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Framatome Additive Manufacturing Overview

Applications, Challenges and Progress

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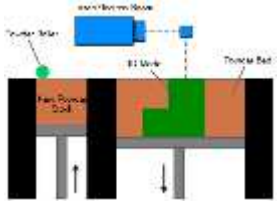
Overview

Background of Framatome's AMT Development and Progress

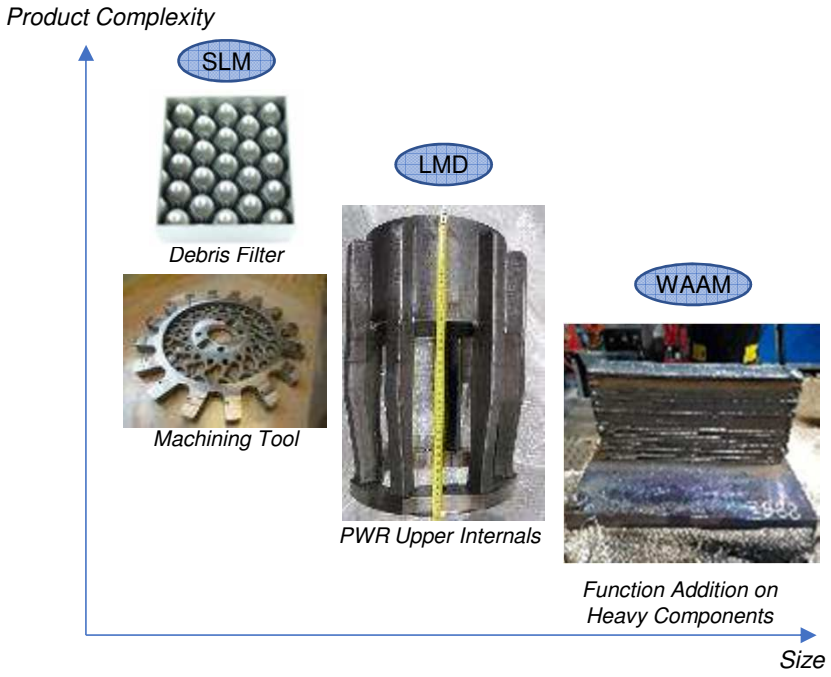


- **2014: Rapid Prototyping Stereolithographic (Resin) Printing**
  - Polymer product production for fast and cheap prototyping investigations
  - Investigation of potential applications, limitations and opportunities
- **2015 - 2018: Material, Processes and Application Development**
  - Additional equipment procurement and broad technology application evaluation
  - Cooperative activities with external companies and research facilities
- **2019 - 2020: Industrial and Nuclear Advanced Manufacturing Technologies (AMTs) Application and Qualification**
  - Material evaluation programs
  - Irradiation performance evaluations
  - Specification, design and manufacturability experience
  - Lead component introduction

General Practices and Uses of AMT
Manufacturing Methods, Equipment and Examples

- **Framatome identifies the value of AMT in maximizing for:**
  - **Optimized component and tool design**
  - **Functional addition / enhanced repair**
  - **Lower product cost with faster application**

- **In supporting implementation of these techniques, a global development approach to AMT was engaged:**
  - **Development of design skills**
  - **Materials characterization**
  - **Study of defects and adequate NDE**
  - **Determination of qualification approaches**



General Practices and Uses of AMT (cont.)

Manufacturing Methods, Equipment and Examples

- **Framatome Equipment Methods (Polymers):**
  - Filament Fused Deposition
  - Stereolithographic Printing
  - Directed Energy Deposition
- **Cooperative Equipment Methods (Metals):**
  - Powder Bed Fusion
  - Direct Metal Melting/Energy Deposition
  - Cold Spray Coating
  - Wire Arc Additive Manufacturing (Direct Energy Deposition)

Design and Prototyping

Tooling, Gaging, Inspection and Manufacturing Equipment

Service, Packaging and Replacement Parts

Test Hardware

In-Reactor Components

Industry Observations and Nuclear Industry Evaluation

Perspective - Applying AMT Effectively in the Nuclear Industry

- **Relatively New Technology Application in the Nuclear Industry but Widely Applied in Industries – High and Low Technology**
  - **High Technology: Aerospace, Medical, Automotive, Military**
  - **Low Technology: Business Machines, Consumer Products**
  - **Technology to market quicker in non-nuclear industries – Also high risk/conservative**
    - More diverse materials and advanced manufacturing methods
  - **Innovation and Development Critical Market Drivers**
- **Nuclear Industry Does Have Success with Similar Manufacturing Technology Transfers and Starting Materials**
  - **Example: Machined ←→Cast ←→Brazed/Welded←→Metal Injection Molding**
- **Adoption of Additional Inspection and Quality Control Technologies**
  - **Examples: Real-time Void Detection and Machine Learning**
- **Large "Upside" with a Quick, Broad and Efficient Implementation**

Nuclear Fuel Related Activities and Progress
Development, Qualification and Application

- **Material Behavior Under Reactor Operating Conditions**
  - **<u>Goal:</u> Obtain material irradiation experience and obtain behavior and response data to support licensing approval for additive manufactured component application and compare with out of reactor evaluation results**
  - **Initiated in 2016 with focus on 316L stainless steel and nickel based Alloy 718**
  - **Various parameters or responses evaluated through analysis of samples placed in the active region (neutron field with coolant interaction) of a commercial nuclear power plant**
    - Mechanical
    - Corrosion
    - Surface Condition and Geometric
    - Material Integrity / Metallography
  - **Three configurations of material segment types tested in Material Test Rods (MTRs)**
    - Standard, Cylinder and Universal

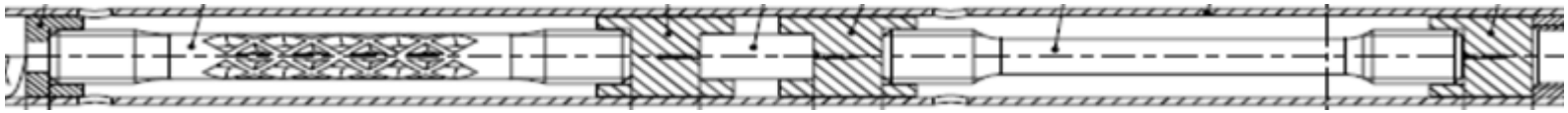
Nuclear Fuel Related Activities and Progress
Development, Qualification and Application (cont.)

- **Material Behavior Under Reactor Operating Conditions (cont.)**
  - **Test samples manufactured using Selective Laser Melting and placed in Material Test Rods for irradiation testing**

Universal

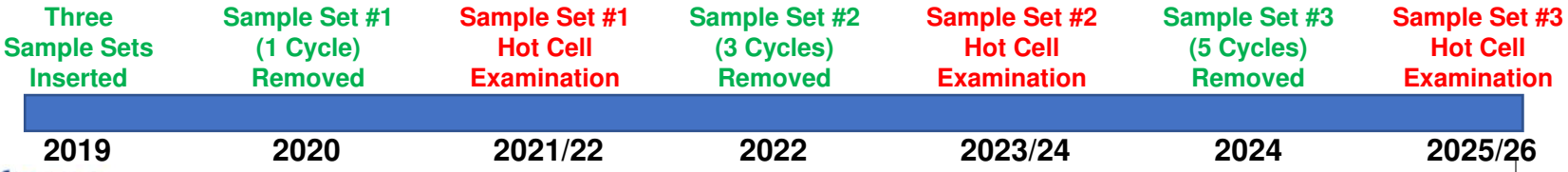
Cylinder

Standard



Test Sample Orientation in MTR Segment – Multiple Segments in Multiple Rods

  - **Samples to be analyzed after 1, 3 and 5 cycles of operation**

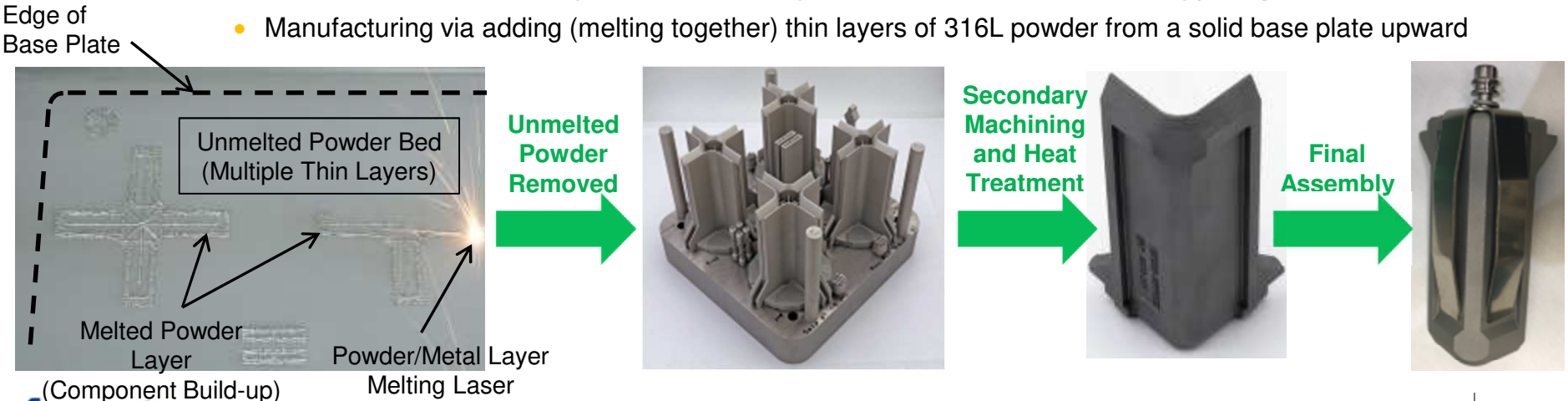


Nuclear Fuel Related Activities and Progress
Development, Qualification and Application (cont.)

- **Fuel Assembly Component Implementation - Channel Fastener**
  - **<u>Goal:</u> Gain experience, demonstrate competency and introduce in reactor nuclear fuel assembly components produced using additive manufacturing**
  - **Accomplished in collaboration with Oak Ridge National Laboratory and TVA as part of the Transformational Challenge Reactor (TCR) program**
  - **Full scope basic product development and implementation project accomplished**
    - Design modification and control for Direct Metal Laser Melting (Powder Bed Fusion) AM technique
      - Drawings, product specifications, material specifications, inspection requirements, etc.
    - Additive manufacturing process/configuration control and optimization – Product manufacturability
    - Qualification and quality control establishment for manufacturing process and final product
    - Licensing and commercial operation of a safety related fuel assembly component in reactor
  - **Four channel fasteners completed and delivered to TVA for Spring 2021 insertion in Browns Ferry Nuclear Power Plant - Unit 2 (Cycle 22) for three cycles of operation**
    - Full pre-irradiation characterizations accomplished – Dimensional, mechanical, chemical and NDE

Nuclear Fuel Related Activities and Progress
Development, Qualification and Application (cont.)

- **Fuel Assembly Component Implementation - Channel Fastener (cont.)**
  - **Anticipated post-irradiation examination plan beginning in 2023 – To be finalized**
    - Poolside visual examination after each cycle of operation
    - Hot cell examinations – visual, dimensional, metallography, tensile tests, fraction toughness, etc.
  - **Direct Metal Laser Melting Manufacturing Process – Directed Energy Deposition**
    - Manufacturing via adding (melting together) thin layers of 316L powder from a solid base plate upward



Nuclear Fuel Related Activities and Progress
Development, Qualification and Application (cont.)

- **Direction Forward for Additive Manufacturing Application**
  - **Near Term – Additional Experience and Industrial/Commercial Application Feedback**
    - Completion of reactor operation material behavior evaluation programs
    - Introduction of additional "existing" fuel assembly components produced using additive manufacturing technologies and materials as additional PWR and BWR fuel assembly lead type programs
      - 316L stainless steel and nickel based Alloy 718 material applications
    - Technology influenced product boundary conditions and performance enhancement capabilities
  - **Product Innovation and Additive Manufacturing Technology Application Optimization**

Fuel Lower Debris Filters

Fuel Upper Grids and Filters

Tooling and Reactor Components

  - **Goal: Industrial product delivery beginning in 2026**

Questions, Comments and/or Opinions

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Thank You!