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Steam Attack Studies in SiC Clad and Advanced Steel Clad

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OECD/NEA Workshop on Accident Tolerant Fuels of LWR's
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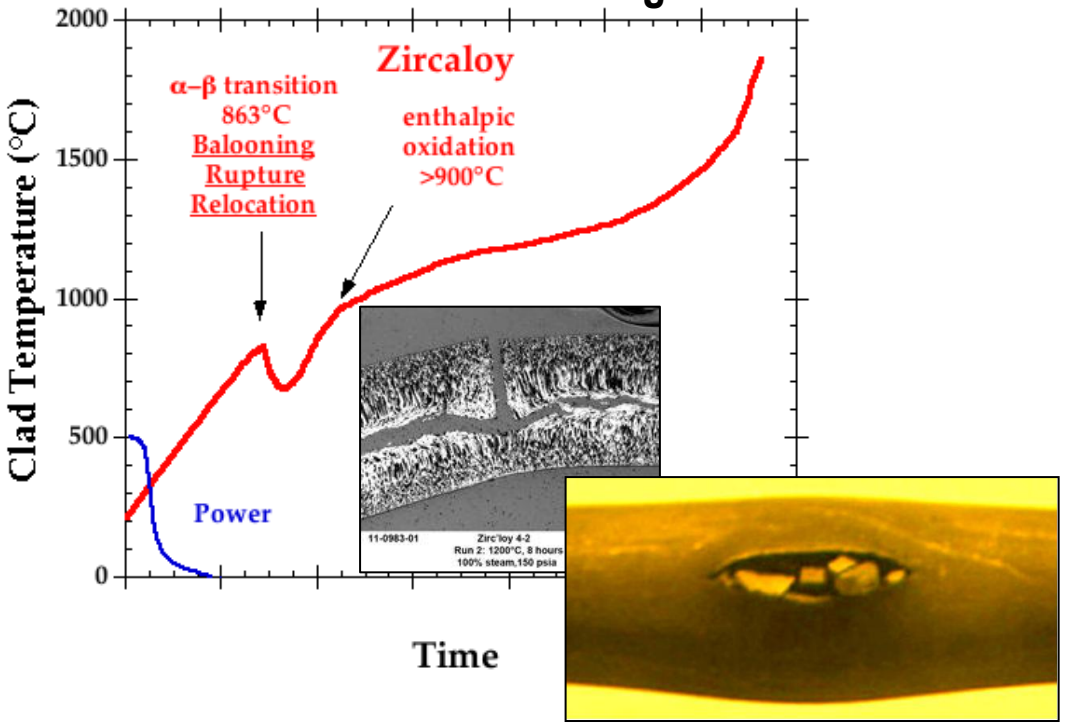
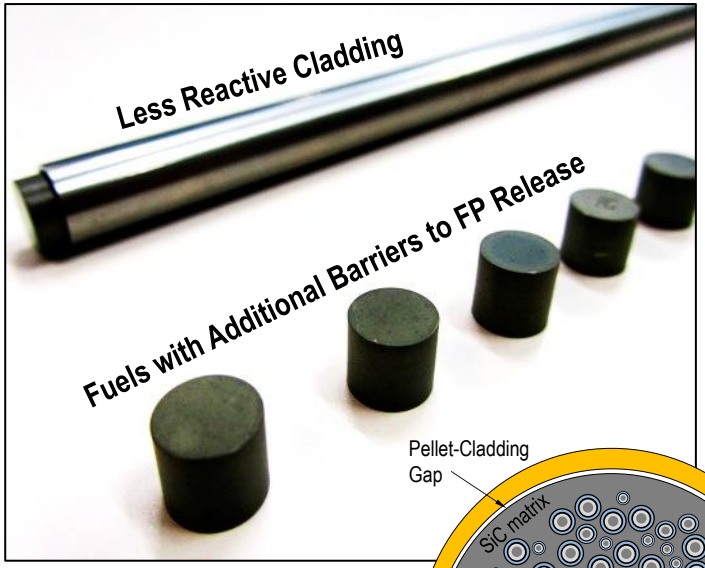
Accident Testing Advanced Fuel

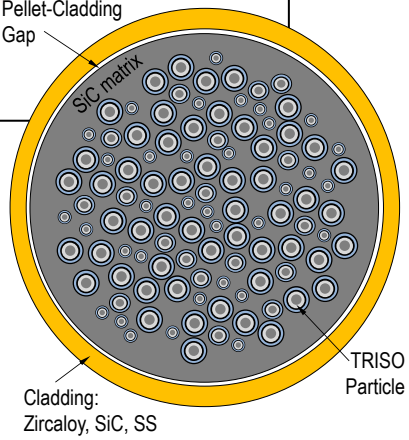
Considerations

Standard LOCA Testing



Testing of Advanced Clad/Fuel



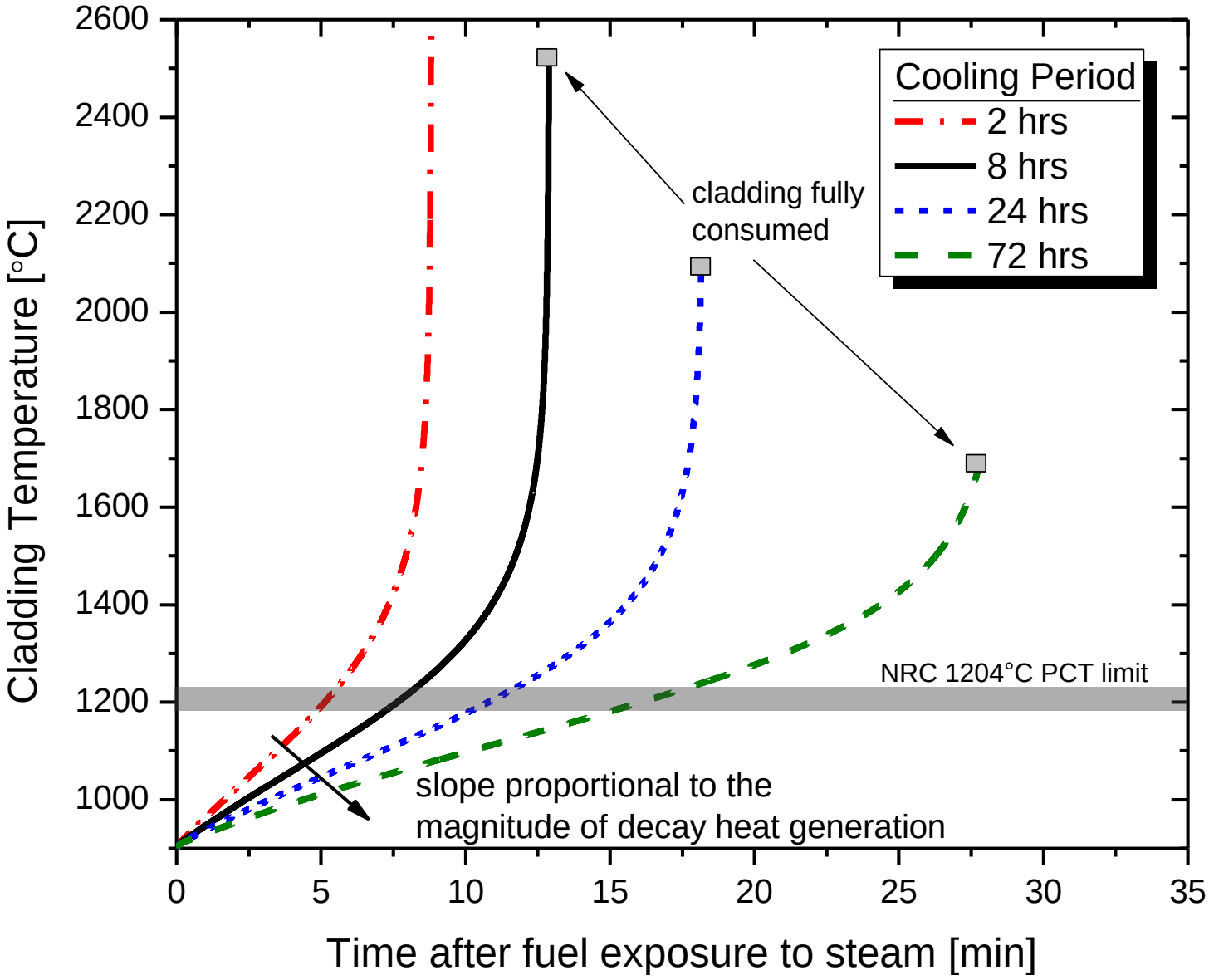


Advanced Fuel Campaign is studying and developing a number of new clad/fuel combinations:

Cladding : Advanced Steel, SiC Clad, Refractory Alloys

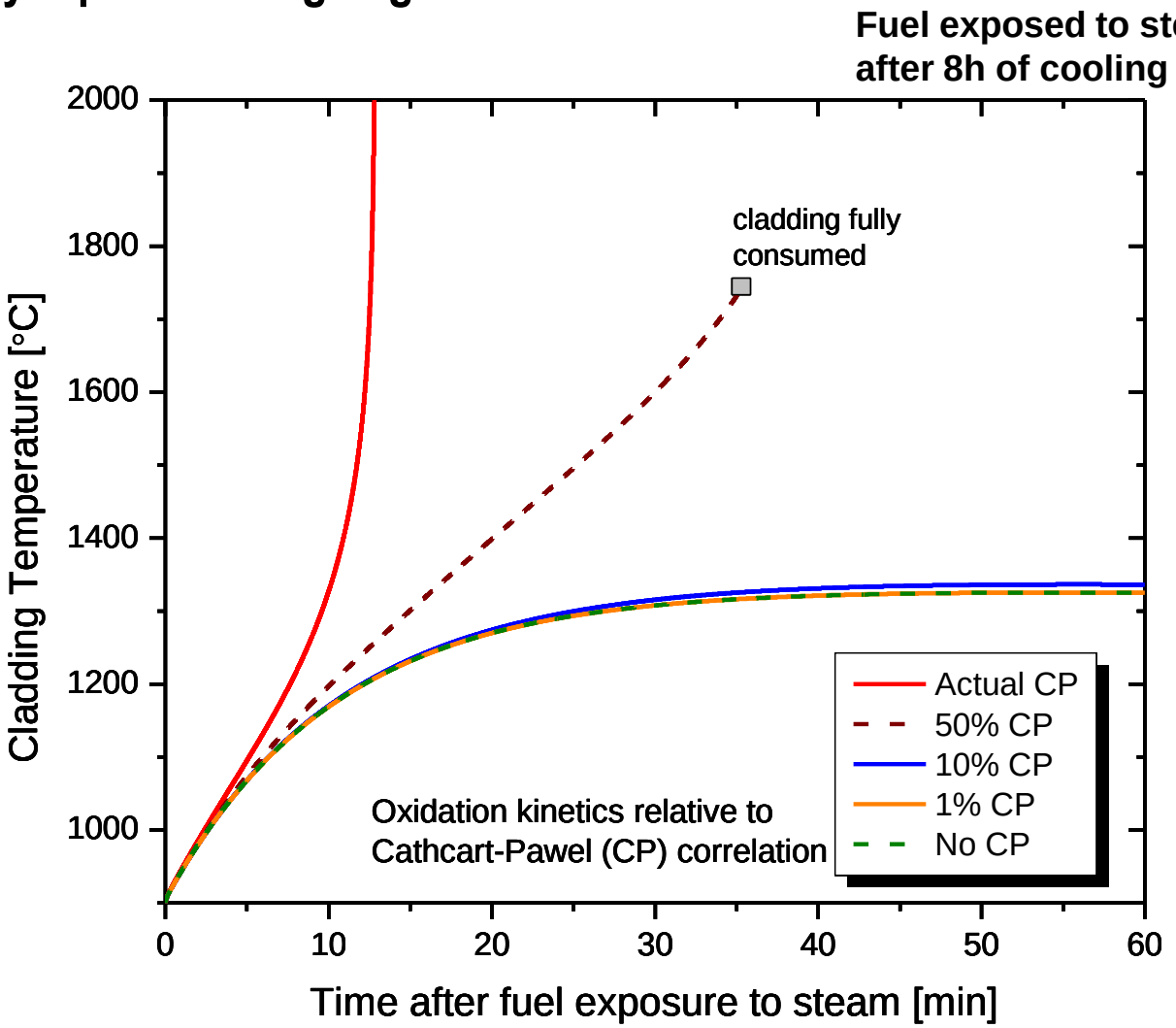
Fuel : Enhanced UO2, TRISO-SiC (FCM), BISO-SiC, TRISO-Metal Matrix

- Guiding Clad Development Effort -
Understanding Requirement to Impact Goal of Reduced Enthalpy

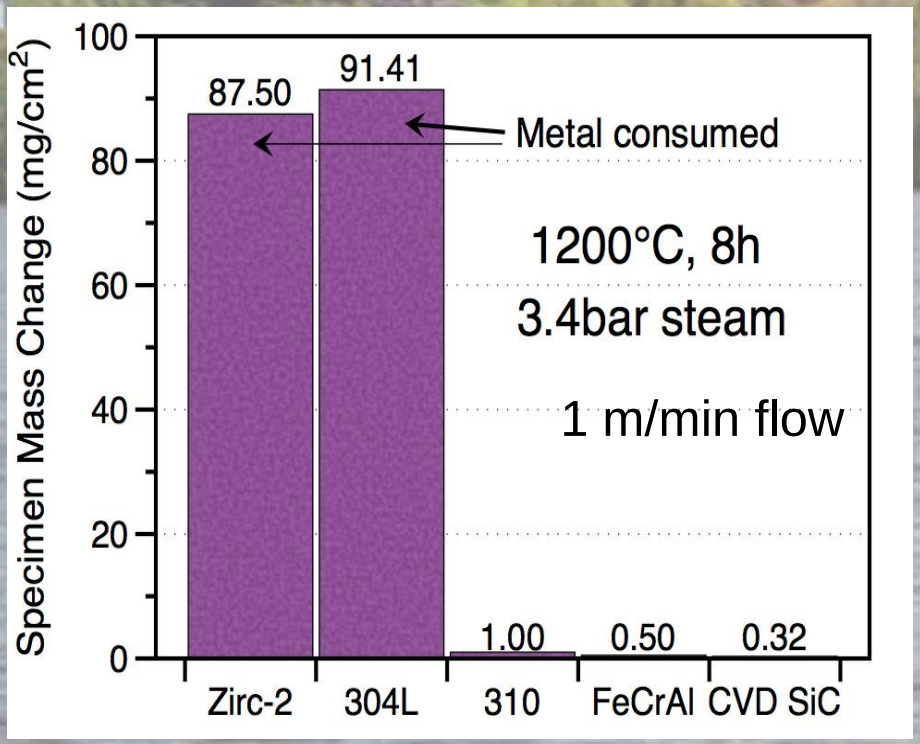


Materials With Slower Oxidation Kinetics Offer Larger Margins of Safety

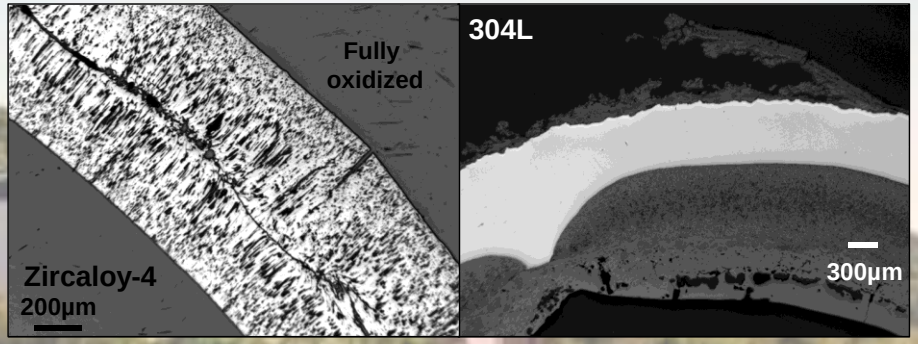
- Materials with slower oxidation kinetics in steam (~ 2 orders of magnitude or less) delay rapid cladding degradation



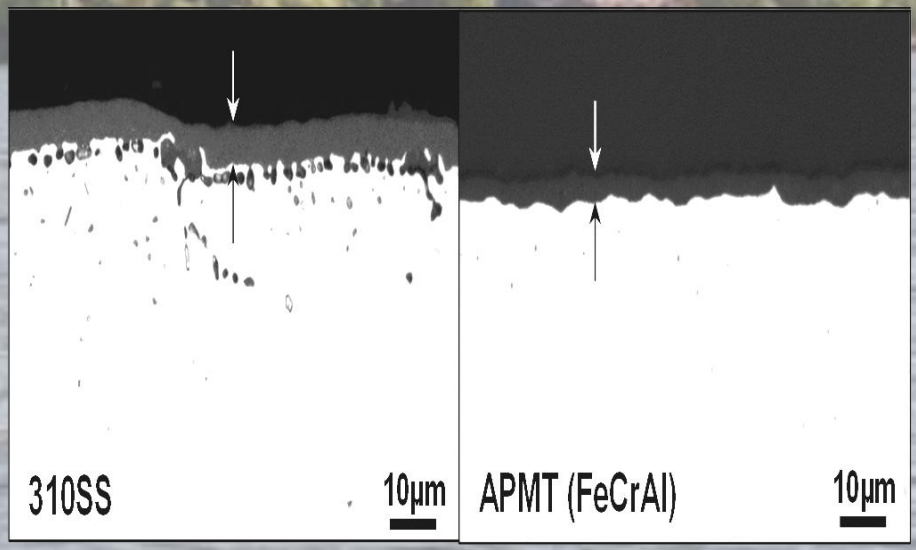
Advanced Fe-based Alloys And SiC Materials Offer Significant Improvements Over Zirconium Alloys and Conventional Stainless Steels



1200C – 8 hours – 3.4 bar Steam



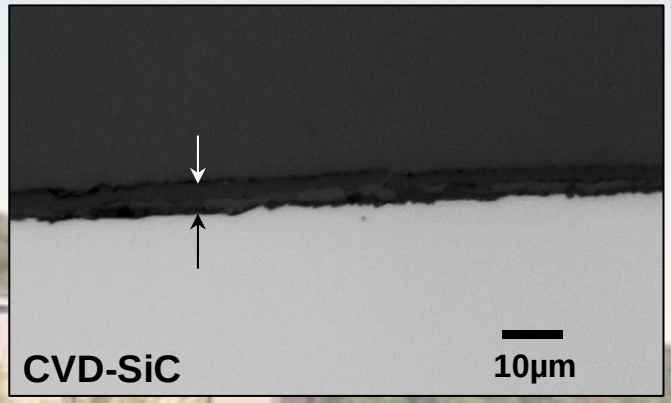
Conventional Alloys: Full or Near Full Consumption

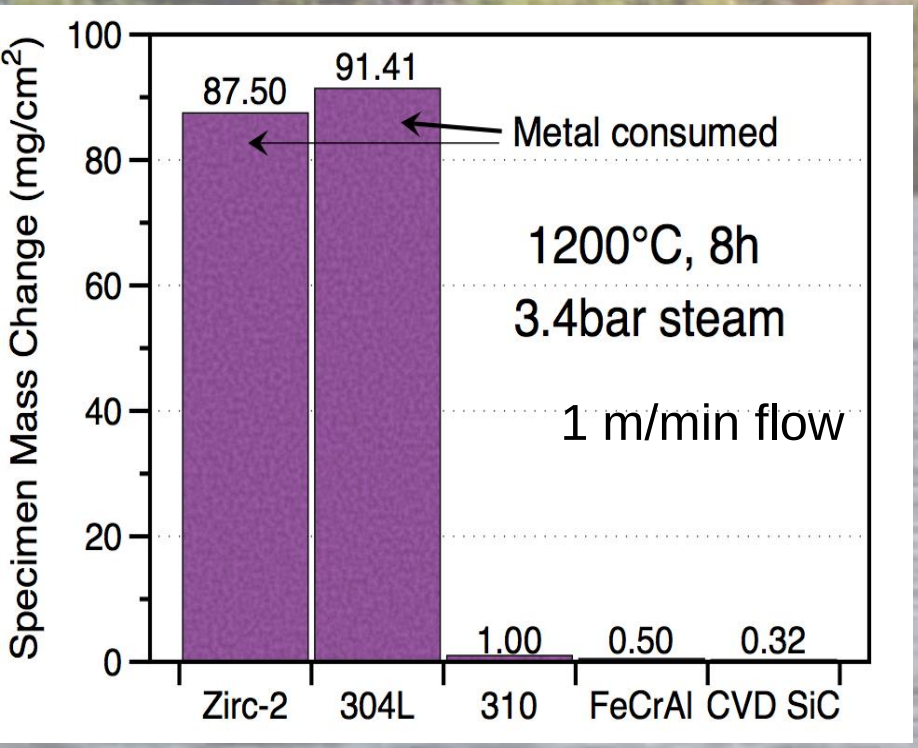


Advanced Fe-Alloys: Minimal Reaction

Advanced Fe-based Alloys And SiC Materials Offer Significant Improvements Over Zirconium Alloys and Conventional Stainless Steels

SiC: Minimal Reaction





Coated

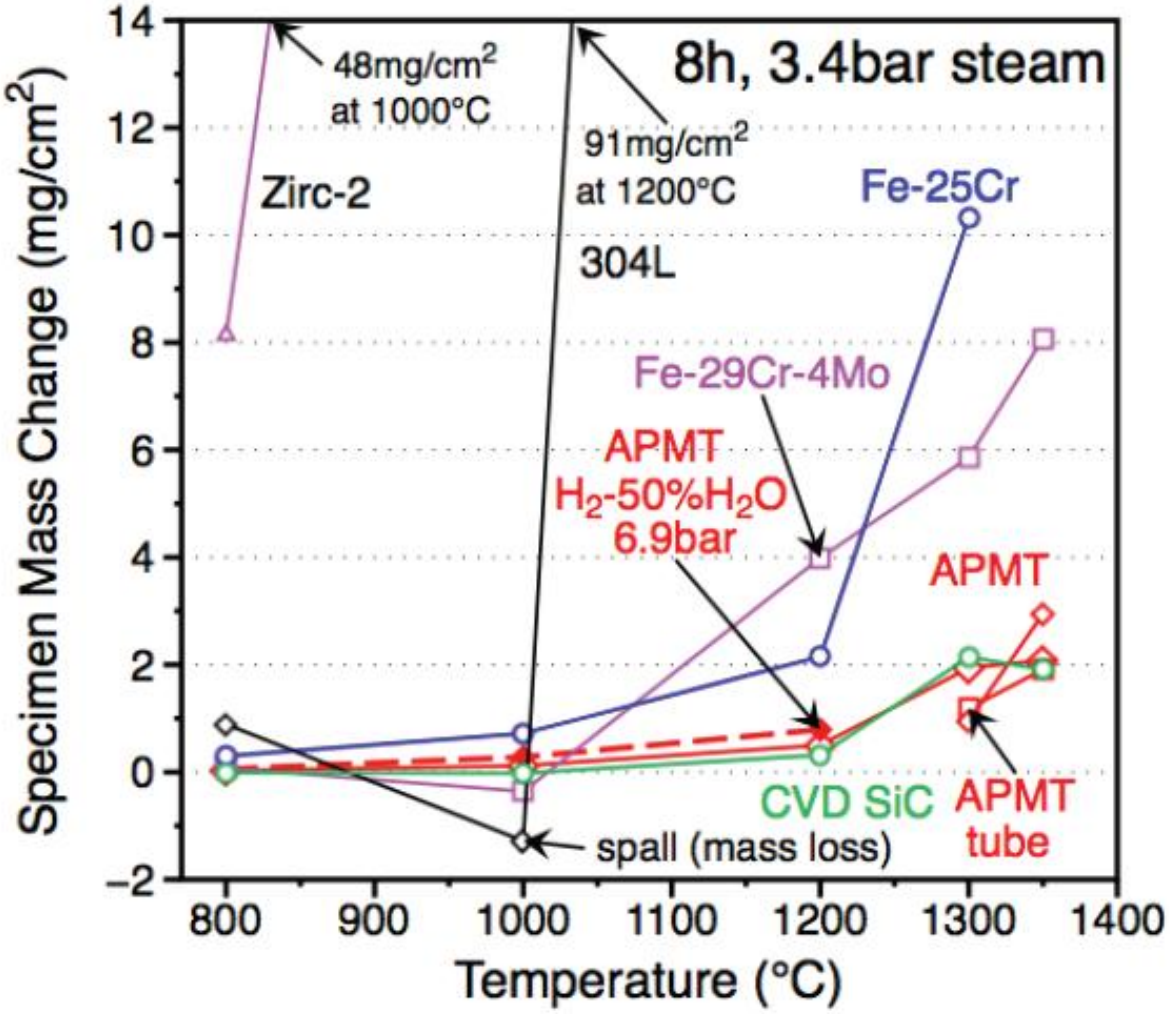
As Fabricated Cross section

Uncoated

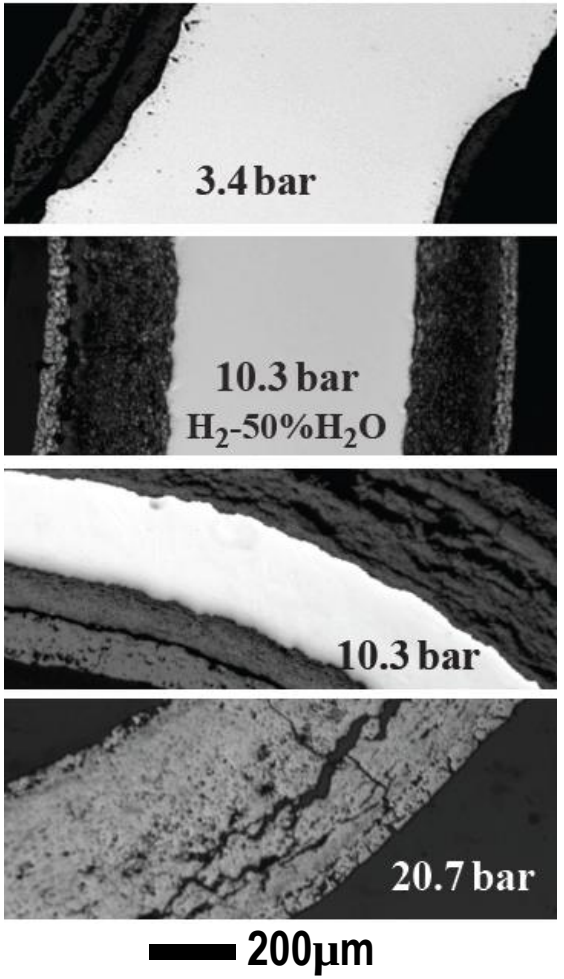
After 1300 °C and 250 psig of 100% steam for 48 hours

High-P Steam Testing Results

- No hydrogen effect was observed on Fe-alloys during 50%H_2-50% steam tests
- Effect of pressure was significant for low oxidation resistance chromia forming alloys. No pressure effect observed on FeCrAl alloys.

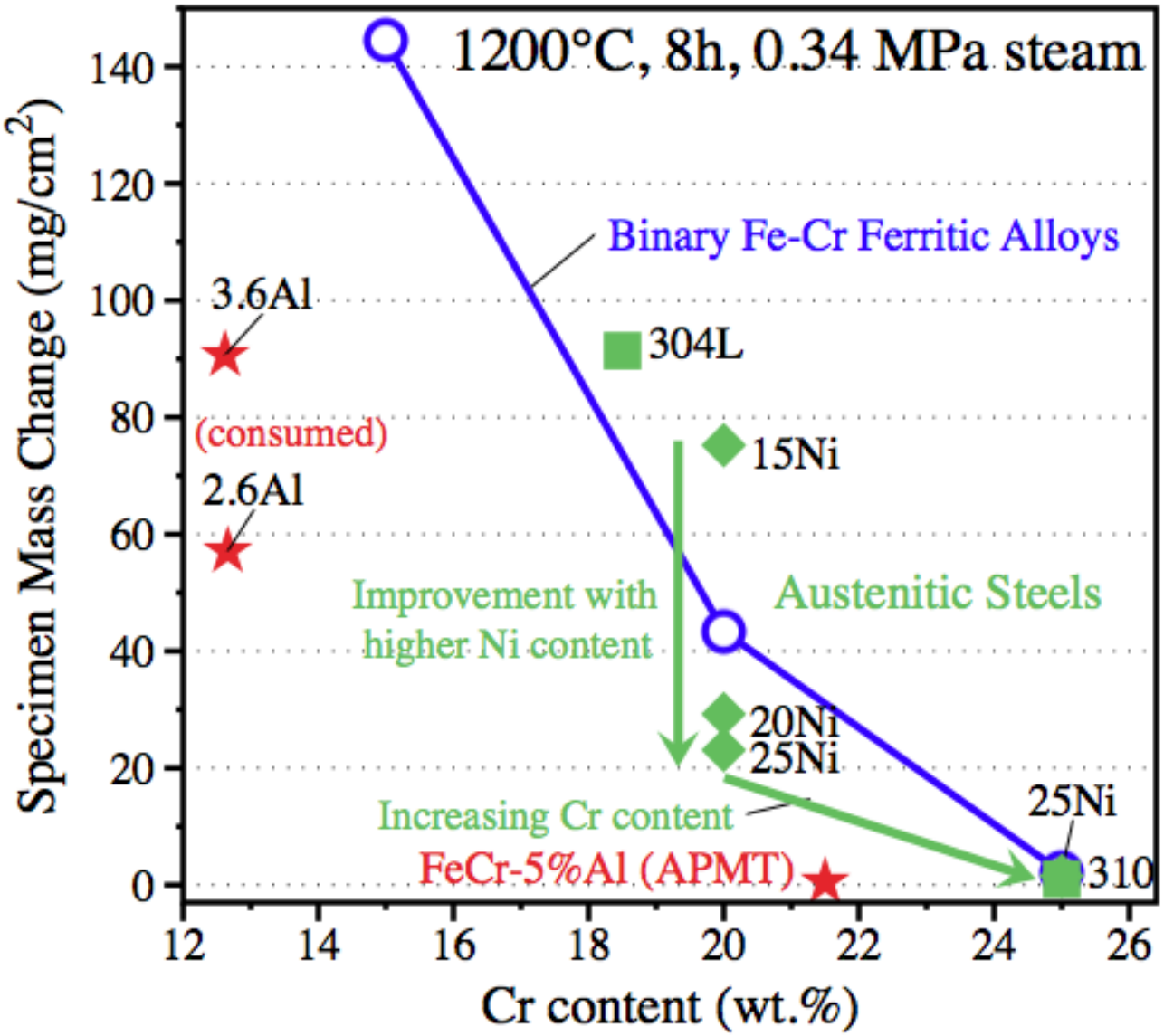


317L Stainless Steel
1200ºC – 8 h tests

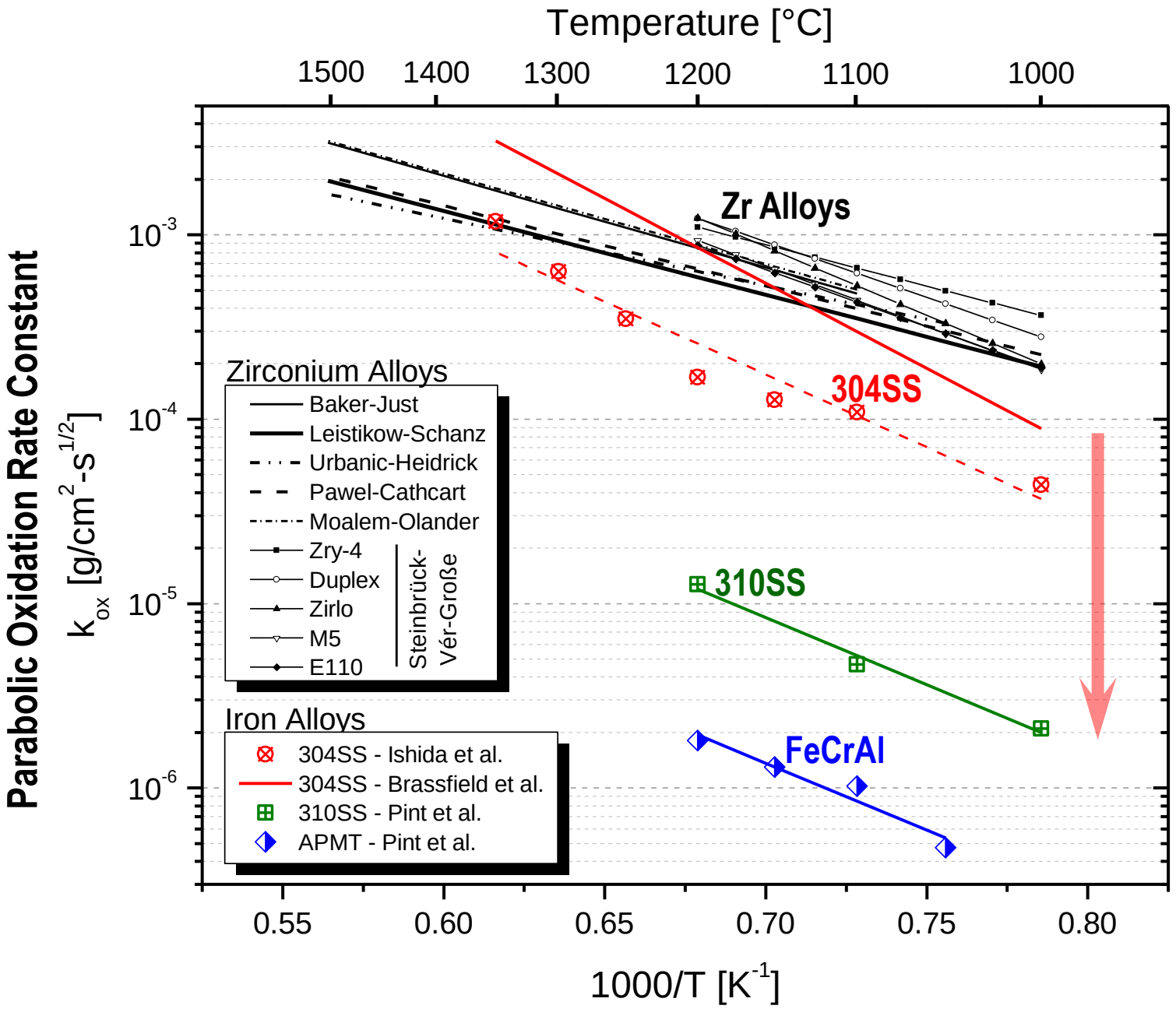


Effect of Fe-Alloy Composition

- Increase in the Cr and Ni content in austenitic steels enhances oxidation resistance. Alumina-forming ferritic alloys exhibit exceptional resistance

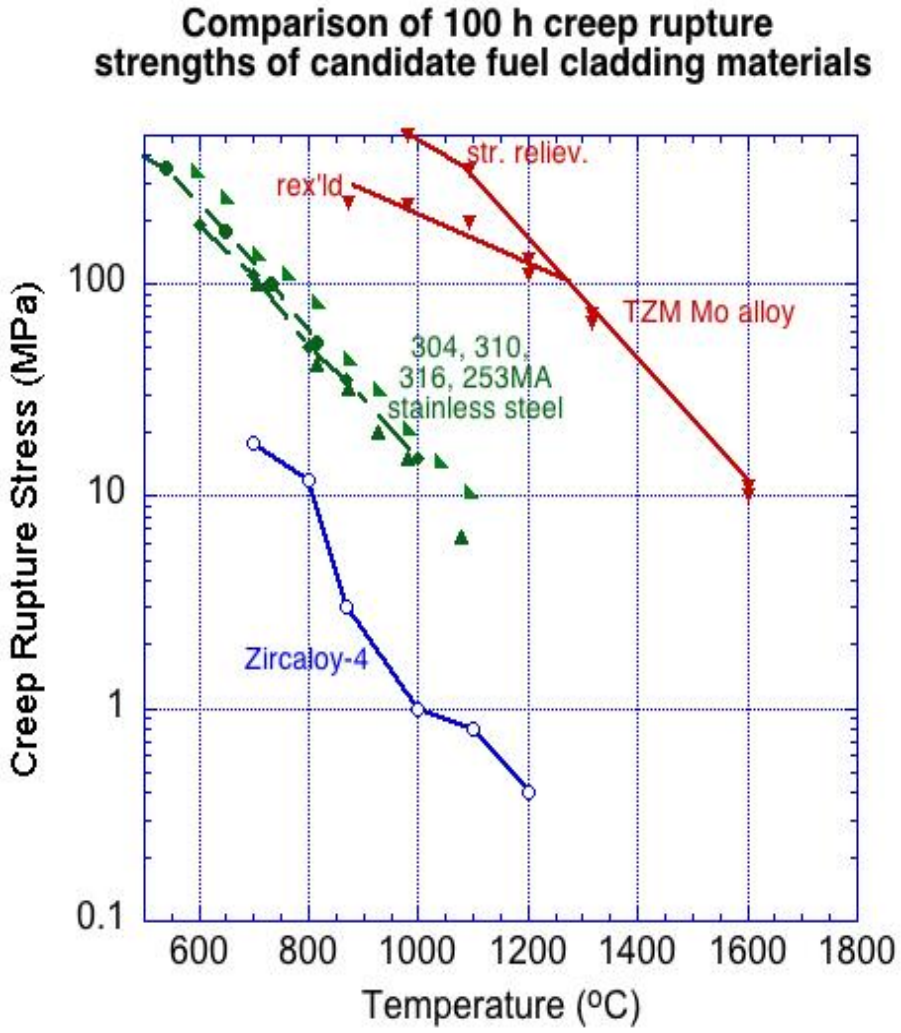


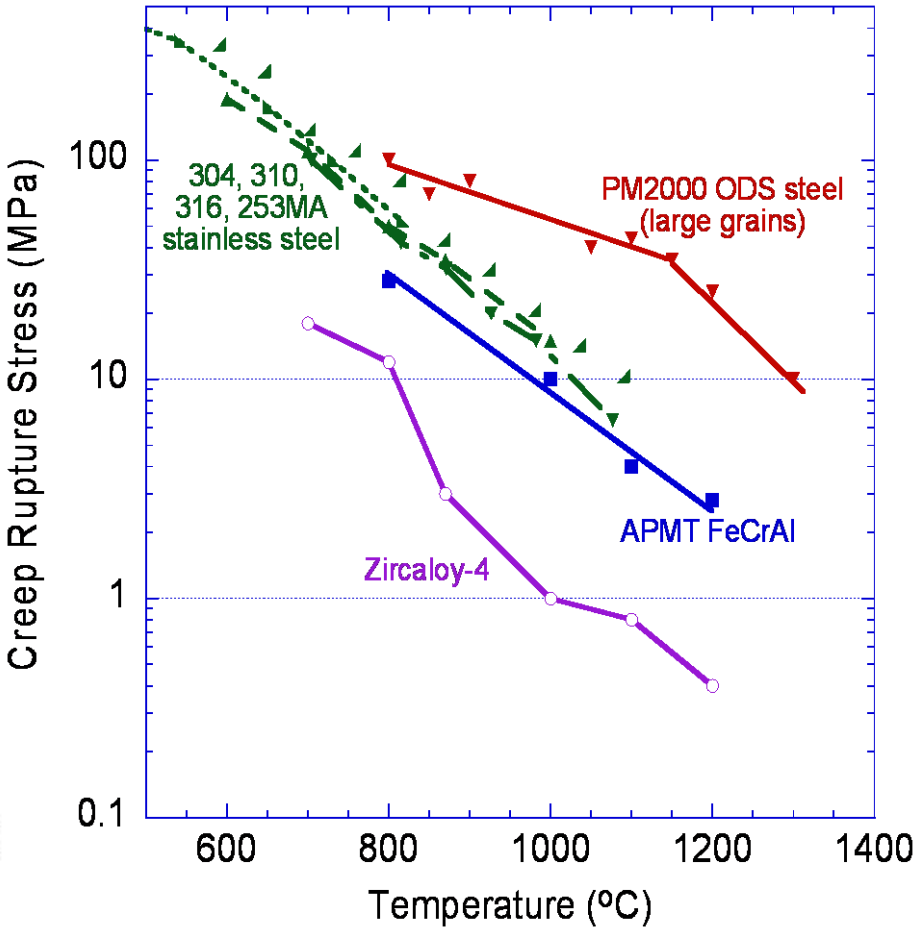
Thermogravimetry Experiments



2 - 3 Orders of Magnitude Reduction in Oxidation Kinetics

Thermal creep strength of some candidate cladding materials



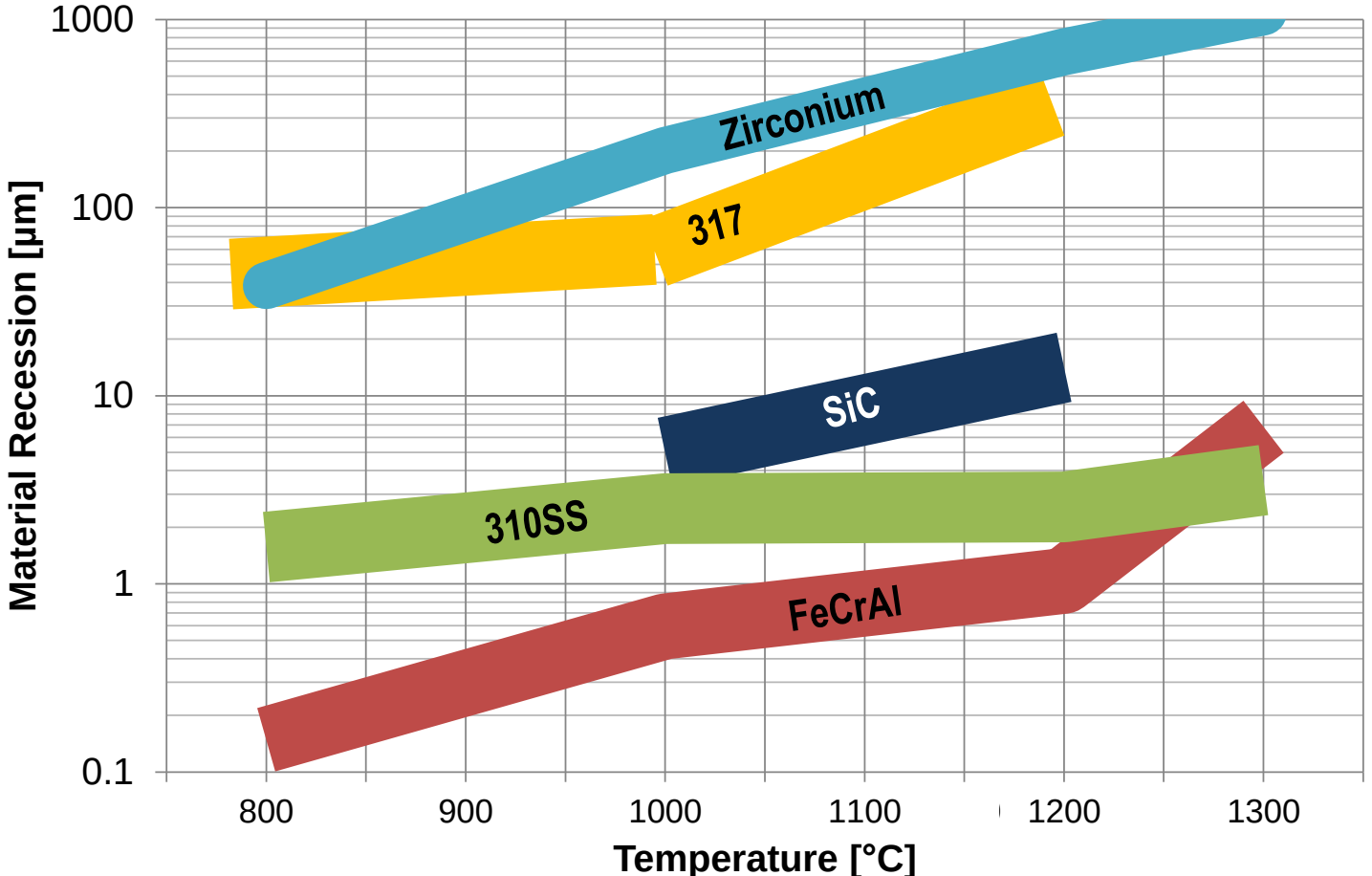


- **Mo alloys and steels (and SiC/SiC, not plotted) offer improved high temperature strength**

High-Pressure Steam Oxidation Tests: Comparison of the Extent of Steam Reaction

Various materials exposed to pure steam for 8 hours (various flow rates and pressures)**:**

- **Zircaloy:** Pawel-Cathcart and Moalem-Olander data
- **317 Stainless Steel:** ORNL high-pressure tests; thickness loss data
- **NITE and CVD SiC:** ORNL high-pressure tests; thickness loss data
- **310 Stainless Steel:** ORNL high-pressure tests; mass gain data converted to thickness loss
- **FeCrAl Ferritic Steel:** ORNL high-pressure tests; mass gain data converted to thickness loss



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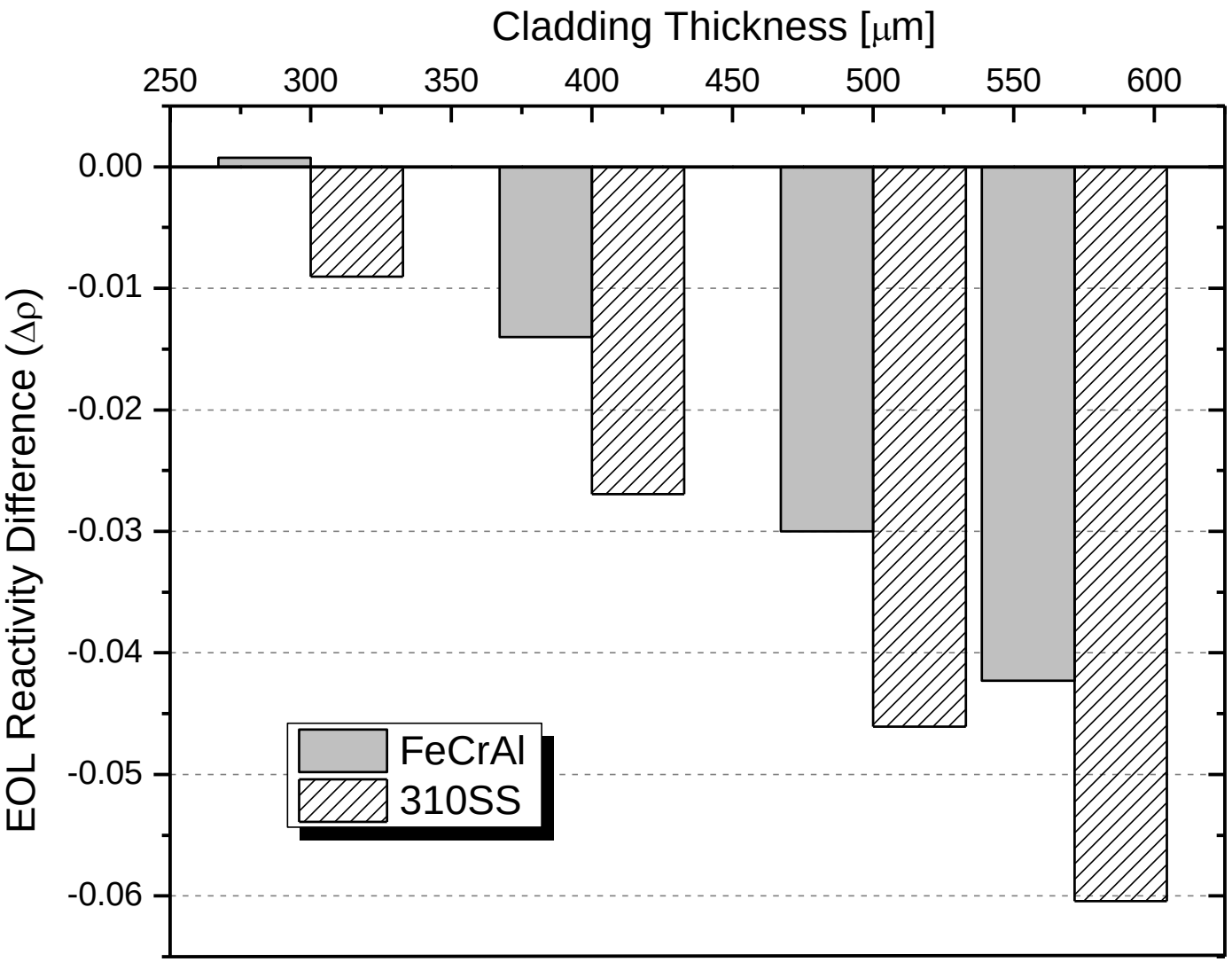
Enrichment-Clad Thickness Trades

UO2 Fuel in Commercial Reactor

HOLDING ENRICHMENT AT CONSTANT 4.9%



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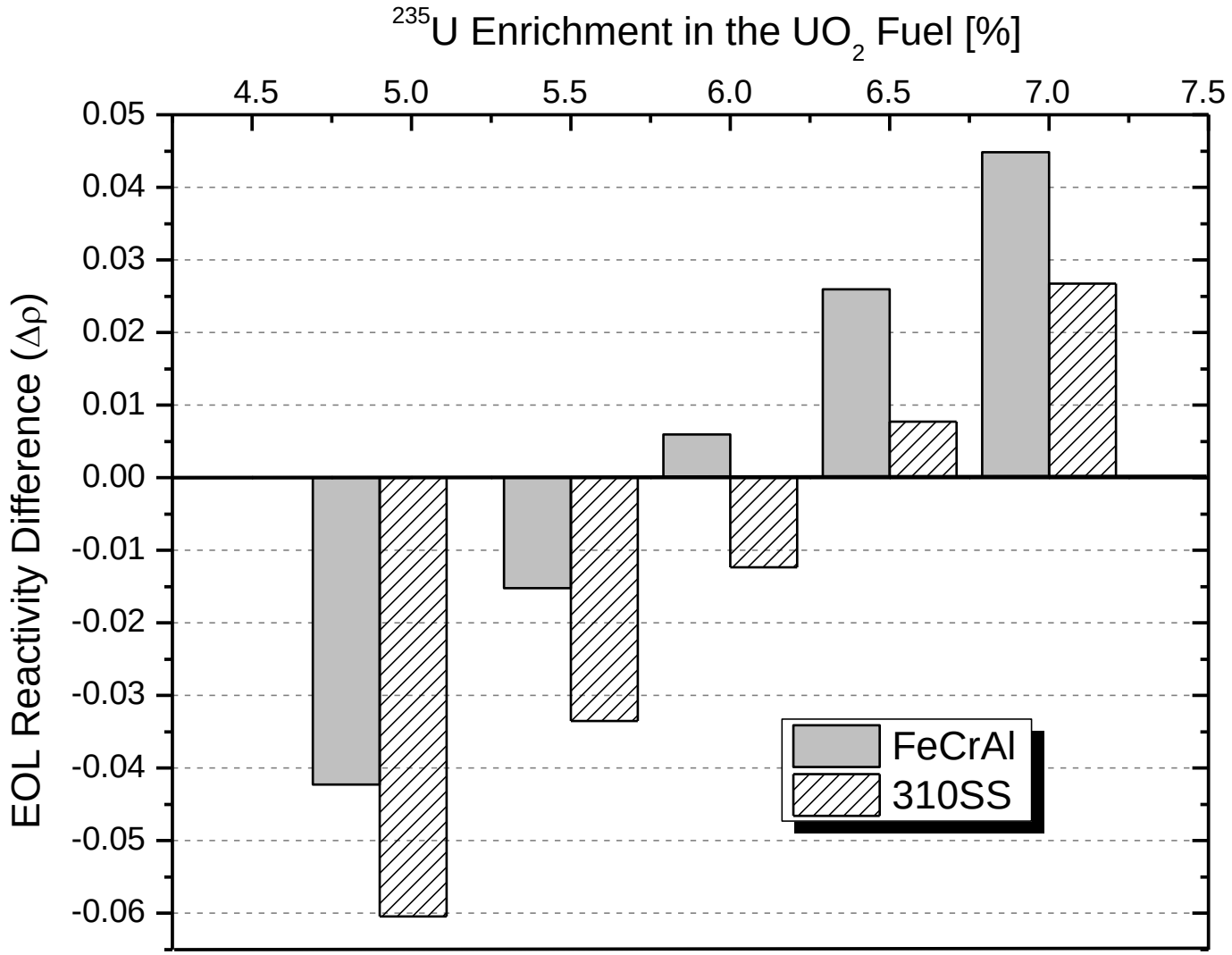
Enrichment-Clad Thickness Trades

UO2 Fuel in Commercial Reactor

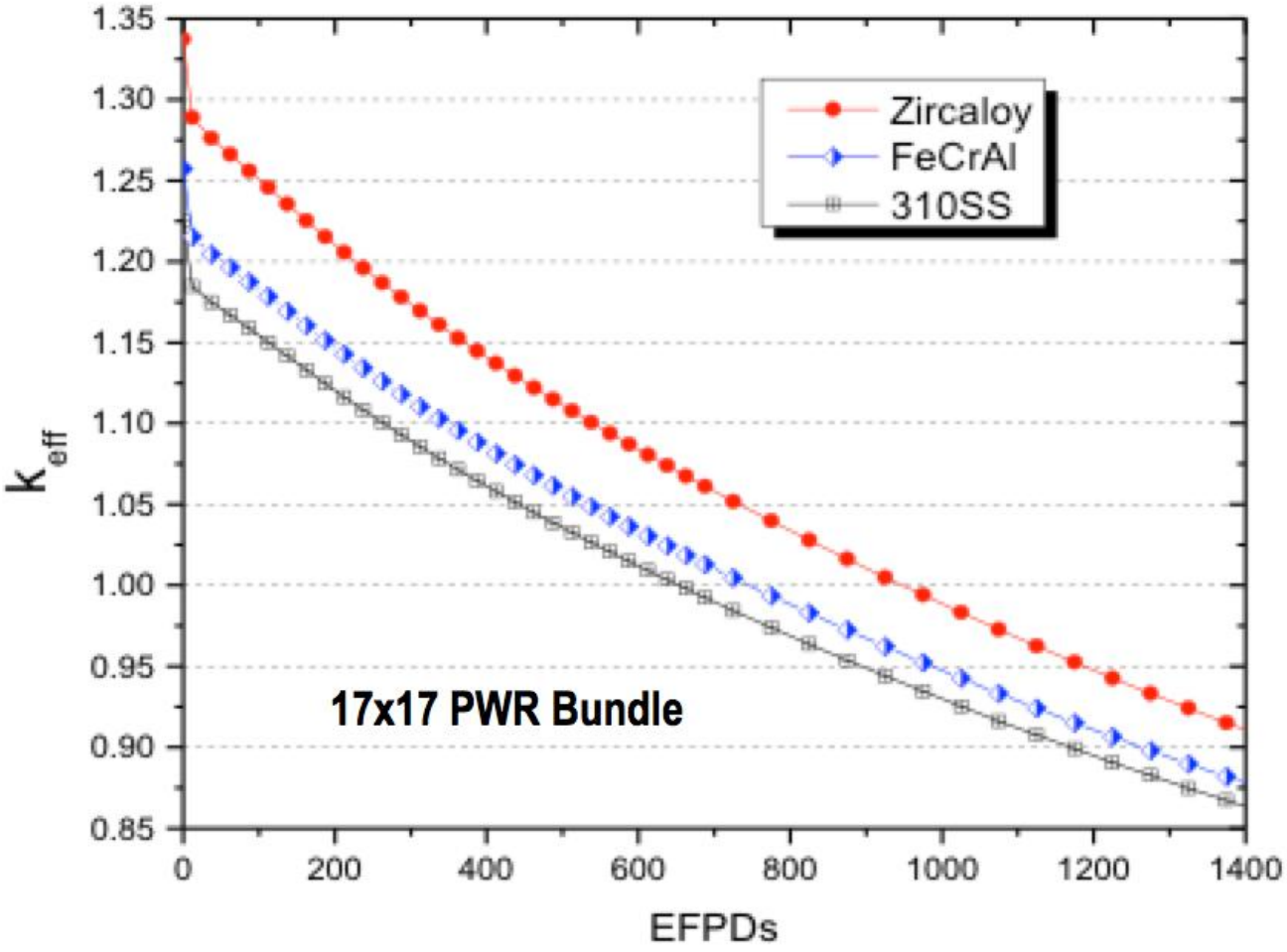
HOLDING CLAD THICKNESS UNIFORM



Neutronics and Economics of Steel Clad

Addressing negative impact of neutron scavanging:

- **Reduce clad thickness** (steel is stronger)
- **Increase ^{235}U enrichment**



Difference In End Of Life Reactivity SS Clad Vs Zr Clad

Neutronics and Economics of Steel Clad

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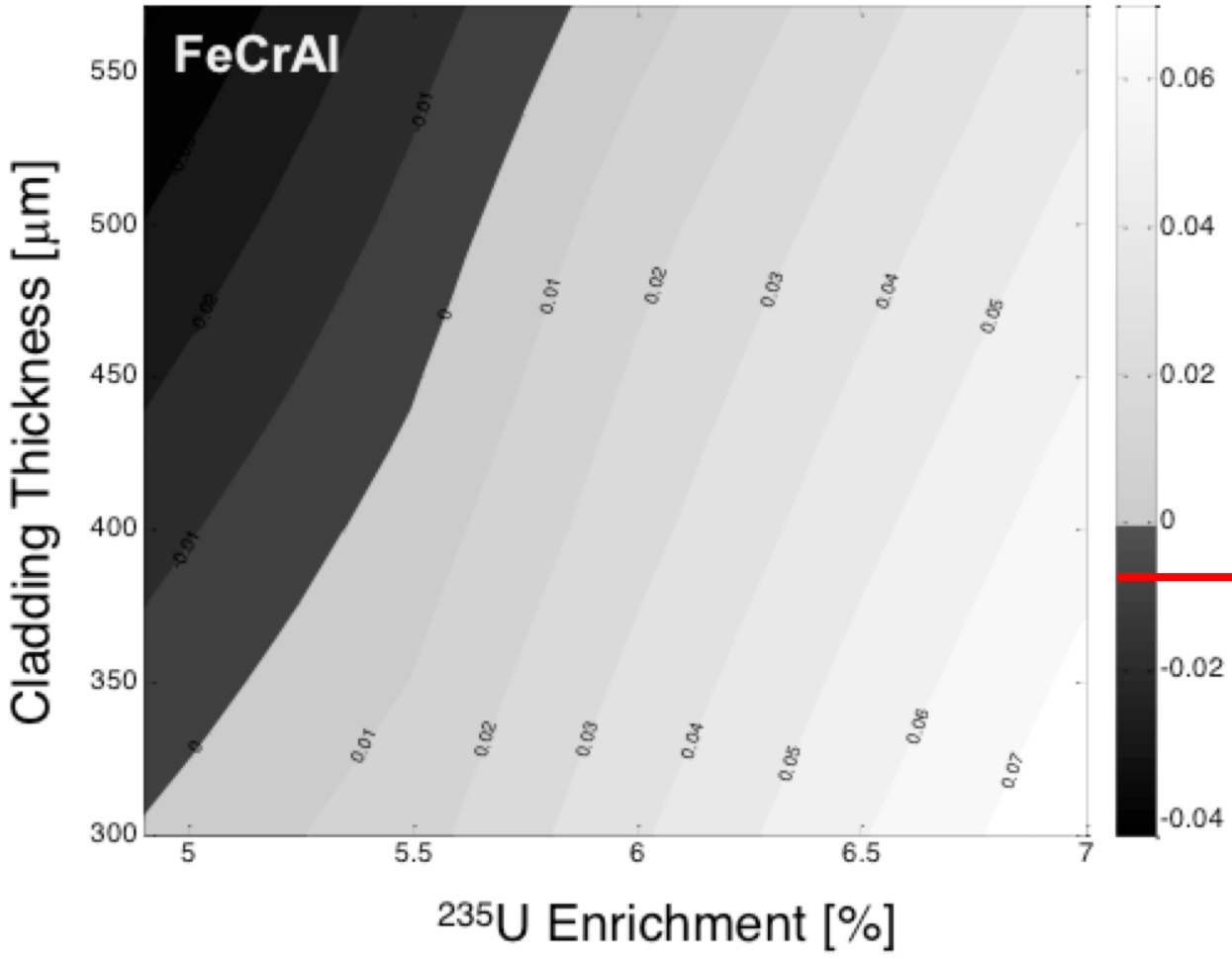

Difference In End Of Life Reactivity SS Clad Vs Zr Clad

- Resistance of steam oxidation is a driving metric for Accident Tolerant Fuel selection and development in the current DOE Advanced Fuel Cycle R&D program.

- Facilities are being utilized and under development for ex-cell and in-cell testing of fuel and clad materials up to 1700°C in steam and steam-hydrogen environments.

- Current focus of advanced clad materials, largely driven by their steam-oxidation performance, are advanced steels and SiC clad.
  - SiC has been evaluated and performance data is being compiled for core accident modeling. Pure forms of SiC are quite stable. Impure forms less so.
  - Certain commercial advanced steels such as FeCrAl, 301, and EBRITE exhibit similar or superior steam-oxidation as SiC in the 1200-1400°C range.
  - New, specifically LWR ATF engineered alloys have been fabricated at ORNL and early steam oxidation studies are promising.

- We are in the early stages of development of these materials. Parallel activities within the FCRD program in areas such as tube development, water corrosion, and irradiation performance on underway. Support for core accident analysis is beginning.