involves inspecting all affected components on a time scale dependent on the critical flaw sizes and the degradation rates for the components
- ASME Code Cases N-770 and N-729 are good examples

Sampling Plan

- Components without an active degradation mechanisms should be sampled to detect unexpected degradation mechanisms
- A statistical basis for the components should be determined, with an initial scope and expansion plan
- Absolute numbers of examinations may be better than percent sampling
- Sampling plan can focus on higher- importance components

Degradation where NDE is not Possible

- If NDE cannot be performed on a component for a given degradation mechanism, alternative steps may need to be taken
  - Surveillance programs with the same material in the same environment
  - Accelerated aging and degradation testing to determine a conservative estimate for the expected component lifetime

Leakage Detection

- While leakage detection may be the NDE method of last resort, it is invaluable
- Leakage detection may be of increased importance for some coolants
- Leakage detection adds a layer of defense in depth on top of the other NDE methods

Develop Certification/Qualification Programs

- What is the exact procedure to perform the NDE, including essential variables and tolerances
- What level of training and/or experience is required for personnel?
- What makes and models of equipment can be used for the NDE?

Graded Approach to use of NDE

- While these ideas apply to NDE in general, how strictly they should be applied is based on the importance of the component
- Qualitative Importance Measures
  - Does the component contain primary coolant?
  - Is the component used for shutdown cooling?
  - Would the component not functioning force a shutdown?
- Quantitative Importance Measures
  - Formal PRA evaluation
  - Consequence of failure
  - Failure modes and effects analysis

Artificial Intelligence in NDE

- AI for NDE data analysis is progressing, but is still not as capable as a trained inspector
- AI could be extremely useful for online monitoring
- The NRC is carefully tracking the development of AI for NDE

Final Thoughts

- The NRC has been considering the need for new NDE programs for new components and new reactor designs using these principles
- The NRC recognizes that the exact implementation of an NDE program will be dependent on the materials, manufacturing methods, and importance of the component
- The NRC is maintaining an awareness of the steps given in the ASME Code Section XI RIM program