U.S. DEPARTMENT OF ENERGY | Nuclear Energy

FC 2: Advanced Fuels

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DOE-NEUP FY2018 Webinar
August 9, 2018

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The FCRD Advanced Fuel Campaign is tasked with development of near term accident tolerant LWR fuel technology and performing research and development of long term advanced reactor fuel options.

Advanced LWR Fuels with enhanced performance, safety, and reduced waste generation

Advanced reactor fuels with enhanced proliferation resistance and resource utilization

Capability Development for Science-based Approach to Fuel Development

- Advanced characterization and PIE techniques
- Advanced in-pile instrumentation
- Separate effects testing
- Transient testing infrastructure

Multi-scale, multi-physics fuel performance modeling and simulation

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FY 2018 NEUP Awards

FY 2018 Nuclear Energy University Program R&D Awards			
Title	Area	PI Last Name	Lead University
Bridging the length scales on mechanical property evaluation	FC-2.1	Hosemann	University of California, Berkeley
Benchmarking Microscale Ductility Measurements	FC-2.1	Kingstedt	University of Utah
Bridging microscale to macroscale mechanical property measurements and predication of performance limitation for FeCrAl alloys under extreme reactor applications	FC-2.1	Wang	University of Nebraska, Lincoln
Microstructure-Based Benchmarking for Nano/Microscale Tension and Ductility Testing of Irradiated Steels	FC-2.1	Wharry	Purdue University
Radiolytic Dissolution Rate of Silicon Carbide	FC-2.3	Bartels	University of Notre Dame
Understanding of degradation of SiC/SiC materials in nuclear systems and development of mitigation strategies	FC-2.3	Hosemann	University of California, Berkeley
Development of Multi-Axial Failure Criteria for Nuclear Grade SiCf-SiCm Composites	FC-2.3	Huang	University of South Carolina
Probabilistic Failure Criterion of SiC/SiC Composites Under Multi-Axial Loading	FC-2.3	Le	University of Minnesota, Twin Cities
Advanced Coating and Surface Modification Technologies for SiC-SiC Composite for Hydrothermal Corrosion Protection in LWR	FC-2.3	Sridharan	University of Wisconsin-Madison
Multiaxial Failure Envelopes and Uncertainty Quantification of Nuclear-Grade SiCf/SiC Woven Ceramic Matrix Tubular Composites	FC-2.3	Subhash	University of Florida
Mechanistic Understanding of Radiolytically Assisted Hydrothermal Corrosion of SiC in LWR Coolant Environments	FC-2.3	Was	University of Michigan

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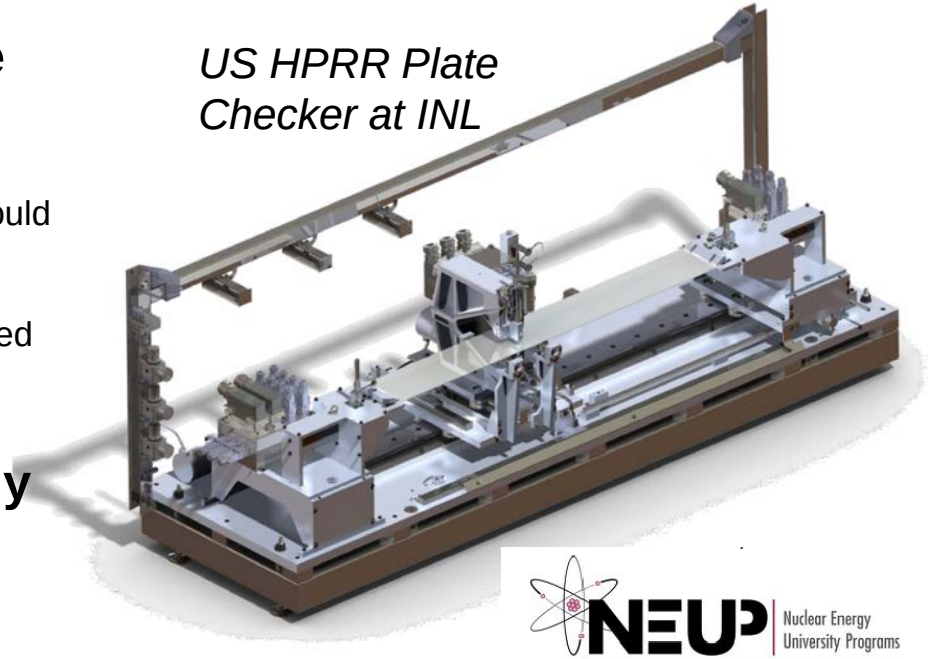
FC 2.1 – Post Irradiation Examination (PIE)/Non Destructive Examination (NDE) Techniques for Corrosion Thickness Measurements on ATF Claddings (Coated-Zr, FeCrAl, SiC) (1)

Federal Manager: Frank Goldner
TPOC: Jason Harp (INL)

- **Proposals are solicited for techniques or a suite of techniques that can be applied to evaluate the surface oxide, surface layer adhesion and sub-surface features, such as micro-cracks and delamination, for a wide variety of accident tolerant cladding concepts.**
- **Techniques developed should be demonstrated to work in a**
  - Remote, high radiation environment
  - Signals from the demonstrated techniques should travel greater than 30 feet from sensor to data collection equipment
  - Signals must pass through a hermetically sealed feedthrough
- **Collaboration with existing ATF cladding vendors will be favorably viewed**

US HPRR Plate Checker at INL



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Post Irradiation Examination (PIE)/Non Destructive Examination (NDE) Techniques for Corrosion Thickness Measurements on ATF Claddings (Coated-Zr, FeCrAl, SiC) (2)

- **Current Program Focus:**
  - Accident Tolerant Fuel Cladding concepts that support needs of proposed accident tolerant candidate concepts prioritized by the industry (Coated-Zr, FeCrAl, SiC)
  - This work is intended to support national lab development and testing capabilities in preparation of initiating PIE on ATR irradiated and TREAT irradiated cladding samples
- **Coating adhesion and oxide layer thickness need to be evaluated for ATF cladding.**
  - The in-pile corrosion and adhesion properties of coated Zr are not currently known.
  - A non-destructive technique that evaluates coating adhesion and oxide layers over a significant portion of the cladding surface is desired.
  - Ideally the developed technique would also be compatible with FeCrAl alloys
  - Composites of SiC are also being investigated and these composites generate very thin oxide layers in pressurized water conditions. The SiC-based cladding concepts also can contain various sub-surface interfaces and the integrity and damage accumulation at those interfaces will be a performance aspect that must be examined and quantified.
- **The oxide layer on zirconium alloys has typically been evaluated with Eddy Current.**
  - This technique typically requires a new set of sensors for every new substrate, and the response of eddy current sensors to ferritic substrates is quite different from non-ferritic substrates.
  - This technique is also only applicable to conductive substrates. Presently, eddy current also cannot distinguish between voids (lack of adhesion) and oxide growth.
- **Priority will be given to applications that clearly support near-term needs of existing ATF industrial application concepts and are scalable to full length rods. Remote hot-cell application experience in the collaboration team will also be given priority.**

Coated Zircaloy Example

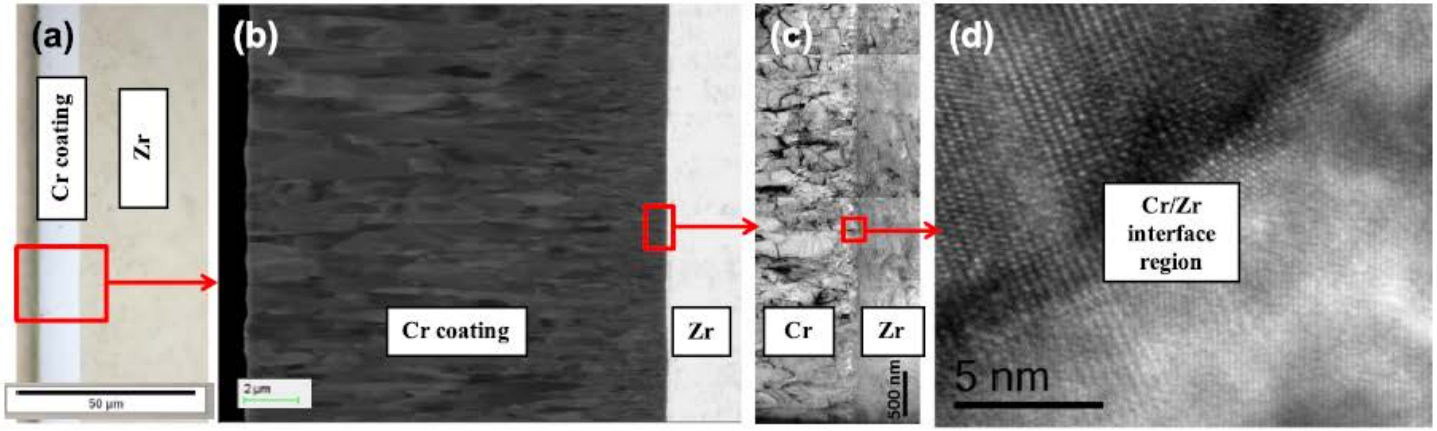

Fig. 4. Metallic Cr coating of thickness 12–15 µm deposited on the surface of Zr-based cladding and characterized by a) optical microscopy, b) backscattered scanning electron microscopy, c) bright field, and d) high resolution transmission electron microscopy. The coating appears to be fully dense and homogeneous while the Zr–Cr interface shows good metallurgical bonding without indications of cracks or voids (courtesy of Jean-Christoph Brachet and colleagues at CEA, SRMA, Paris-Saclay University, France).

FeCrAl Example

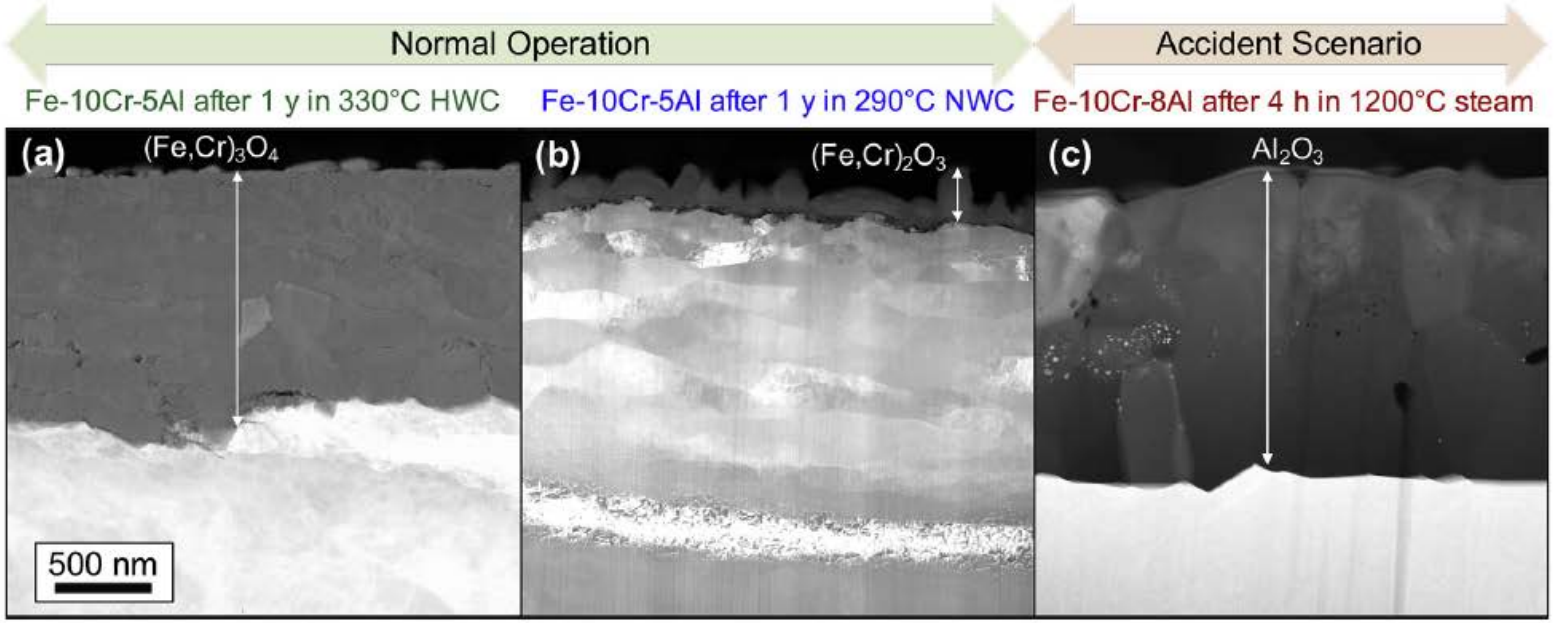

Fig. 7. Depending on the environment, various protective films form on the surface of FeCrAl alloys. a,b) In low and high oxygen activity aqueous environments, and largely insensitive to the Cr content in the alloy within a 10–18 wt% Cr window, protective Cr-rich spinel or hematite films form [162]. c) Under high temperature steam oxidation, if a critical and sufficient combination of Cr and Al is present in the alloy [134], protective alumina forms. High angle annular dark field (HAADF) transmission electron images are courtesy of Kinga Unocic.

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FC 2.3 – Investigations into Non-Traditional Solid Fuels for Advanced non-Light Water Reactors

- **Fuel concepts proposed should support one or more of the following reactor designs:**
  - HTGRs/VHTRs, FHRs, LFRs, GFRs, SFRs
- **Irradiation testing and PIE are advantageous but not required**
  - Use of ion beam irradiation is an option
- **Priority will be given to proposals which include both experimental and modeling and simulation activities**
- **Proposals must include:**
  - Brief description of fuel and it's application
  - Which challenge will be addressed and how addressing the proposed challenge will further the development of this fuel
  - Clearly defined research objectives, timelines and deliverables

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- **Please review previous fuel related awards on www.neup.gov.**

Key Items to Consider

- **Must show relationship to elements of the Advanced Fuels Program**
  - Priority given to proposals that support LWR accident tolerant fuel and fast reactor fuel concepts under study by FCRD
- **Review previous NEUPs to avoid duplication of activities**
- **Include reasonable timelines and deliverables**
- **Proposals tying experimental activities with modeling, where applicable, will be given higher priority**
  - Should support codes and models being developed by FCRD and NEAMS