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Development of Test Articles for Surrogate Materials Surveillance

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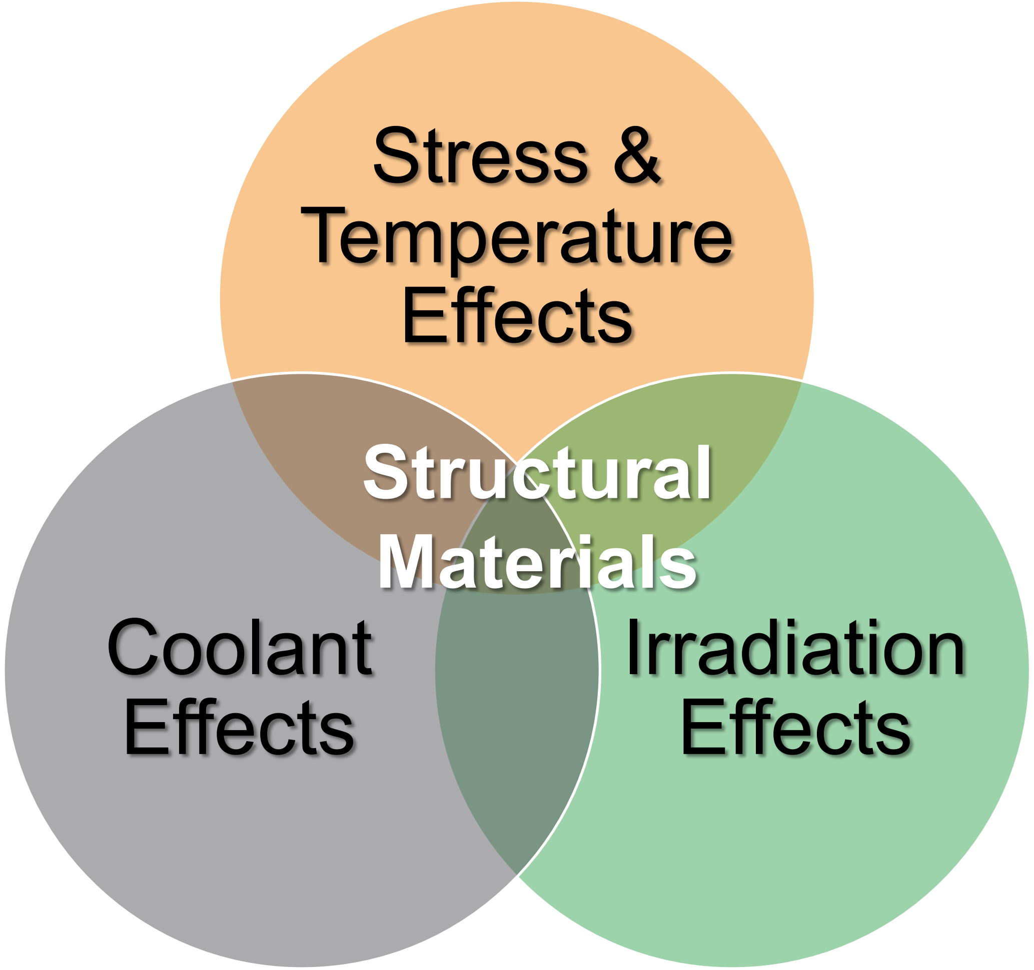
Collaborators

- Argonne National Laboratory
  - Mark Messner, Yoichi Momozaki, Ed Boron
- Idaho National Laboratory
  - Michael McMurtrey, Nedim Cinbiz
- Subject Matter Expert
  - Robert Jetter

Materials Degradation During Advanced Reactor Operations

- Information on materials degradations during advanced reactor operations is limited
- Effects of materials degradations during reactor operations are synergistic, involving:
  - Irradiation, corrosion, elevated temperature exposure and stress (creep-fatigue loading)
- Establishment of surrogate materials surveillance program for the management of materials degradations would be an important pathway in support of the timely licensing of advanced reactors

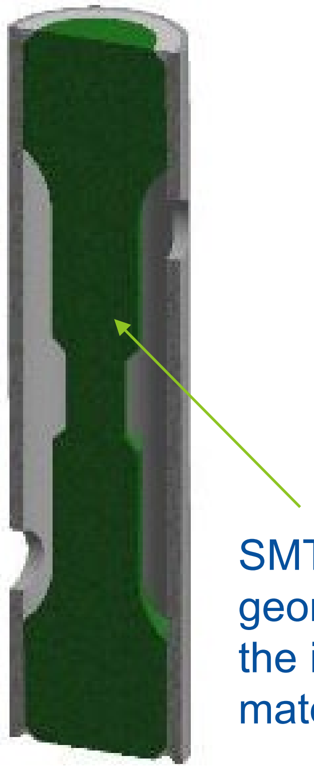


Surrogate Materials Surveillance Test Articles Development

SMT specimen (Yanli Wang, ORNL)

- Motivated by the SMT specimen that can introduce realistic structure-like mechanical response
- Combined with the basic idea of using thermal expansion mismatch within a test article to generate “load” passively
- Led to an initial concept for a passive surveillance test article
- Difficult to find the right kind of thermal expansion mismatch to induce tensile “load” in the test material

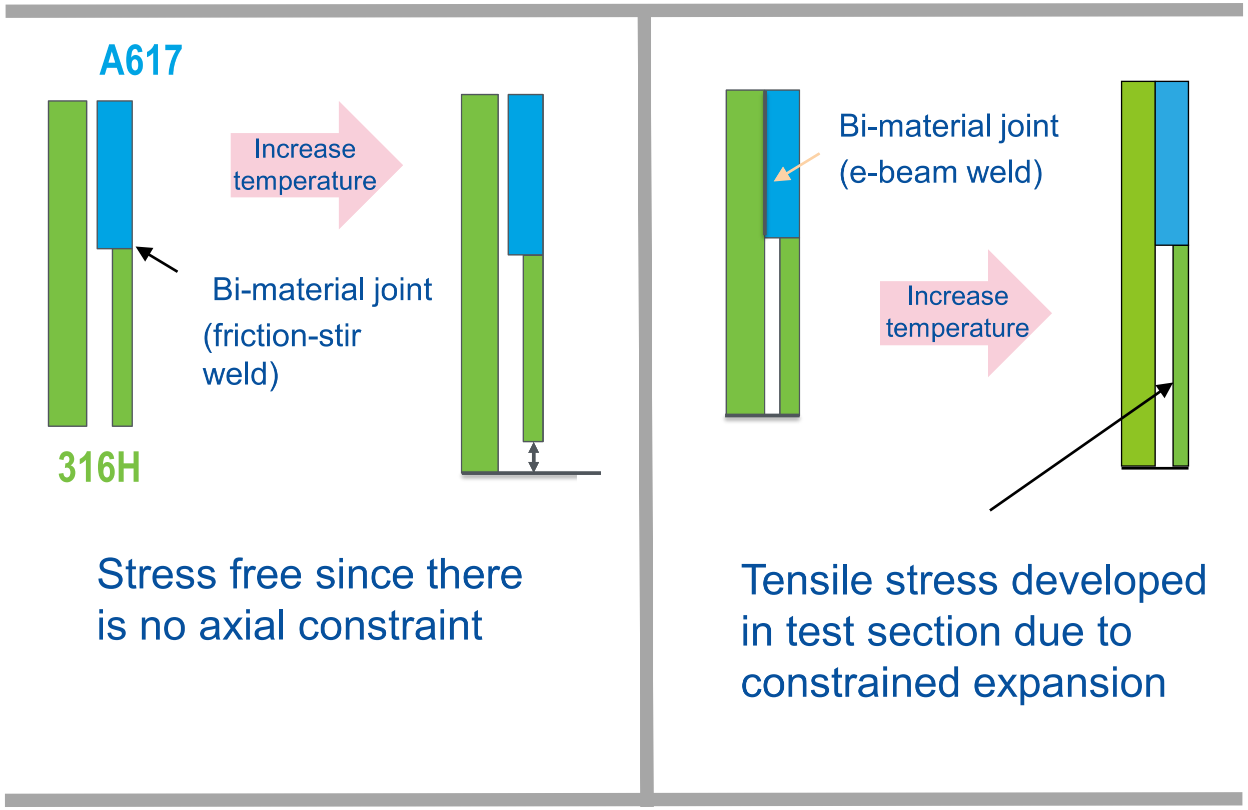
Cross section of axi-symmetric test article



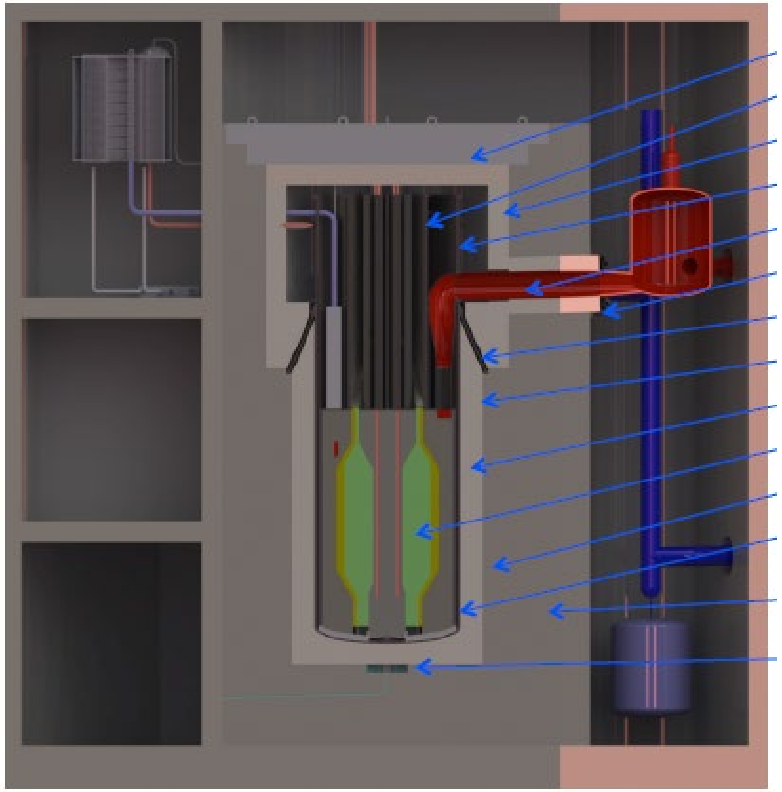
SMT geometry for the inner test material

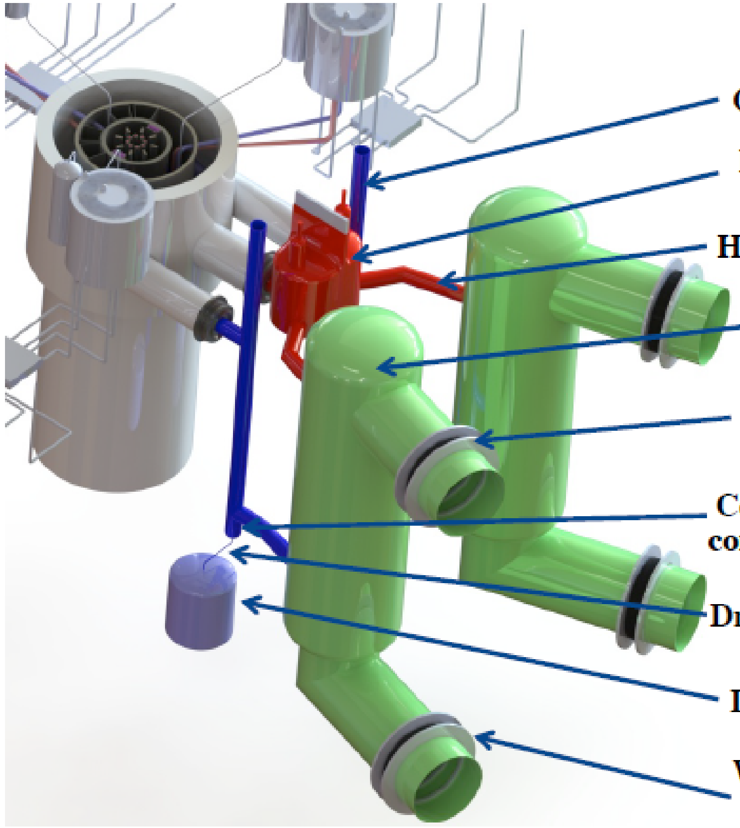
Basic Concept: Passively Loaded by Mismatch in Thermal Expansion Coefficients

- Provides creep-fatigue loading with configurable strain range and elastic follow up factor
- Does not require any penetration of the reactor coolant boundary, except, potentially, for monitoring sensors
- Relies on large CTE mismatch, challenging for stainless steel
- Fabricated a test article with 316H (test material) driven by A617 (driver material)
  - Conducted a thermal cycling Proof-of-Concept testing to demonstrate the viability of the approach



How to Surveil the Structural Integrity of a Critical Location in a Component Using a Test Article?

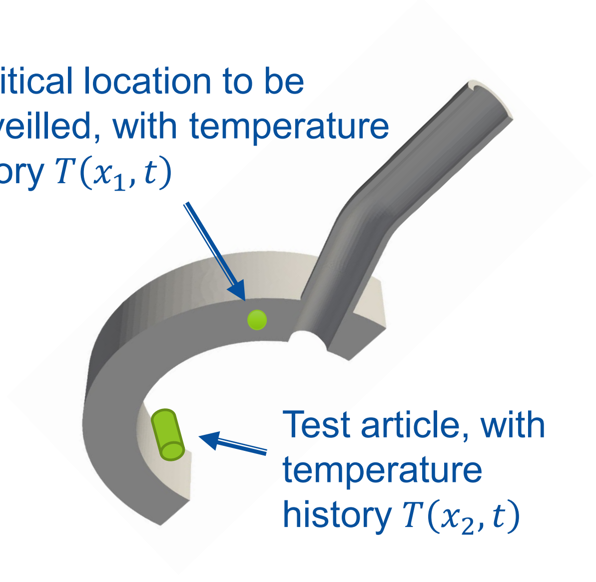


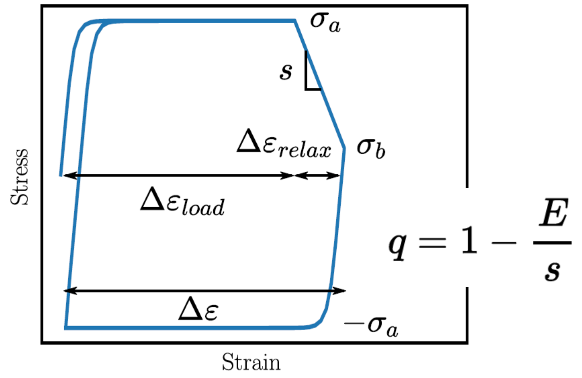


Mk1 PB-FHR, (L) Reactor vessel and cavity, (R) Heat transport system

Ref: Mark-1 PB-FHR Technical Description, UCBTH-14-002, 2014

Structural Integrity Surveillance

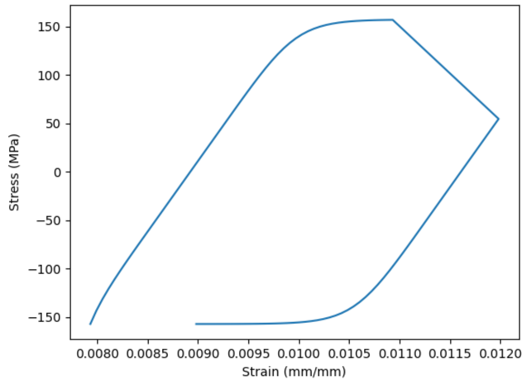




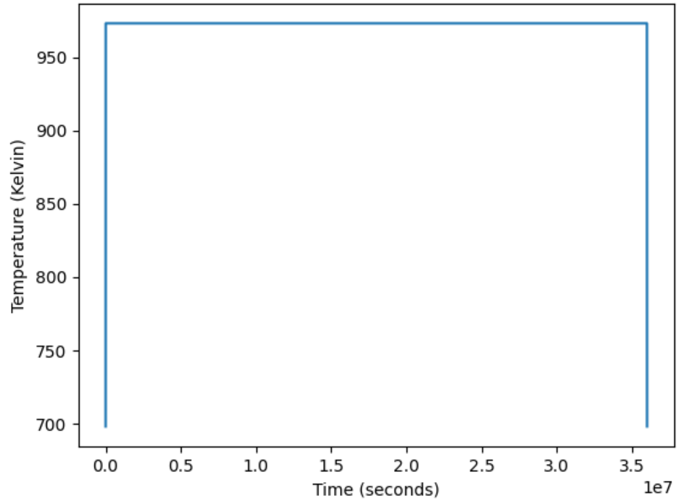
Stabilized Hysteresis Loop

- Thermal hydraulic analysis of plant operating transients would lead to development of temperature distribution and history in the coolant and the structural components
- Thermal cycling $T(x_1, t)$ will generate stabilized cyclic stresses $\sigma_{ij}(x_1, t)$ and strains $\varepsilon_{ij}(x_1, t)$ at critical location x_1
- In the effective stress and effective strain space, the stress-strain hysteresis loop can be characterized by a number of parameters
- Question: Can the geometry of the surveillance test article be sized to reproduce the key characteristics of the hysteresis loop of the component at x_1, due to the thermal cycling of the surveillance test article at location x_2
- Conclusion: Possible to capture two key parameters: (i) strain range $\Delta\varepsilon$, and (ii) elastic follow-up factor q, which measures the structural characteristic

Developed a Test Article Sizing App



Hysteresis loop at x_1 (component)

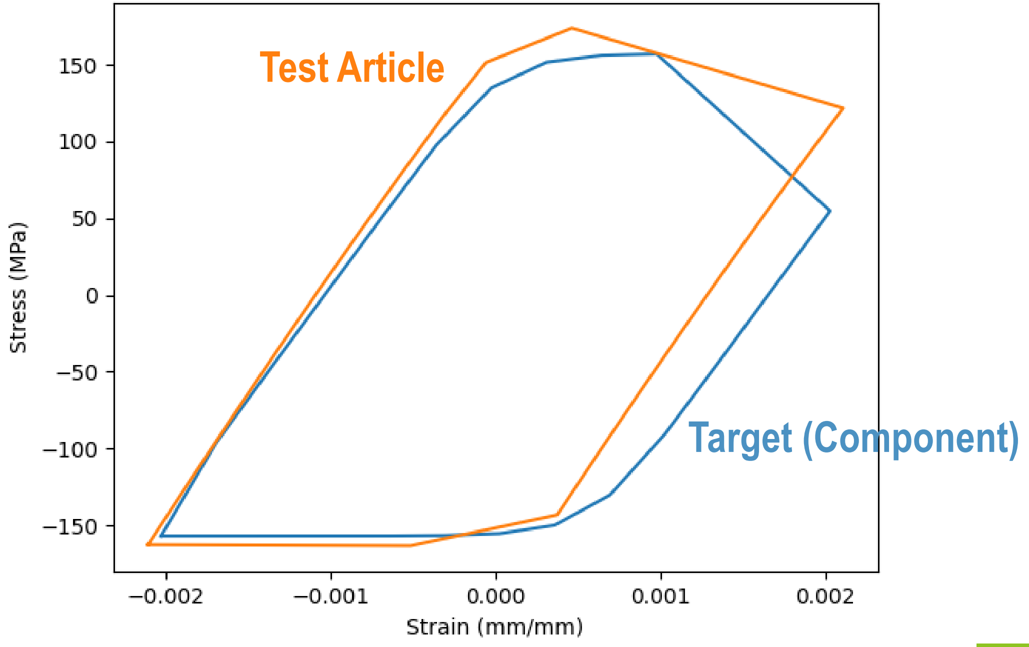


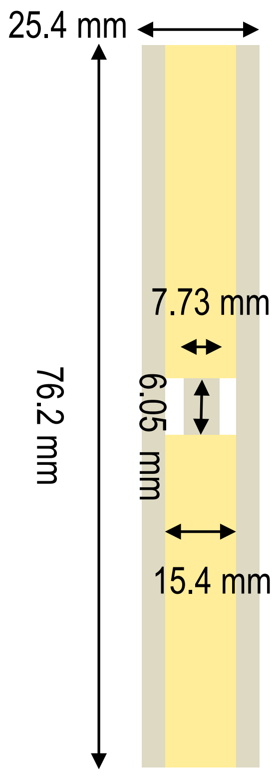
Temperature cycle at x_2 (test article)

Provide geometric constraints:

- Overall test article OD: 1 inches = 25.4 mm
- Overall test article length: 3 inches = 76.2 mm

Results: best specimen design and resulting stress/strain hysteresis

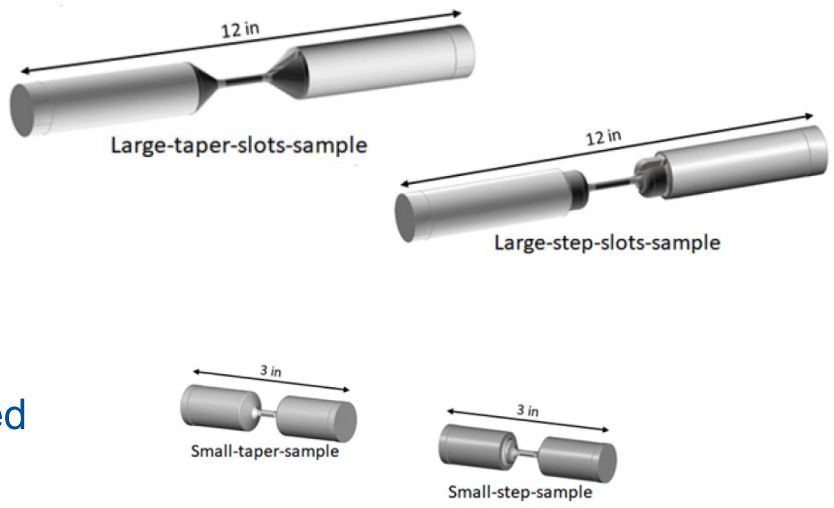




Cross-section

Developed Two Families of Passively Loaded Test Articles

- Two "families" of test articles with different objectives
  - Large test articles (12" long):
    - Develop basic fabrication technology
    - Instrument and test to assess test article design/acceptance procedures
  - Small test articles (3" long):
    - Demonstrate that a reactor-scale test articles can be fabricated using the same techniques
    - Assess joint strength by thermal testing



Small test articles ready for final assembly

Large test articles ready for final assembly

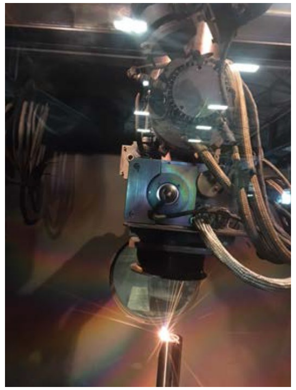
Test Articles Fabrication Completed – Both Types Follow the Same Basic Process

1. Start with A617 and 316H cylindrical stock

2. Stir-friction weld together 2 pieces of A617 to 1 piece of 316H

3. Machine inner specimen from welded rod, machine casing from larger diameter cylindrical stock

4. Join casing and inner specimen with electron beam welds



5. Completed test articles

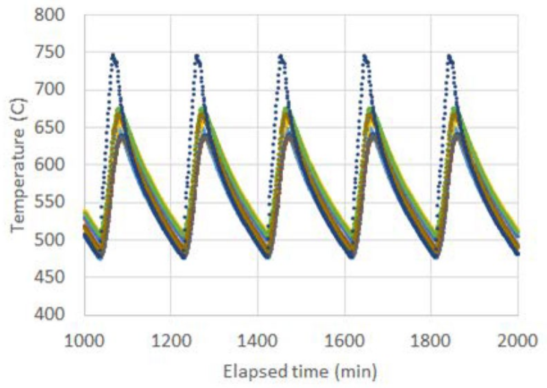
Long-Term Thermal Cycling Test Initiated

- Both families of test articles completed and in furnace for long-term cycling test
  - Large test articles:
    - Instrumented with thermocouples and strain gauges
  - Small test articles:
    - Ensure realistically-sized test articles for in-reactor deployment can be fabricated
    - Cycle to failure to make sure failure occurs in the gauge region (weld strength)
- Thermal cycling test started, will continue until test article fails

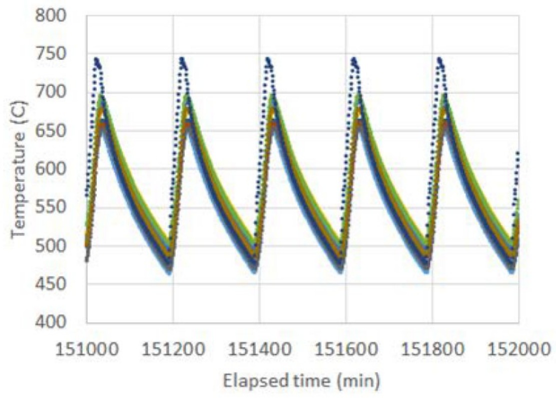
Test articles (small and large) in box furnace

Results from Ongoing Thermal Cycling Tests

Box furnace temperature

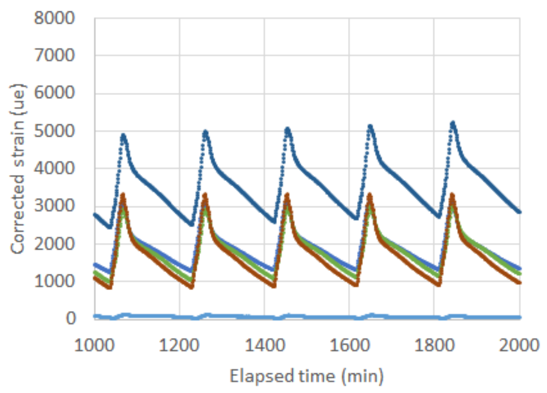


Test articles temperatures

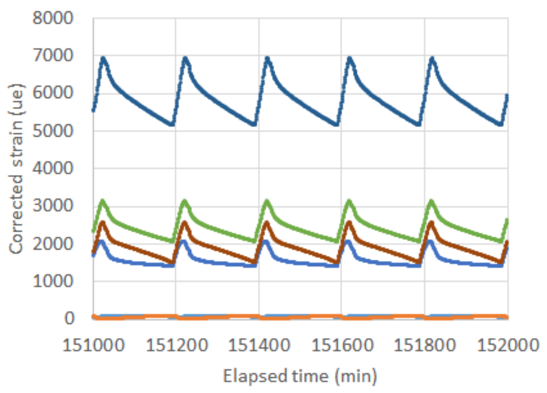


Temperature histories:
(L) at the start of the test,
(R) around 2021-9-7

Temperature cycling
period ≈ 3.3 hours



Mechanical strain histories:
(L) at the start of the test,
(R) around 2021-9-7

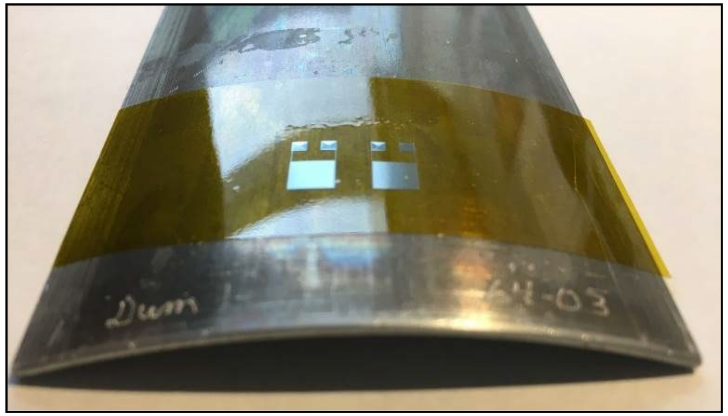


Next Steps

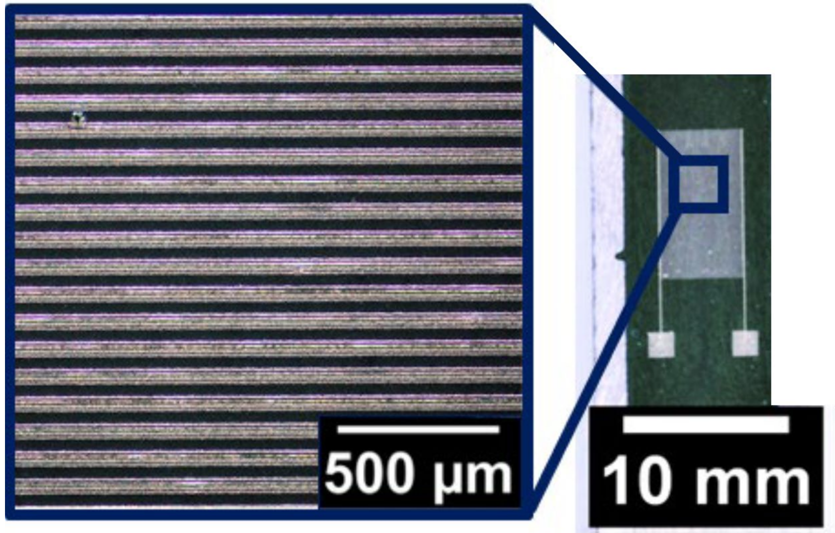
- Continue thermal cycling tests till failure
- Complete fabrication scoping task on replacing Alloy 617 by Mo-TZM as driver material
- Develop protocol for controlled temperature cycling
- Explore feasibility of further reducing the test article size from 3-inch long to 1.5 or even 1-in long for practical deployment
- Explore strain measurement methods for small-sized test article to provide validation data

Strain Measurement

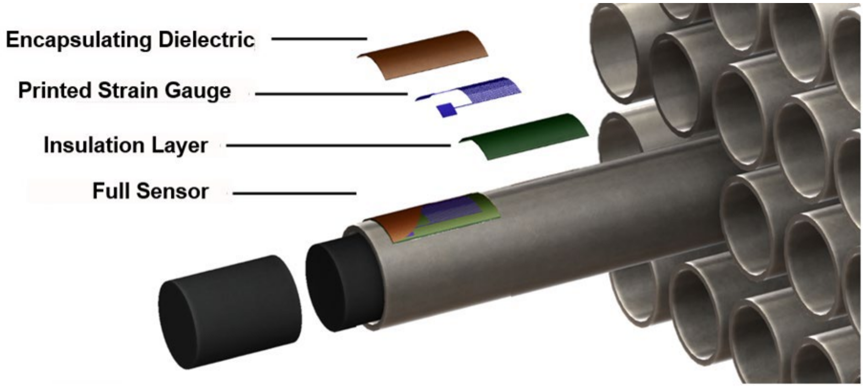
- Strain measurement on small test articles is challenging
  - Small size (0.1” diameter or less gauge section)
  - Curved surface
  - High temperatures
- INL, in conjunction with Boise State University (BSU), have been developing printed strain gauges under the Advanced Sensors and Instrumentation (ASI) Program that would address these issues and allow real-time strain measurement
- Will leverage this ASI development for the ART-MSR work



Advanced Manufactured thin film strain gauge on curved ATR fuel plate



Strain gauge printed at BSU



Printed strain gauge design (ASI)

Parallel Effort by the Advanced Reactors Regulatory Development Program

- Produce a guidance document that will present regulatory options to leverage the materials surveillance technology being developed by the ART Program for Advanced Non-Light Water Reactor (ANLWR) industry stakeholders to review and endorse
- Example options:
  - Develop and implement a materials degradation management program that would provide early warnings on structural degradation and on impending structural failure of safety significant components
  - Develop a strategy for the ANLWR industry to balance and potentially reduce part of the upfront new materials data requirements from ongoing long-term materials testing

Thank You.