Corrosion of Dummy “EE” Plate 19 in YA-M Type ATR Fuel Elements During PALM Cycles INL/EXT-16-38324

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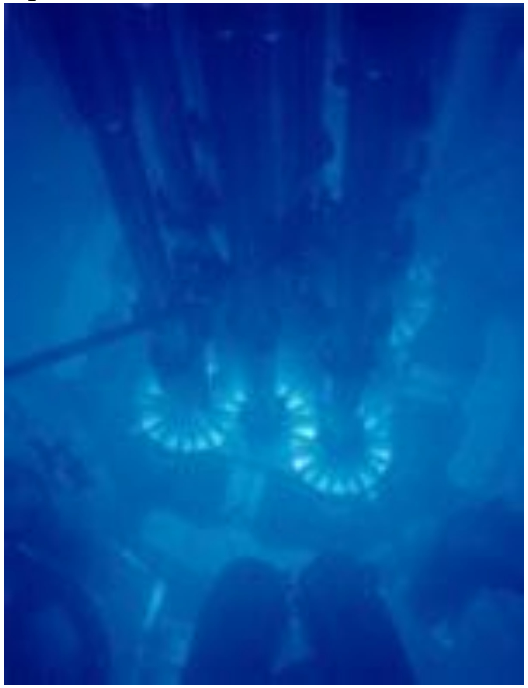

TRTR Conference

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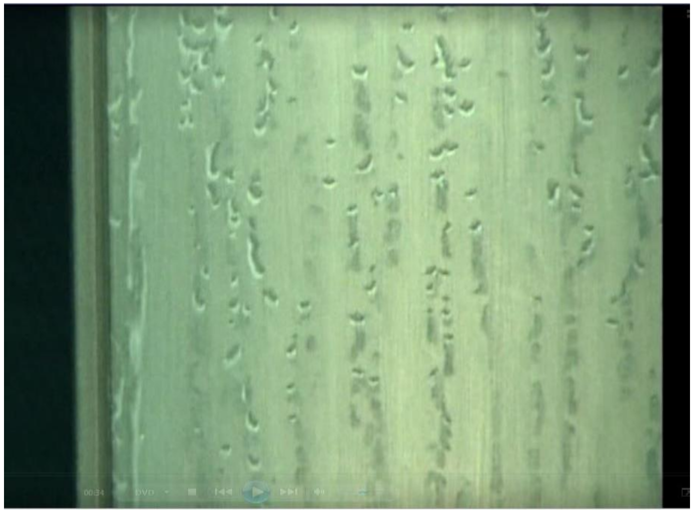
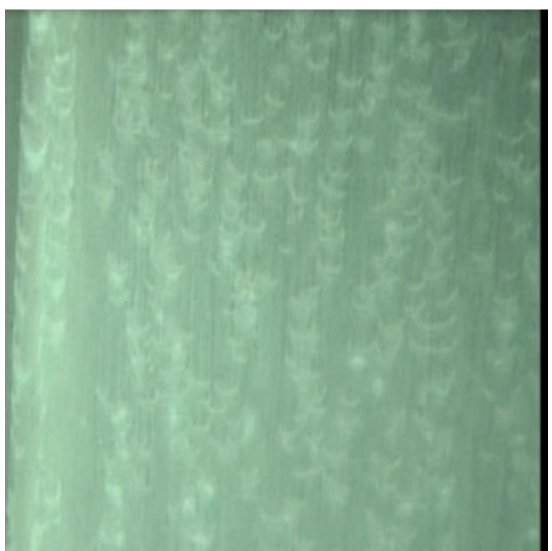
Introduction

- Advanced Test Reactor (ATR) Cycle 153B-1 was a 14-day, high-power, powered axial locator mechanism (PALM) operating cycle that completed on April 12, 2013.
- Cycle 153B-1 was a typical operating cycle for the ATR and did not result in any unusual plant transients. ATR was started up and shut down as scheduled.
- The PALM drive physically moves the selected experiments into and out of the core to simulate reactor startup and heat up, and shutdown and cooldown transients, while the reactor remains in steady state conditions.
- After the cycle was over, all 40 fuel elements were removed from the core and inspected. Several thousand flow-assisted erosion/corrosion pitting and "horseshoeing" defects were readily observed on the surface of the aluminum dummy "EE" plate 19 on all eight of the previously new YA-M type fuel elements.
- Similar pitting degradation was observed after PALM cycle 156A-1.

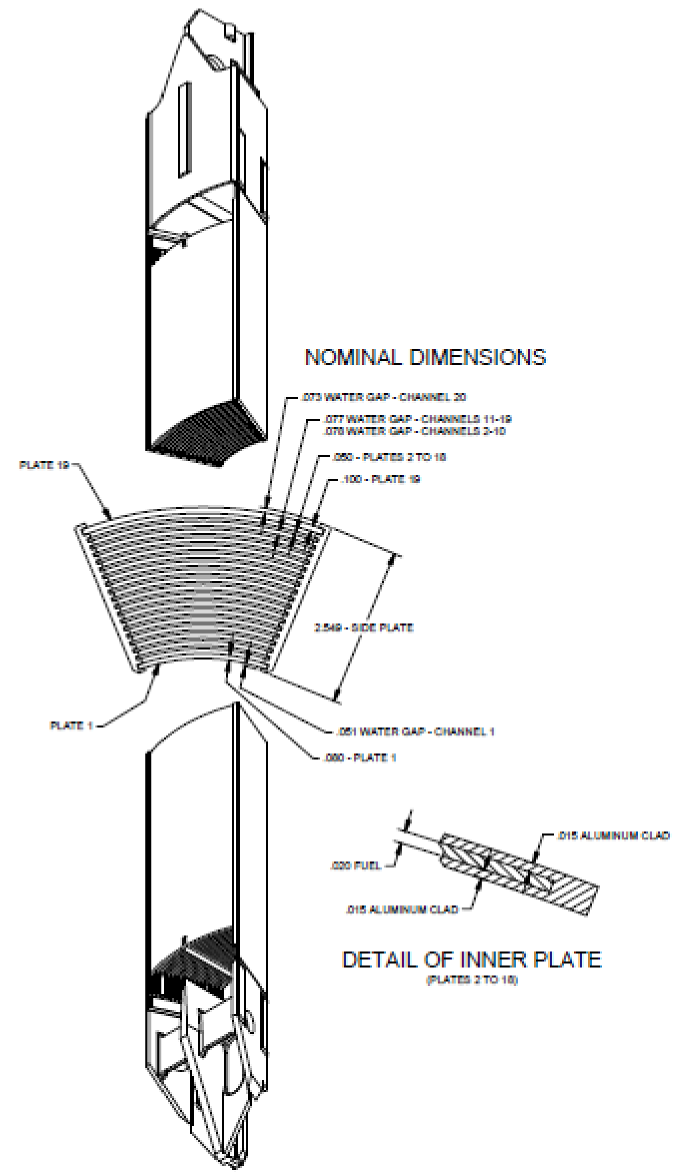
Pitting Degradation on ATR YA-M Elements





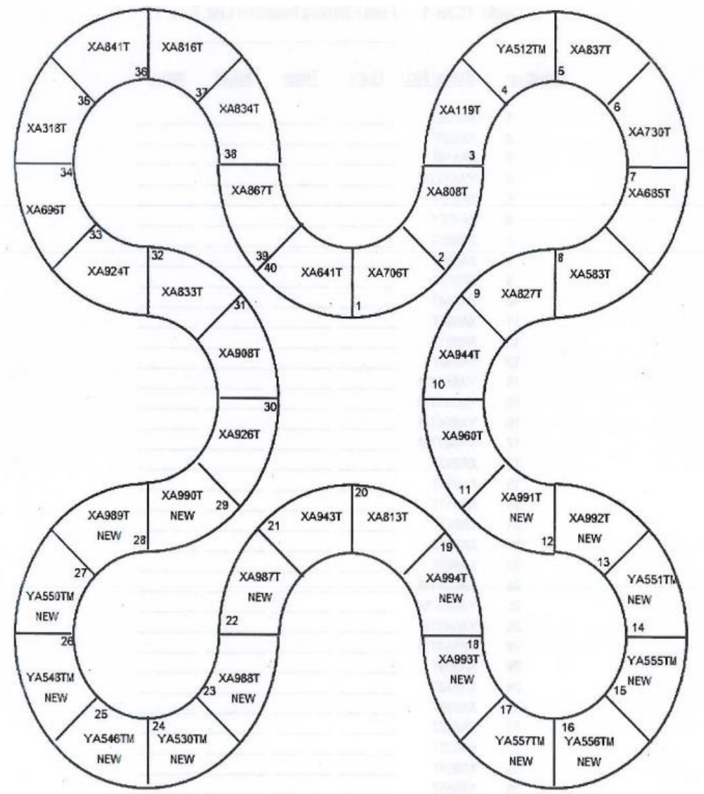
ATR Fuel Element

- Uranium Aluminide UALx fuel matrix
- Aluminum cladding
- 7F/XA Standard Element
- YA-M Type Element – No fuel in plate 19 and narrower side plates
- 45° sector of a right cylinder
- 19 fuel plates
- 20 coolant channels



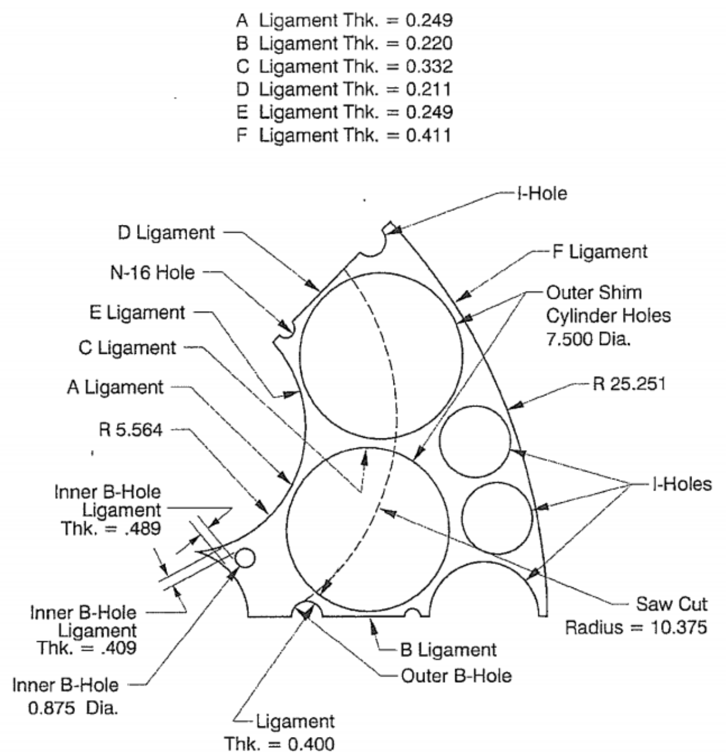
Configuration of the fuel elements ATR Core

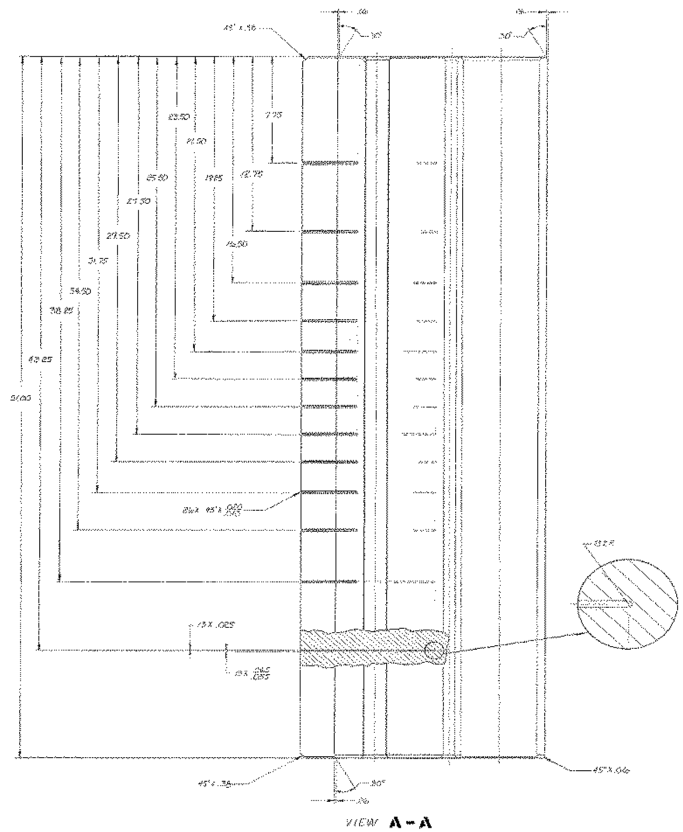
- Almost 50 years of operation.
- Rated 250 MW thermal.
- 110 MW typical operations.
- High power in the south.
- Low power in the north.
- 4 quadrants.
- 5 lobes.
- YA-M elements loaded in the south in positions F14-F18 and F24-F28.
- Recycled YA-M element in position F-4 was unaffected.



ATR Beryllium Reflector Block

- ATR beryllium reflector block ligaments
- Horizontal saw cuts





Possible Contributors to Pitting Degradation

- Higher reactor power – 180 MW vs. 110 MW
- Higher lobe power – 55 MW vs. 23 MW
- Higher flux tilt across the core – 55 MW SW lobe vs. 20 MW NE and NW lobes
- Higher flow rates – 3 primary coolant pumps (PCPs) vs. 2 PCPs
- Higher flow velocities – 47 feet/second (ft/s) vs. 43 ft/s
- Transient core conditions for experiments – PALM vs. steady state
- Beryllium age – late in core internal changeout (CIC) life vs. early in CIC life
- Undetected changes in ATR primary coolant or canal water chemistry

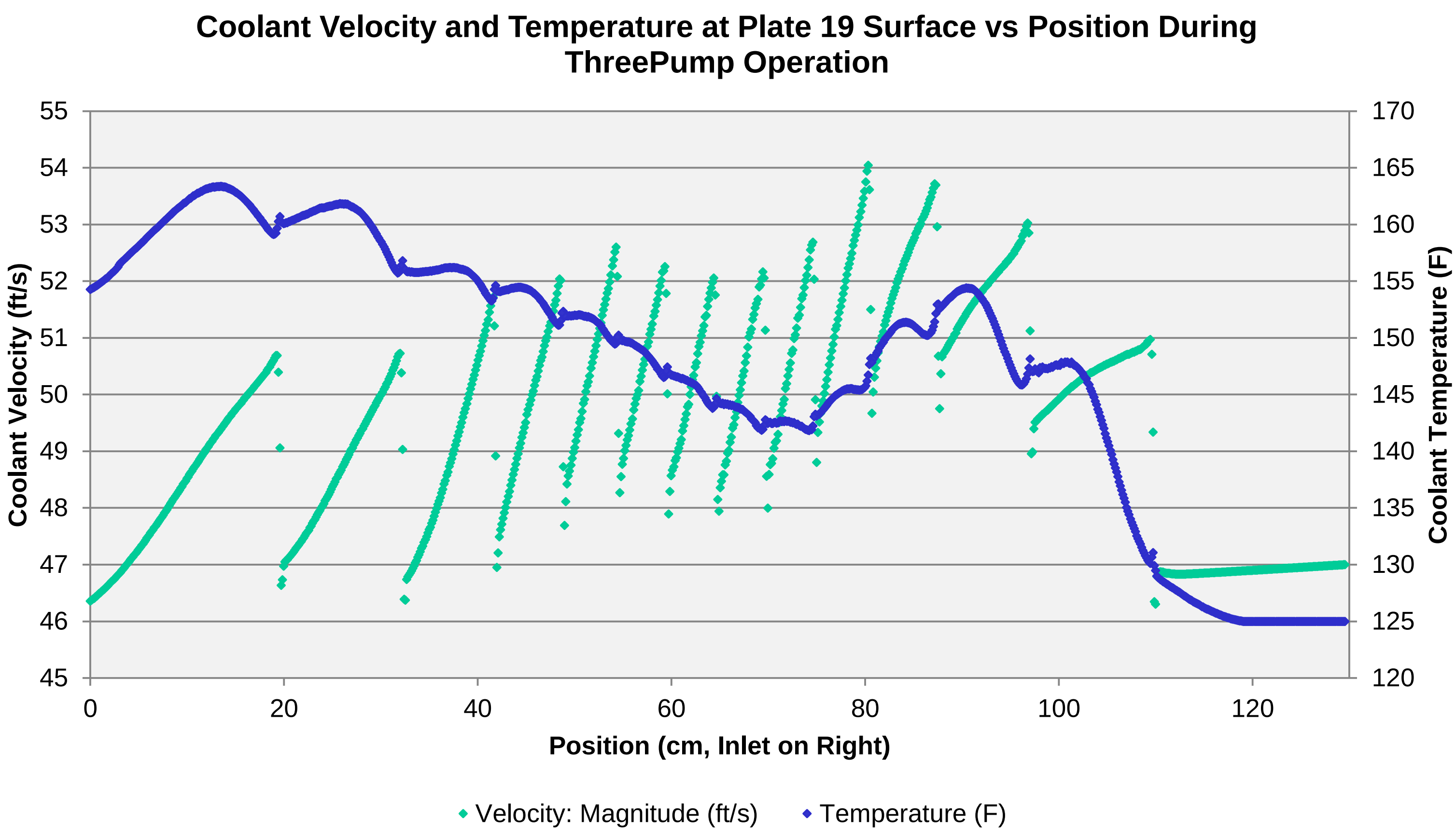
Possible Contributors to Pitting Degradation

- Different fuel element type – YA-M vs. XA/7F
- Coolant channel 20 width – 0.073 in. vs. 0.058 in. due to modified side plates
- Plate 19 – Aluminum “dummy” plate vs. fuel plate
- Power density – 18 fuel plates vs. 19 fuel plates
- Plate fabrication – cold roll vs. hot roll
- Lower temperature annealing process – 775°F (413°C) Program anneal vs. 900°F (482°C) Blister anneal
- Possible changes in the fabrication process
- Contaminants introduced during the fabrication process – 2005 vs. 2014 production runs.

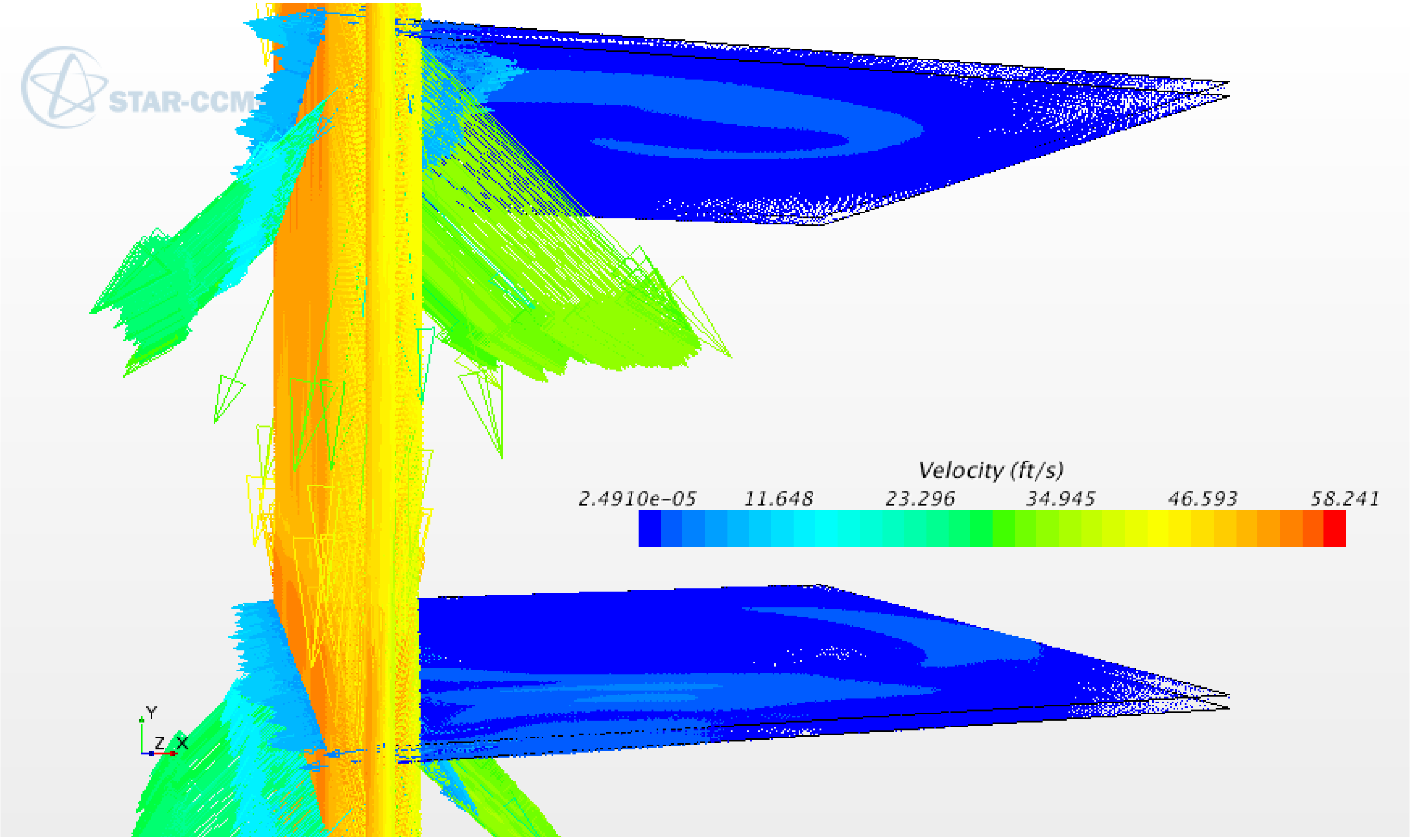
Evaluations and Computer Modeling

- This technical evaluation was the result of interdisciplinary multi-physics simulations and experimental work.
- The role of the several important factors potentially affecting corrosion behavior of the aluminum 6061 “dummy” plate was evaluated, paying special attention to such methods and techniques as computational thermodynamics and kinetics of phase transformations (Thermo-Calc and JMatPro); neutronics modeling using MCNP and HELIOS; thermal-hydraulics modeling using supercomputer modeling with STAR-CCM+.

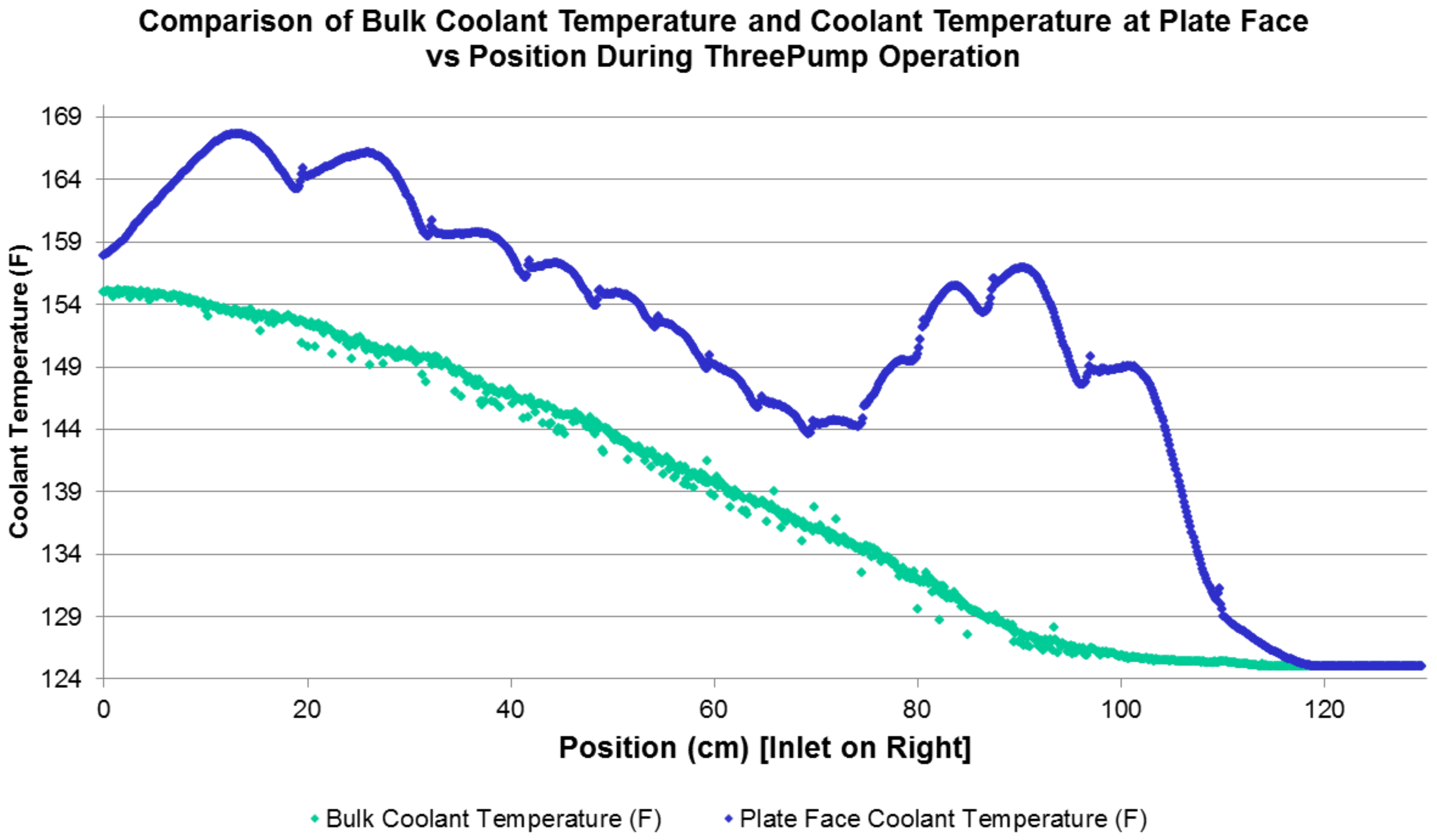
Coolant velocity and temperature in Channel 20



Flow Velocities at Each Horizontal Saw Cut



Bulk Coolant Temp Compared to Plate Face



Evaluation Results

- The observed pitting degradation appears to be the result of a combination of higher reactor power levels, higher primary coolant flow rate, and narrowing of the coolant channel 20 due to modified side plates on YA-M type fuel elements and possible swelling of the beryllium reflector blocks late in life prior to core internal changeout (CIC).
- The chamfer at the edge of the horizontal saw cuts in the Beryllium reflector blocks created the turbulent flow conditions that contributed to the flow erosion/corrosion pitting degradation of the aluminum dummy plate on YA-M type fuel elements. Modeling showed that a wider coolant channel 20 or larger chamfers would have reduced the potential for this flow erosion/corrosion.

Fabrication Changes and Path Forward

- The fabrication process was revised to include an additional blister anneal at 900°F (482°C) for 2 hours to allow for additional crystal growth during production of the dummy EE plates. The first YA-M fuel elements to be fabricated using the revised process are scheduled to be fabricated in 2016, and are expected to be loaded in the ATR core in 2017.
- Many of the affected YA-M type fuel elements have been recycled and loaded into the ATR core for additional operating cycles with no detrimental effects.

ATR Pitting Degradation

Questions?