Overview of Framatome's Activities Supporting Additive Manufacturing of Nuclear Fuel Components

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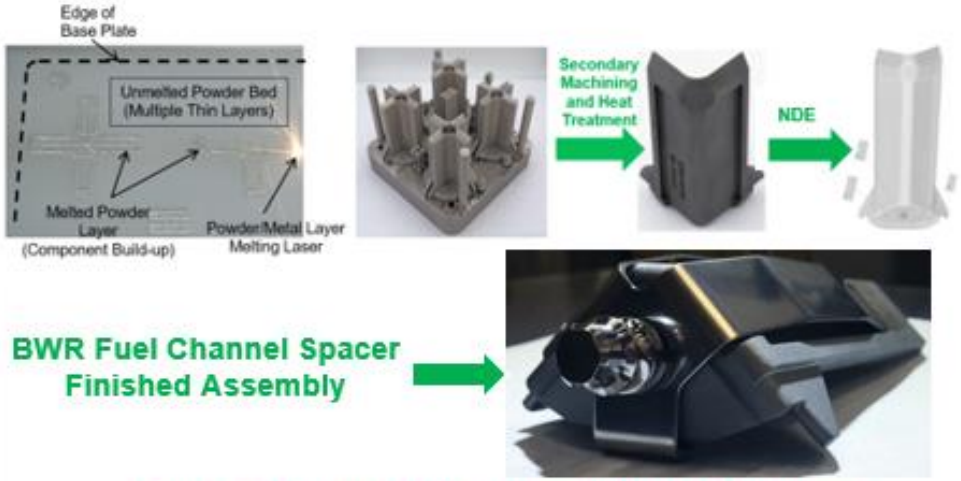
Framatome's Additive Manufacturing Focus for Fuel and Other Components

Objective :
- Enhancing Performance
- Reducing Manufacturing Costs
- Speeding up Market Readiness

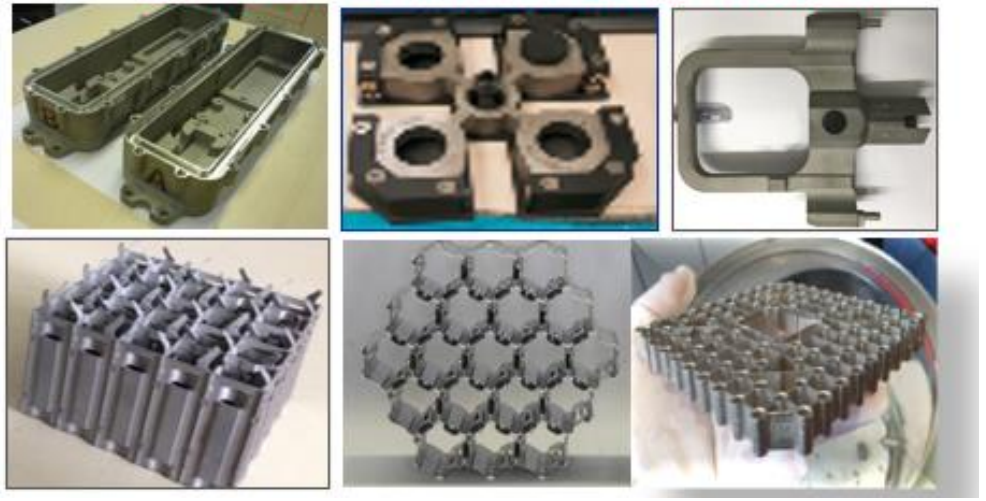
Value Adders of Additive Manufacturing
- Design Optimization
- Functional Additions
- Enhanced Repair Scenarios
- Fast Prototyping

Engaging a Global Development Approach
- Design Skills
- Materials Characterization
- Study of Defects and Adequate Non-Destructive Examination (NDE)
- Qualification Approaches

Current Applications
- Manufacturing Tooling and Gauging
- Component Prototyping, Development and Testing
- Lead Fuel Test Components

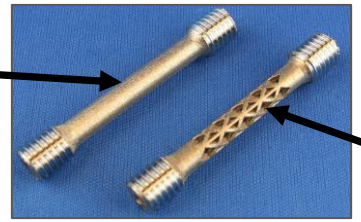


General Additive Manufacturing Process Overview

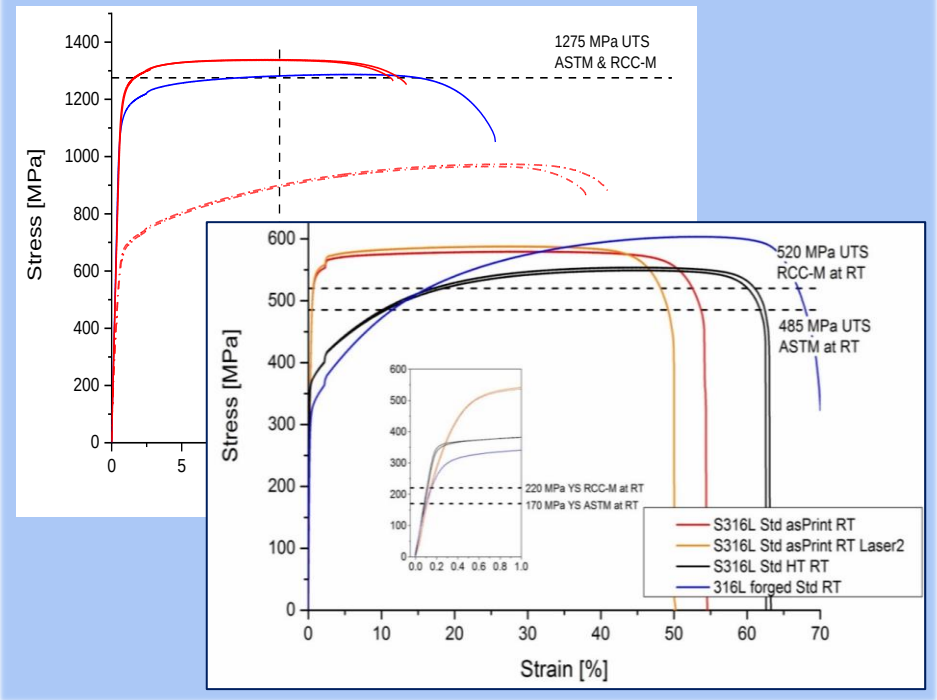


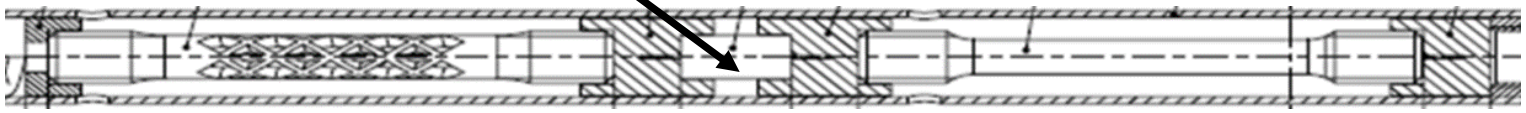
Additive Manufacturing Applied Material Evaluation – 316L SS and Inconel 718

Support of Licensing Approval for Additive Manufactured Component Applications
- In and Out of Pile Material Evaluation
- Test segments manufactured using Selective Laser Melting



Out of Pile Testing - Mechanical properties at the level of forged standards and no corrosion deviation

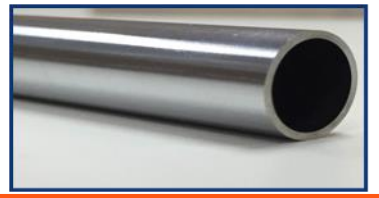




In Pile Testing - Gösgen Nuclear Power Plant (PWR)

- In Pile irradiation accomplished using Material Test Rods (MTRs), with multiple axially arranged segments arranged in multiple MTRs
  - Initiated in 2019 and planned for up to 5 cycles of irradiation
  - Samples subjected to coolant and neutron flux
- Sample removal accomplished after 1 and 3 cycles of operation
  - Hot cell examinations progressing
- Information to be collected to evaluate:
- Evolution of material mechanical and microstructural properties due to irradiation
- Corrosion kinetics
- Additive manufacturing effects (i.e., build direction, roughness, …)

Additive Manufacturing for Fuel Rod Coating – PROtect EATF Fuel Rod Cladding



PROtect → Chromium-Coated M5$_{Framatome}$ Cladding

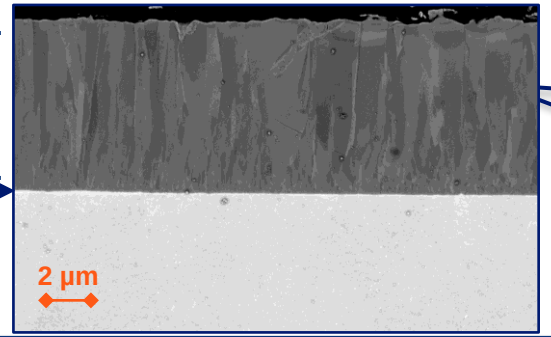
With Collaborative Support from Gösgen-Däniken AG, CEA, I3P, US DOE and BPI

Mastering the coating process, with a large variety of coating processes tested, necessary before selecting a process

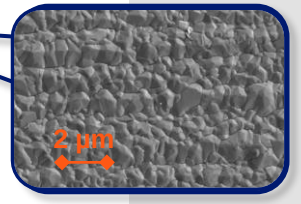
- Physical Vapor Deposition
- High Performance Magnetron Sputtering Process

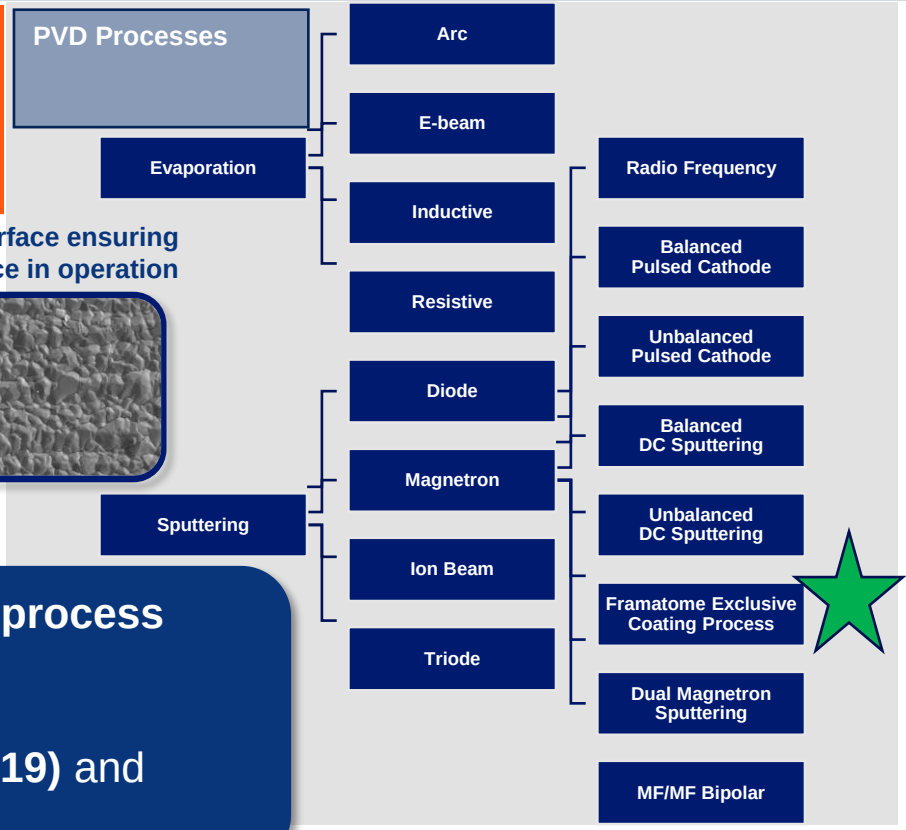
Dense & Thin coating (10-20µm)

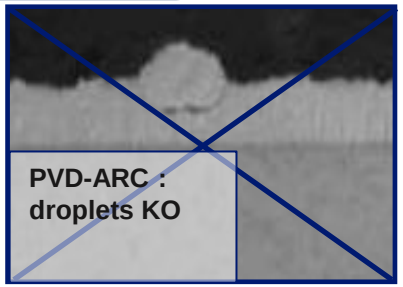
Smooth interface granting good coating adhesion cladding unaffected by the coating

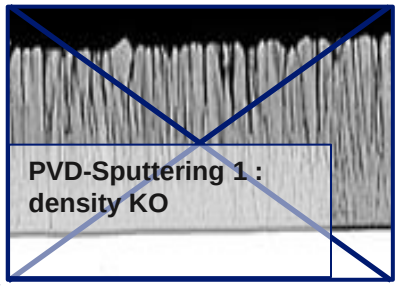


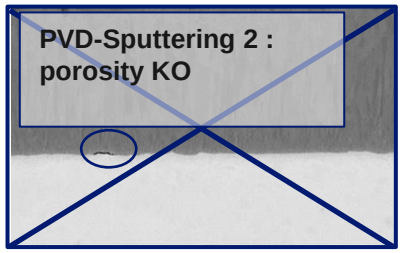
Smooth surface ensuring performance in operation











Over the last 10 years, **Framatome exclusive coating process performance** has been :

- **Demonstrated out of pile** in lab,
- **Confirmed in pile (Lead Fuel Rod Program since 2019)** and
- **Continuously optimized** for EATF application

Direct Nuclear Fuel Assembly Component Application – BWR Channel Fastener

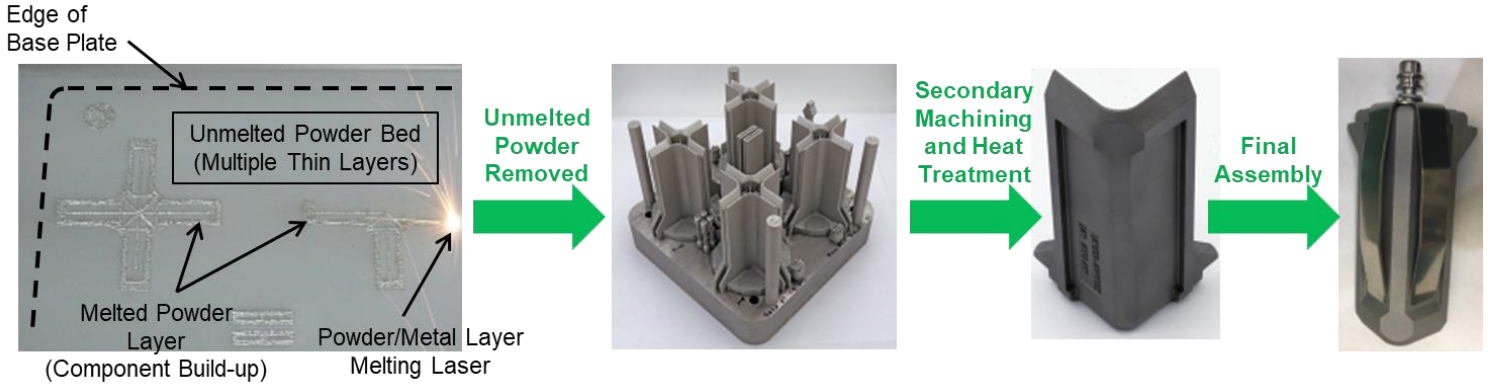
Collaboration with Oak Ridge National Laboratory and TVA as Part of the Transformation Challenge Reactor (TCR) Program

Gain experience, demonstrate competency and introduce in reactor nuclear fuel assembly components produced using additive manufacturing

- Direct Metal Laser Melting Manufacturing Process – Directed Energy Deposition (ORNL)
- 316L Stainless Steel

Full Scope of Basic Product Development and Implementation Activities Accomplished

- Design modification
- Product specifications
- Additive manufacturing process/configuration control and optimization for product manufacturability
- Product qualification and quality control
- Licensing and commercial operation validation of a safety related component in reactor



Four Channel Fasteners Delivered - Browns Ferry, Unit 2 Nuclear Power Plant

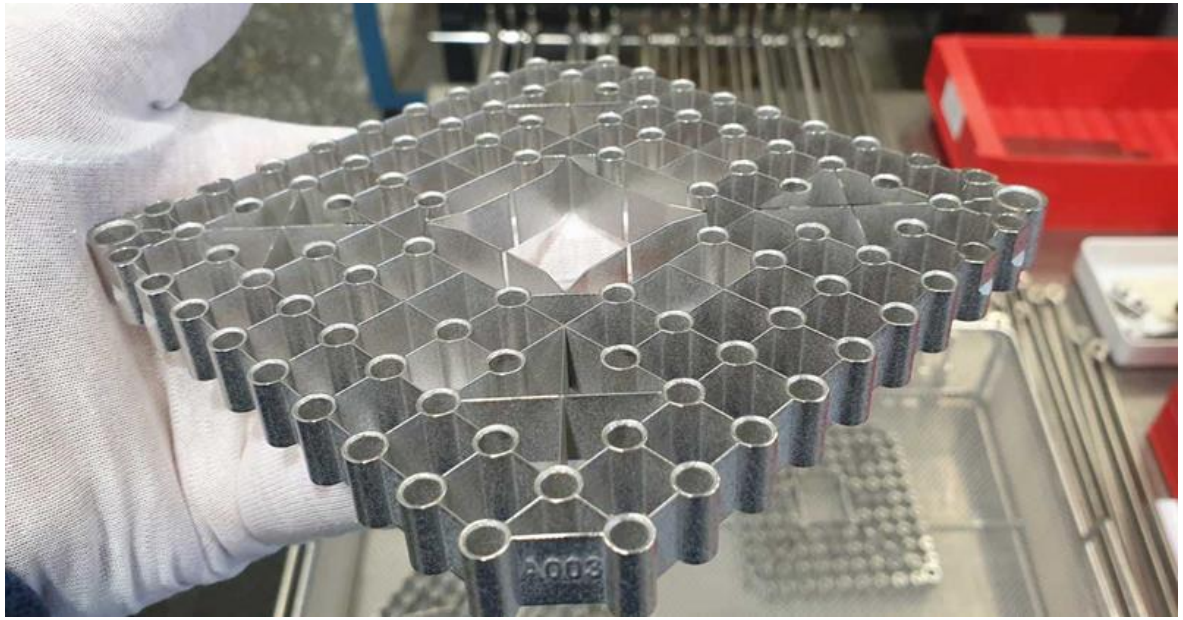
- Inserted in Spring of 2021
- Planned for up to 3 cycles of irradiation
- Post-Irradiation examinations planned in 2025 (visual) and 2027 (detailed)

Direct Nuclear Fuel Assembly Component Application – BWR Upper Tie Plate Grid

Framatome Product Design and Manufacturing Optimization and Using a Industrial/Commercial Additive Manufacturing Company (KSB)

Demonstrate Framatome's ability to bring customer value using additive manufacturing and gaining experience (Framatome and customer) with design, industrial manufacturing and irradiation behavior

- Laser Powder Bed Melting Manufacturing Process
- 316L Stainless Steel



Using Advantage of Industrial Additive Manufacturing for Product Optimization

- Innovative design for enhanced debris filtering
- Opportunity to consolidate supply chain
- Gain experience for methodology control and additive manufacturing experience

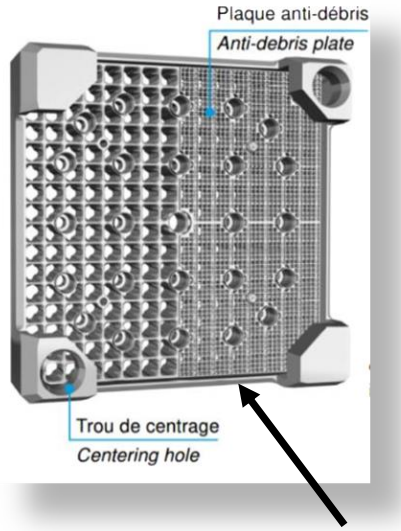
Components Delivered and Operating in Reactor - Forsmark, Unit 3 Nuclear Power Plant

- Inserted in 2022
- Planned for 4 or 5 cycles of irradiation
- Post-Irradiation examinations planned in 2027

Nuclear Fuel Assembly Component Development Activities - Examples

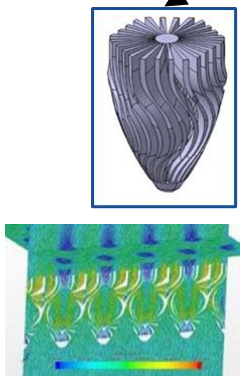
Debris Filters and Flow Conditioning Components

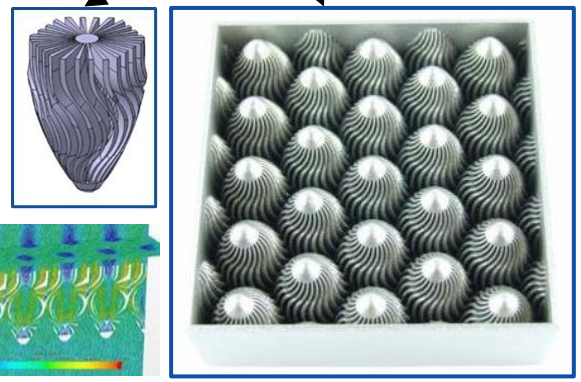
Product Performance Improvement via Available Design and Manufacturing Flexibility – Debris Filtering & Flow Conditioning



PWR

BWR



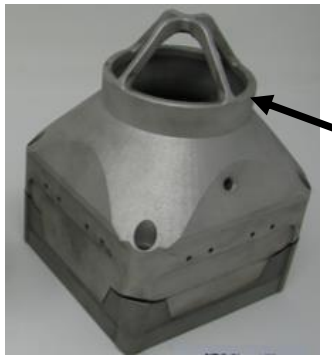


Larger Components and Assemblies (Collaboration with NovaTech)

ATRIUM 11 Lower Tie Plate Assembly

- Minimized supports during additive manufacturing build process
- Reduction in number of assembly components for fewer processes and fit-ups
- Minimal geometric differences to avoid product re-qualification
- Minimized post additive manufacturing build processes
  - Heat treatment for residual stress removal
  - Wire EDM process used to remove component for build plate
  - Final machining to precise fit-up feature geometry

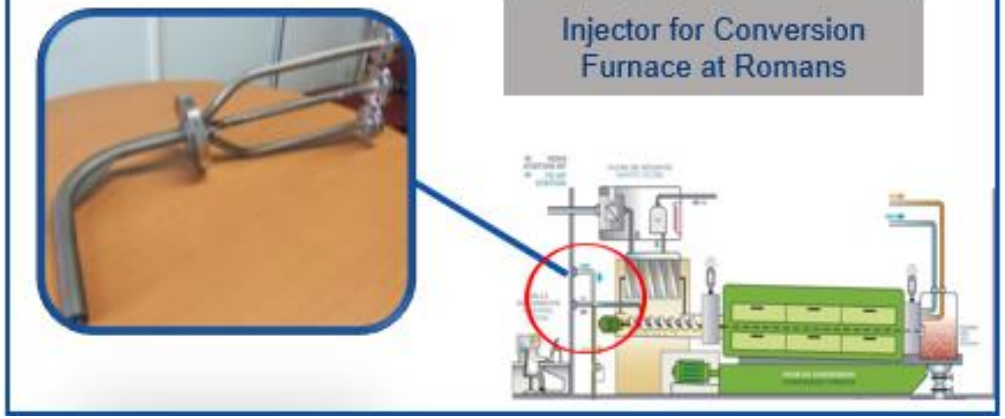
Conventional Design



Additive Manufactured Design

Non-Fuel Assembly Additive Manufacturing Applications at Framatome - Examples

Additive Manufacturing is Currently Used for "Day to Day" Applications Within Framatome



Injector for Conversion Furnace at Romans

Tooling and Gauging

Rapid Prototyping for Testing

Sensor Box for Castor Transportation

Questions, Comments and/or Observations

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Thank you