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NRC Draft Guidelines Document
Laser – Directed Energy Deposition

Mark Yoo
Office of Nuclear Regulatory Research
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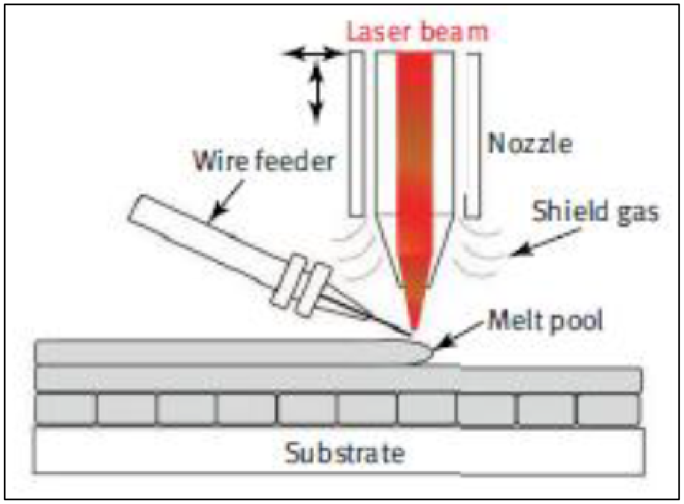
Outline

- Overview of Laser-Directed Energy Deposition (L-DED)
- Technical Basis for L-DED Draft Guidelines Document (DGD)
- Tie to Draft AMT Review Guidelines (Table 1)
- L-DED Technical Assessment
  - Table 2A: Material-generic Process Topics
  - Table 2B: 316L Material-Specific Properties / Performance Topics
- Conclusions

Laser-Directed Energy Deposition

- Process:
  - Wire or powder fed through nozzle into laser for melting
  - Fundamentally welding using robotics/ computer controls



Schematic of DED process

- Potential Applications
  - Medium sized Class 1, 2, and 3 components
  - Larger components than laser-powder bed fusion are possible due to faster production and greater build chamber volumes

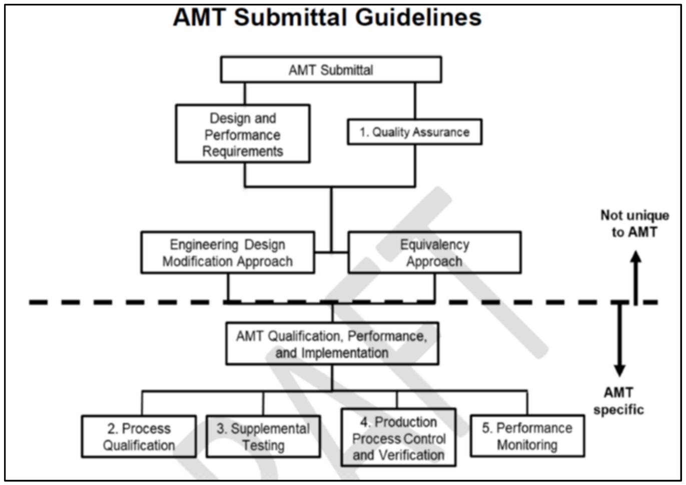
https://www.osti.gov/pages/servlets/purl/1437906

Draft AMT Review Guidelines

- Provides guidelines to assist NRC staff reviewing requests to use AMTs and identifies the range of information that could be necessary in a submittal
- General Review Philosophy:
  - **Sufficient**: all important (i.e., safety-significant or safety-related) attributes for the specific application of an AMT are addressed in sufficient technical depth to justify its use.
  - **Flexible**: a variety of both technical and regulatory approaches can be used to demonstrate that these important attributes are addressed.
  - **Minimize technical and regulatory burden**: the level of detail in which a submittal must address the applicable requirements and technical basis may vary depending on the safety significance of the application and the maturity of the AMT.

Appendix A Process Flow Chart

- Describes an approach to qualification and performance considerations
  - Quality Assurance
  - Process Qualification
    - Essential Variable Identification
    - Qualification Testing
  - Supplemental Testing
    - As needed to demonstrate design requirements in applicable environmental conditions
  - Production Process Control and Verification
  - Performance Monitoring
    - Could include inspection, aging management, post-service evaluation



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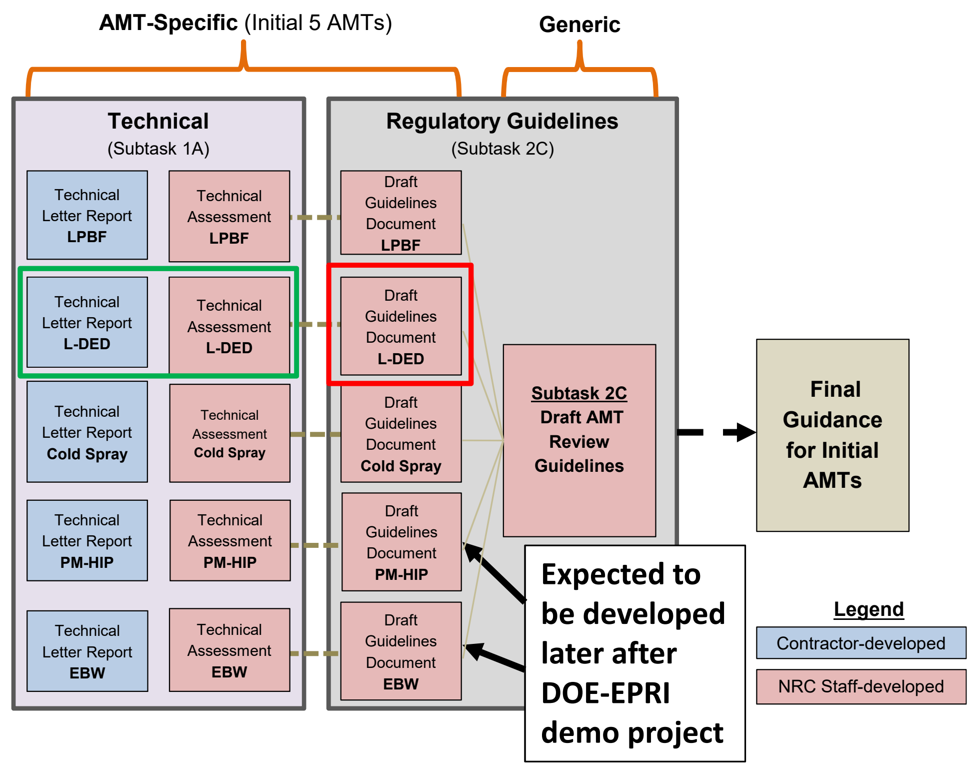
Technical Basis for L-DED Guidelines

- DGD is based on two technical documents (ML21301A077)
  - Technical letter report from Oak Ridge National Laboratory (ORNL)
  - NRC staff technical assessment of L-DED

- DGD builds on the NRC technical assessment and provides guidelines, <u>when finalized</u>, to the NRC staff by identifying important considerations when reviewing a submittal requesting the use of L-DED



L-DED Technical Basis Documents

- Technical letter report on L-DED from ORNL
  - Documents the current state of L-DED with respect to material microstructures and properties relative to conventional manufacturing
  - Identifies technical and codes and standards gaps in ensuring quality and sufficient properties and performance for L-DED-fabricated components
- NRC staff technical assessment
  - Provides context to the gaps identified in the ORNL report from NRC's perspective
    - Considers other relevant technical information, such as NRC regulatory and research experience, technical meetings and conferences, codes and standards activities, EPRI and DOE research products
  - Highlights key technical information related to L-DED-fabricated components in nuclear applications

Use of the Term Safety Significance

- The safety significance of each identified difference/topic in the L-DED DGD refers to the impact on component performance.
  - The overall impact to plant safety is a function of component performance and the specific component application (e.g., its intended safety function).
- The L-DED DGD and its supporting documents do not address the impact on plant safety, as such an assessment would not be possible without considering a specific component application.
  - In addition to the technical review guidelines in the L-DED DGD, the NRC staff should consider the specific component application and the potential for secondary consequences, such as debris generation and associated impacts, when assessing the impact to overall plant safety.

Tie to Draft AMT Review Guidelines (Table 1)

Difference / Topic	Process Qualification	Supplemental Testing	Production Process Control and Verification	Performance Monitoring
Process-Driven: L-DED machine process control, Powder feedstock quality, Wire feedstock quality, L-DED build process management and control, Witness specimens, Thermal post-processing, Weldability / Joining	X		X	
Process and Properties: Local geometry impacts on component properties and performance, Heterogeneity and anisotropy in properties, Residual stress, Porosity, Surface finish*, Tensile properties, Initial fracture toughness	X	X		
Performance under Aging: Thermal aging, SCC and corrosion resistance, Fatigue, Irradiation effects, High Temperature Time- Dependent Aging Effects, Weld integrity		X		X

- The applicable primary elements may vary on a case-by-case basis, depending on the licensee's approach to demonstrating quality and safety.
- Table 1 provides an example of applicable elements and reflects that not every element in Appendix A to the draft AMT review guidelines is applicable to every difference listed in Table 1.

*also ties to Production Process Control and Verification

Tables 2A and 2B

- Tables 2A and 2B provide the technical review guidelines
- Material-generic vs. material-specific
  - Table 2A lists the generic differences / topics (generally process focused)
  - Table 2B lists the material-specific (generally properties and performance focused) differences / topics for L-DED 316L stainless steel
- Differences identified in Table 2B involving material-specific properties and performance would likely need to be considered for any newly fabricated material (316L or not) using L-DED
  - In general, material-specific data are important for any nuclear L-DED-fabricated component to ensure adequate component performance in the applicable environment

Content of Tables 2A and 2B

- Difference
  - Lists the differences between L-DED and traditional manufacturing identified in the NRC technical assessment
- Key Technical Information
  - Summarizes the key technical information documented in the NRC technical assessment for easy reference
- Technical Review Guidelines
  - Provides additional guidelines related to the differences between L-DED and traditional manufacturing that the staff should consider when evaluating how a licensee's or applicant's submittal addresses the differences between L-DED and traditional manufacturing

DGD Example – Table 2A, Process-Driven

Difference	Key Technical Information	Technical Review Guidelines
L-DED Machine Process Control	• Control of L-DED files is needed to ensure process control. Improper file control can significantly impact final component properties and performance and affect fabrication replication. Cybersecurity, database traceability, managing software updates, and similar items are highly important to ensuring end-use component quality. • Machine calibration is vital for fabrication replication, particularly ensuring correct feedstock deposition parameters, laser power, laser spot size, travel speed, and atmospheric quality control in addition to geometric tolerances. For LP-DED, this includes contamination minimization if recycling powder.	**Process Qualification** • The applicant should identify the essential variables related to L-DED machine process control and demonstrate that controlling these variables within identified ranges will ensure reliable, adequate, and repeatable component properties and performance. • At a minimum, the process qualification should consider the following essential variables: ○ software file preparation (e.g., L-DED software version, and L-DED software settings) ○ calibration of L-DED machine and subsystems (e.g., build stage, feedstock deposition, laser optics, atmosphere control) • The applicant should identify additional specific essential variables and their ranges as appropriate. **Production Process Control and Verification** • During production, the applicant should demonstrate that process control and verification will maintain the production process within the qualified essential variable ranges. • The applicant can use a variety of machine process controls approaches to demonstrate process control and verification, including, but not limited to periodic machine calibration verification.

DGD Example – Table 2A, Process and Properties

Difference	Key Technical Information	Technical Review Guidelines
Porosity	• Porosity is known to adversely affect fatigue life, SCC, and irradiation-assisted stress corrosion cracking (IASCC), though the precise quantitative impact depends on the material and porosity characteristics (pore frequency, pore size, pore morphology, and total void fraction). • Machine parameters and scan strategy refinement have the potential to address porosity concerns; however, they may vary significantly based on the geometry and materials used. • Porosity is more prevalent in LP-DED than LW-DED due to the internal porosity and trapped gas in powder feedstock that does not exist in wire feedstock. • For post-processing, HIP with appropriate parameters has been	**Process Qualification** • Through process qualification, the applicant should provide sufficient data to demonstrate that porosity will be managed sufficiently to ensure reliable and adequate component properties and performance. • Post-processing through heat treatment, HIP, or both, may significantly reduce porosity; the applicant should demonstrate this. • The applicant should consider the following key characteristics of porosity when assessing porosity: ○ pore density ○ pore distribution (e.g., location relative to the surface) ○ pore size ○ pore morphology ○ total void fraction • The applicant should identify additional specific characteristics as appropriate. **Supplemental Testing** • The applicant should demonstrate that the porosity in an L-DED-fabricated component will not unacceptably degrade material properties and performance due to in-service aging. ○ This demonstration should be performed on a sample that is representative of, or bounds, the component's qualified pre-service condition, including post-processing.

DGD Example – Table 2A, Process and Properties

Difference	Key Technical Information	Technical Review Guidelines

Surface Finish	• Surface roughness is generally greater in as-built L-DED parts compared to similar forged materials.
	  ○ The layer-by-layer nature of LP-DED combined with the tendency to weld unmelted powder particles to the component surfaces produces a rough outer surface in LP-DED.
	  ○ LW-DED typically has a bead-like surface due to the layer-by-layer deposition but does not have the added roughness of attached particles.
	• Higher surface roughness can lead to reduced fatigue life and reduced SCC and corrosion resistance.
	• Surface finish can be improved by post-processing such as subtractive machining, or other surface treatments.
	• For components with complicated geometries, hybrid manufacturing
		Process Qualification
		• Through process qualification, the applicant should provide sufficient data to demonstrate that surface roughness will be managed sufficiently to ensure reliable and adequate component properties and performance.
		• Post-processing through precision machining, shot peening, or other surface treatment may be able to significantly reduce surface roughness but should be demonstrated.
		Supplemental Testing
		• The applicant should demonstrate that the surface finish in an L-DED-fabricated component will not unacceptably degrade material properties and performance due to in-service aging.
		  ○ This demonstration should be performed on a sample that is representative of, or bounds, the component's qualified pre-service condition, including post-processing.
		Production Process Control and Verification
		• During production, the applicant should demonstrate that process control and verification will maintain the production process within the qualified essential variable ranges for post-processing.
		• The applicant can use a variety of approaches to demonstrate process control and verification, including, but not limited to, the following:
		  ○ testing final components on a sampling basis
		  ○ validated monitoring of post-processing parameters.

DGD Example – Table 2B, Process and Properties

Difference	Key Technical Information	Technical Review Guidelines

Initial Fracture Toughness	• Limited data on 316L L-DED materials have shown significantly lower initial fracture toughness depending on post-processing than similar forged materials. This may be due to porosity or other defects that may be reduced with optimized processing parameters and thermal post-processing.
	  ○ However, 316L L-DED is still expected to have adequate initial toughness.
	• Data in representative environments is important to demonstrate that fracture toughness will be adequate to meet component design assumptions.
	• Thermal post-processing with appropriate parameters would be expected to improve fracture toughness.
		Process Qualification/Supplemental Testing
		• For process qualification and supplemental testing, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate fracture toughness for the intended function of the component.
		  ○ The corresponding analysis can demonstrate acceptable safety margins using approaches such as the following:
		    ▪ demonstrating equal or superior performance by comparison to fracture toughness for conventionally manufactured materials
		    ▪ analyzing design requirements to demonstrate sufficient fracture toughness for design and flaw evaluation purposes

DGD Example – Table 2B, Performance Under Aging

Difference	Key Technical Information	Technical Review Guidelines

SCC and Corrosion Resistance	• Data in representative environments is important to demonstrate that changes in material performance due to SCC will not be degraded to a greater degree in L-DED materials than forged materials.
	• Post-processing with appropriate parameters would be expected to make material properties and performance more similar to conventional forged materials.
	• In 316L, the silicon content in the powder can create oxides that have adverse effects on SCC growth rates. Consideration should be given on oxide content in powder acceptance (virgin and recycled) criteria.
		Supplemental Testing/Performance Monitoring
		• Through supplemental testing and performance monitoring, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate SCC and corrosion resistance for the intended function of the component.
		  ○ The corresponding analysis can demonstrate acceptable safety margins by using approaches such as the following:
		    ▪ demonstrating equal or superior performance by comparison to SCC and corrosion resistance performance for conventionally manufactured materials
		    ▪ addressing uncertainties in the data on SCC and corrosion resistance and the implications to in-service performance through additional performance monitoring as appropriate

Conclusions

- L-DED DGD has been developed as a "draft not for use"
  - The DGD builds on the ORNL technical letter report and NRC staff technical assessment to provide the technical review guidelines and associated key technical information
- The L-DED DGD is consistent with the draft AMT review guidelines and addresses the same primary elements
  - Technology-specific DGDs are anticipated to be incorporated in some form into the final AMT guidance

References

- Draft AMT Review Guidelines
  - ADAMS Accession No. ML21074A037
- L-DED Draft Guidelines Document
  - ADAMS Accession No. ML22143A951
- L-DED Technical Letter Report and Technical Assessment
  - ADAMS Accession No. ML21301A077
- NRC Public Site on AMTs
  - https://www.nrc.gov/reactors/power/amts.html

Questions ?

NRC Draft Guidelines Document
Cold Spray

Bruce Lin
Office of Nuclear Regulatory Research
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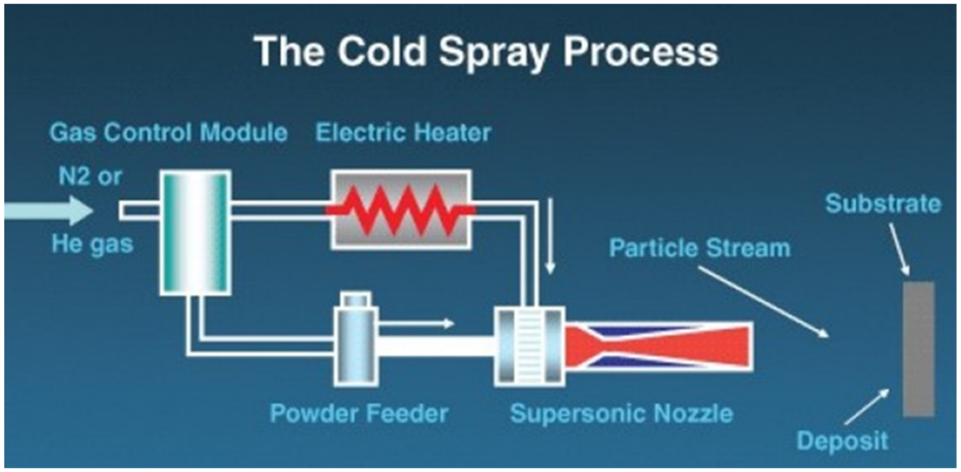
Outline

- Overview of Cold Spray (CS)
- Technical Basis for CS Draft Guidelines Document (DGD)
- Tie to Draft AMT Review Guidelines (Table 1)
- CS Technical Review Guidelines
- Conclusions

Cold Spray

- Process:
  - Powder is sprayed at supersonic velocities onto a metal surface and forms a bond with the part
  - This can be used to repair existing parts or as a mitigation process



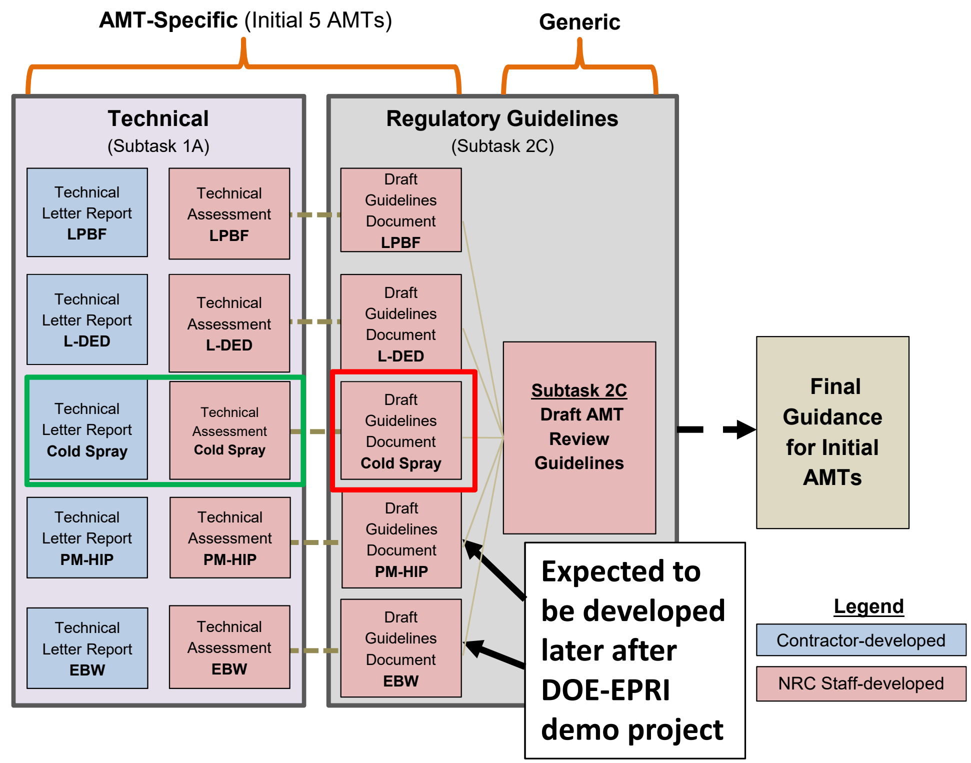
Schematic of CS process

- Potential Applications
  - Mitigation or repair of potential chloride-induced stress corrosion cracking (CISCC) in spent fuel canisters
  - Mitigation or repair of stress corrosion cracking (SCC) in reactor applications

https://www.army.mil/article/148465/army_researchers_develop_cold_spray_system_transition_to_industry

Technical Basis for CS Guidelines

- DGD is based on two technical documents (ML21263A105)
  - Technical letter report from Pacific Northwest National Laboratory (PNNL)
  - NRC staff technical assessment of CS
- DGD builds on the NRC technical assessment and provides guidelines, <u>when finalized</u>, to the NRC staff by identifying important considerations when reviewing a submittal requesting the use of CS



CS Technical Basis Documents

- Technical letter report on CS from PNNL
  - Provides an overview of CS technology and highlights important considerations for qualification of CS process
  - Identifies knowledge gaps associated with using CS for nuclear power applications
- NRC staff technical assessment
  - Provides context to the gaps identified in the PNNL report from NRC's perspective
  - Highlights key technical information related to the use of CS for nuclear applications
  - Assesses the properties and performance characteristics of CS for both structural and nonstructural applications

Structural vs. Nonstructural

- Structural applications
  - Likely to be thicker
  - Credit the CS material for load-bearing capacity such that either the CS material entirely or the CS material in conjunction with the substrate meet the full structural strength requirements
- Nonstructural applications
  - Likely to be thinner
  - Do not credit the CS material for any load-bearing capacity
  - Only credit the CS material for non-structural purposes, such as corrosion mitigation or wear resistance
- The determination of whether a particular application is structural or non-structural will largely be dependent on whether the CS material is needed to meet structural requirements

Tie to Draft AMT Review Guidelines (Table 1)

Topic	Process Qualification	Supplemental Testing	Production Process Control and Verification	Performance Monitoring
Process-Driven: Factory/field application, Power quality and processing, Surface preparation, Process parameter and controls, Post-processing, Witness specimens, Non-destructive examination	X		X	
Process and Properties: Local geometry impacts on component properties and performance*, Adhesion strength, Porosity, Edge effects, Tensile properties, Initial fracture toughness	X	X		
Performance: Corrosion/Erosion resistance, Wear resistance, SCC resistance, Fatigue resistance, Irradiation effects, Thermal aging, High temperature time- dependent aging effects		X		X

- The applicable primary elements may vary on a case-by-case basis, depending on the licensee’s approach to demonstrating quality and safety.
- Table 1 provides an example of applicable elements and reflects that not every element in Appendix A to the draft AMT review guidelines is applicable to every topic listed in Table 1.

*also ties to Production Process Control and Verification

CS Technical Review Guidelines

- Tables 2 and 3 provide the technical review guidelines
  - Table 2 addresses CS process considerations
  - Table 3 covers properties and performance characteristic for CS materials
- Topics identified in Tables 2 and 3 involving CS process and properties and performance would likely need to be considered for application of CS in nuclear component
  - Not all topics identified in the tables need to be addressed but only those that are relevant for the particular application
  - In general, application-specific data will need to be generated to demonstrate adequate CS performance to meet the intended function of the CS materials

Content of Tables 2 and 3

- Topic
  - Identifies the key aspect of the CS process or property / performance characteristics
- Key Technical Information
  - Summarizes the key technical information associate with the specific topic for use of CS in nuclear applications
- Technical Review Guidelines
  - Provides additional guidelines to support the staff’s evaluation of the proposed use of CS

DGD Example – Table 2 Process Consideration

Topic	Key Technical Information	Technical Review Guidelines
Surface Preparation	• Poor surface preparation results in poor adhesion, or bonding, to the substrate. • Failure to remove oxide layers from a substrate surface before CS application can negatively impact coating performance. • Surface preparation examples include grit blasting, abrasive pads, and wire brushes or wire wheels. • The surfaces to receive CS deposits should be cleaned to remove oil, grease, dirt, paint, oxides, and other foreign material that could affect CS adhesion. • Section 2.2.4 of the PNNL TLR discuss surface preparation and post cleaning in more detail.	**Process Qualification** • Through process qualification, the applicant should identify the necessary surface conditions including the necessary surface roughness and cleanliness for achieving a good quality coating. Cleaning procedures should not cause any damage to the surfaces that are to be coated that may detrimentally affect CS adhesion or component performance. **Production Process Control and Verification** • During CS application, measures should be employed to protect the surface to be coated from dust, dirt, moisture, and other contaminants that may detrimentally affect CS adhesion. • The applicant can use a variety of post process quality testing such as adhesion testing and NDE to validate the adequacy of surface preparation practices and procedures.

DGD Example – Table 3 Properties and Performance

Topic	Key Technical Information	Technical Review Guidelines

Adhesion Strength	• Adhesion strength of 10–20 kilopounds per square inch (ksi) is common on a properly prepared surface, and adhesion strengths greater than 30 ksi are not uncommon for CS adhesion strength of higher strength alloys.
	• Thick oxides and surface contamination can significantly reduce the adhesion strength of the CS coating.
	• Adhesion strength may be limited by the bond strength of the epoxy when epoxy-based adhesion tests (ASTM-C633, ASTM-D4541) are used. The triple-lug shear testing described in MIL-J-24445A can be used to reach adhesion values not limited to epoxy strength.
		Process Qualification/Supplemental Testing/Performance Monitoring
		• For process qualification and supplemental testing, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments (e.g. temperature, chemistry, stress), to show adequate adhesion strength of the CS material to the substrate over the intended service life.
		  ○ The corresponding analysis can demonstrate acceptable performance using approaches such as the following:
		    ▪ demonstrating adequate adhesion strength by adhesion tests
		    ▪ experience from previous applications of CS in similar environments using similar process and material
		    ▪ NDE may be used to confirm adhesion quality.

DGD Example – Table 3 Process and Properties

<table>
<tr><th>Topic</th><th>Key Technical Information</th><th>Technical Review Guidelines</th></tr>
<tr><td>Corrosion / Erosion Resistance</td><td>For corrosion resistance, the most used coatings are forms of nickel, copper, aluminum, or titanium.
Short-term testing using ASTM standards may be used to screen corrosion and erosion resistance of material combinations in representative environments.
Corrosion testing using representative test conditions may be necessary to demonstrate the long-term behavior of CS protective coatings.</td><td>Supplemental Testing/Performance Monitoring
Through supplemental testing and performance monitoring, the applicant should provide an analysis, supported by sufficient data in representative or bounding environments, to show adequate corrosion/erosion resistance for the intended function of the CS component over the intended service life.
The corresponding analysis can demonstrate meeting design requirements by using approaches such as the following:
demonstrating equal or superior performance by comparison to corrosion / erosion performance for substrate materials (assuming similar in-service inspection frequency and methods)
addressing uncertainties in the data on corrosion / erosion and the implications to in-service performance through conservative design assumptions, additional margins in analyses, surveillance programs, in-service inspection, or additional performance monitoring as appropriate</td></tr>
</table>

Conclusions

- CS DGD has been developed as a "draft not for use"
  - The DGD builds on the PNNL technical letter report and NRC staff technical assessment to provide the technical review guidelines and associated key technical information
- The CS DGD is consistent with the draft AMT review guidelines and addresses the same primary elements
  - Technology-specific DGDs are anticipated to be incorporated in some form into the final AMT guidance

References

- CS Draft Guidelines Document
  - ADAMS Accession No. ML22143A952
- CS Technical Letter Report and Technical Assessment
  - ADAMS Accession No. ML21263A105
- NRC Public Site on AMTs
  - https://www.nrc.gov/reactors/power/amts.html

Questions ?