UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

**Grant #** 31310021M0053
**Grantee:** Virginia Commonwealth University

**Title of Grant:**
**Advanced Characterization of ATF cladding for understanding their degradation under short-time temperature excursions and implications in dry storage**

**Period of Performance:** 9/27/2021-9/26/2024 (FY21 Notice of Funding Opportunity NOFO)

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## Executive Summary

The proposed project will investigate the oxidation, degradation, and mechanical behavior of Crcoated Zircaloy and FeCrAl alloys accident-tolerant fuel (ATF) claddings under short-time temperature excursions and dry storage conditions. The implementation of ATF claddings for light water reactors (LWRs) or advanced reactor designs requires fuel reliability and safety during design-basis and beyond-design-basis accident scenarios. Given the high-temperatures during accident scenarios, understanding of the materials' surface chemistry and the evolution of preexisting oxides as a result of in-reactor operation when accident scenarios occur is critical. The materials' fast response toward accident scenarios will be studied by simulating rapid and controlled high-temperature excursions followed by quenching using an induction furnace experimental setup. These tests will be followed by investigations of the materials' behavior under dry storage conditions. This project will lead to knowledge of oxidation mechanisms and kinetics, ultimately explaining materials' performance and safety limits. Advance destructive and nondestructive characterization techniques will be implemented for the valuation of the ATF cladding materials. The advanced surface and mechanical characterization performed by the destructive testing will allow us to develop a rapid non-destructive examination (NDE) tool based on X-ray fluorescence (XRF) and high-fidelity radiation transport modeling for quality control of cladding materials before and after the proposed testing conditions. The combined experimental and computational analysis will provide a robust platform that U.S. regulatory entities and fuel vendors can use during licensing and commercial use of ATFs in advanced nuclear reactors.

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## *Presentations and Publications*

*The list of publications was submitted with the final report after grant expiration.*

- Surface Chemistry and Microstructure of FeCrAl Alloys After Rapid Heating in Steam Environments and Quenching. Victoria Davis, Lilith Miller, James Cahill, Braden Goddard,

Reza Mohammadi, Rajnikant V. Umretiya, Carlos E. Castano, Jessika V. Rojas. (Under submission to the Journal of Nuclear Materials)

- Modeling and Benchmarking XRF Analysis using MCNP for Applications in Accident Tolerant Fuel and Cladding*"* *https://doi.org/10.1016/j.pnucene.2024.105487*

- Post-Quench Ductility of FeCrAl Alloys Subjected to High Heating Rates. Victoria Davis, Caleb King, Lilith Miller, Braden Goddard, Reza Mohammadi, Carlos Castano, Rajnikant Umretiya, Andrew Hoffman, Jessika Rojas. 2024 TMS Annual Meeting & Exhibition (Oral presentation).

- Surface Chemistry and Microstructure of FeCrAl Alloys Under High Heating Rates Post-quenching. Victoria Davis, Caleb King, Lilith Miller, Braden Goddard, Reza Mohammadi, Carlos Castano, Rajnikant Umretiya, Andrew Hoffman, Jessika Rojas. 2024 TMS Annual Meeting & Exhibition. (Poster presentation).

- Oxidation and Post-quench Ductility of Chromium Coated Zircaloy-4. Victoria Davis, Caleb King, Lilith Miller, Braden Goddard, Reza Mohammadi, Carlos Castano, Rajnikant Umretiya, Andrew Hoffman, Jessika Rojas. 2024 TMS Annual Meeting & Exhibition (Poster presentation).

- Cr-Coated Zircaloy-4 Surface Chemistry and Microstructure Following High-Temperature Excursions and Quenching. Victoria Davis, Caleb King, Lilith Miller, Braden Goddard, Reza Mohammadi, Carlos Castano, Rajnikant Umretiya, Andrew Hoffman, Jessika Rojas. 2024 TMS Annual Meeting & Exhibition (Poster presentation).

- Oxidation of FeCrAl Alloys Exposed to High-Temperature Steam and Quenching. Victoria Davis, Lilith Miller, Braden Goddard, Carlos E. Castano, Reza Mohammadi, Jessika V. Rojas. 2024 ANS Student Conference.

- Design and Fabrication of a Cone-Segments System to Implement Expansion Tests in Nuclear Fuel Cladding. Lilith Miller, Victoria Davis, Braden Goddard, Carlos Castano, Reza Mohammadi, Jessika V. Rojas. 2024 ANS Student Conference.

- X-ray Fluorescent Assessment of Surface Defects on Chromium-Coated Zircaloy-4 Cladding. James T. Cahill, Braden Goddard, Carlos Castano, Reza Mohammadi, Jessika V. Rojas. 2024 ANS Student Conference.

- Microstructural Evolution of Zr-702 Under Rapid Heating Profiles. Victoria Davis, Caleb King, Christian England, Braden Goddard, Carlos E. Castano, Reza Mohammadi, Jessika Rojas. ANS Transactions, Volume 128, Number 1, June 2023, Pages 294-297. https://www.ans.org/pubs/transactions/article-53346/

- Rapid Temperature Excursions and Dry Air Cooling of Zircaloy-4. Caleb King, Victoria, Christian England, Braden Goddard, Carlos E. Castano, Reza Mohammadi, Jessika Rojas. ANS Transactions, Volume 128, Number 1, June 2023, Pages 298-301.https://www.ans.org/pubs/transactions/article-53347/

- X-ray Fluorescence Modeling Using Monte Carlo Methods. James Cahill, Caleb King, Tristan Norrgard, Braden Goddard, Carlos E. Castano, Reza Mohammadi, Jessika Rojas. 2023 ANS Student Conference, April 2023 Knoxville TN.

- Effects of High-Temperature Excursions and Water Quenching on Zr-702. Victoria Davis, Caleb King, Christian England, Braden Goddard, Carlos E. Castano, Reza Mohammadi, Jessika Rojas. 2023 ANS Student Conference, April 2023 Knoxville TN.

- Using Induction Heating for Rapid Temperature Excursion Testing of Zircaloy-4. Caleb King, Victoria Davis, Christian England, Braden Goddard, Carlos E. Castano, Reza Mohammadi, Jessika Rojas. 2023 ANS Student Conference, April 2023, Knoxville TN.

- FeCrAl Accident Tolerant Nuclear Fuel: Current Status and Future Developments. Tristan Norrgard, Caleb King, Braden Goddard, Carlos Londono, Reza Mohammadi, Jessika Rojas. 2022 ANS Student Conference, April 2022.

- The Benefits of Chromium-coated Zircaloy Cladding as Accident Tolerant Nuclear Fuel. Caleb King, Tristan Norrgard, Braden Goddard, Carlos Londono, Reza Mohammadi, Jessika Rojas. 2022 ANS Student Conference, April 2022.

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**Patents**

N/A