INL/MIS-24-79533-Revision-0

Element Redistribution in Irradiation Metallic Fuel from the Experimental Breeder Reactor-II (EBR-II)

August 2024

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Idaho National Laboratory

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

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Background and Motivation

Fuel experiments conducted within EBR-II are key resources for understanding the complex performance of metallic fuels proposed for use in next-generation reactors. Constituent redistribution and fuel-cladding chemical interaction (FCCI) are demonstrated irradiation behaviors that alter local thermomechanical properties and cladding integrity. It is essential to understand the mechanisms of each phenomena to advance the technical readiness level of these fuels and attain higher resource utilization. Quantitative chemical analysis of high burnup metallic fuel samples obtained through electron microprobe analysis (EPMA) provides critical data to inform individual element behavior during irradiation.

Methodology

Sample Information
- Peak Clad Temperature: 600 °C
- Peak Power: 45.9 kW/m
- D9 clad U-19Pu-10Zr
- Irradiated to ~10 at.%

Data Collection

Electron Probe Micro Analyzer

Radial Traverse

Cladding Traverse

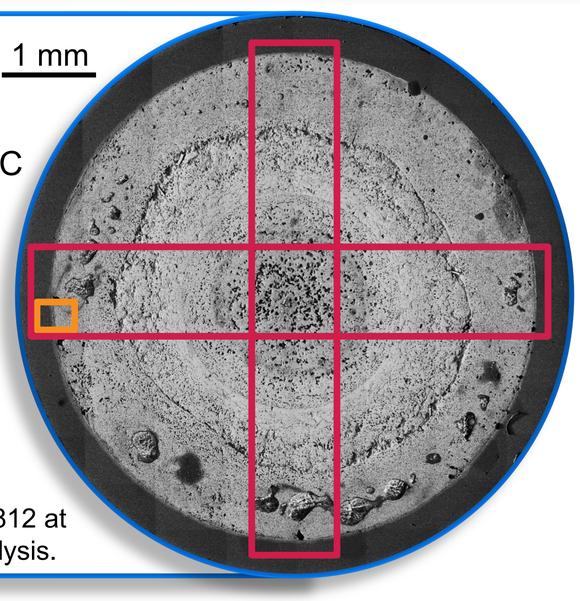

Fig. 1 SEM image of fuel pin X441A-A812 at 0.65 x/L, showing regions of EPMA analysis.

Radial Redistribution of Fuel Constituents

Table 1. Averaged weight composition, within 99% confidence, of fuel constituents, showing four rings of radial migration compared to the uniform, as-fabricated values.

Element	Region 1	Region 2	Region 3	Region 4	As-fabricated
U (wt. %)	42.4 ± 0.4	66.5 ± 0.7	86.6 ± 0.9	63.2 ± 0.6	71
Pu (wt. %)	21.8 ± 0.3	19.5 ± 0.3	11.7 ± 0.2	22.3 ± 0.3	19
Zr (wt. %)	34.2 ± 0.5	12.1 ± 0.2	0.93 ± 0.01	13.0 ± 0.2	10

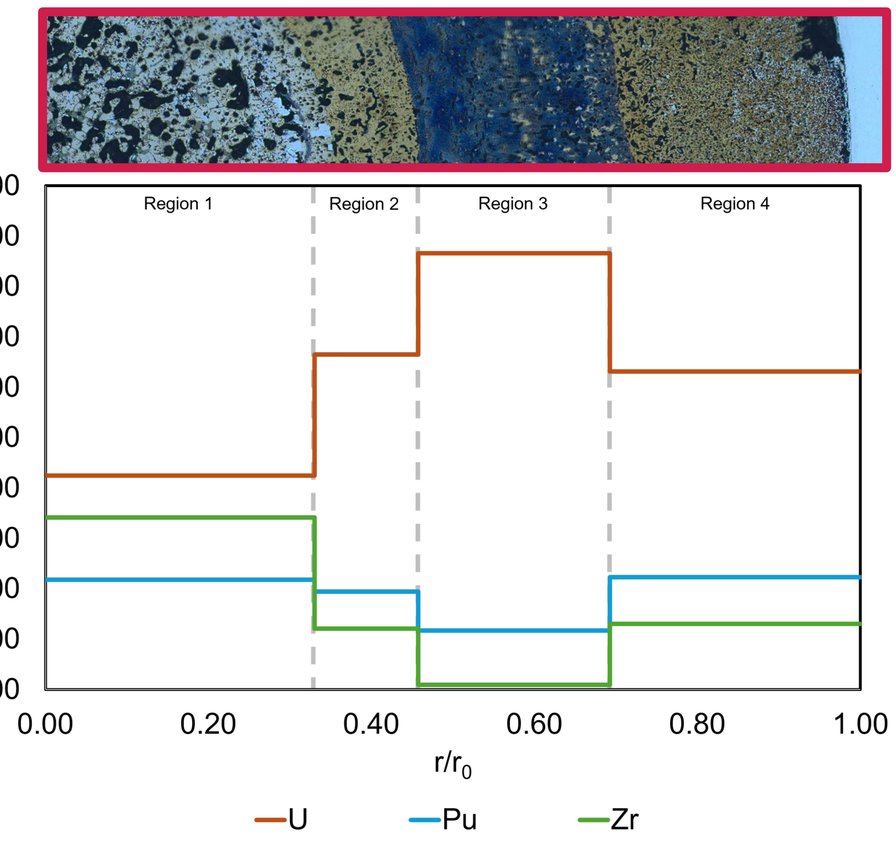

Fig. 2 Plot of averaged weight composition of fuel constituents in four regions of constituent redistribution overlayed with metallography of the fuel pin radius, showing element rings of element depletion and enrichment. The different colored regions from metallography are the result of different oxidation behaviors, typically attributed to altered compositions.

Interdiffusion at Fuel-Cladding Interface

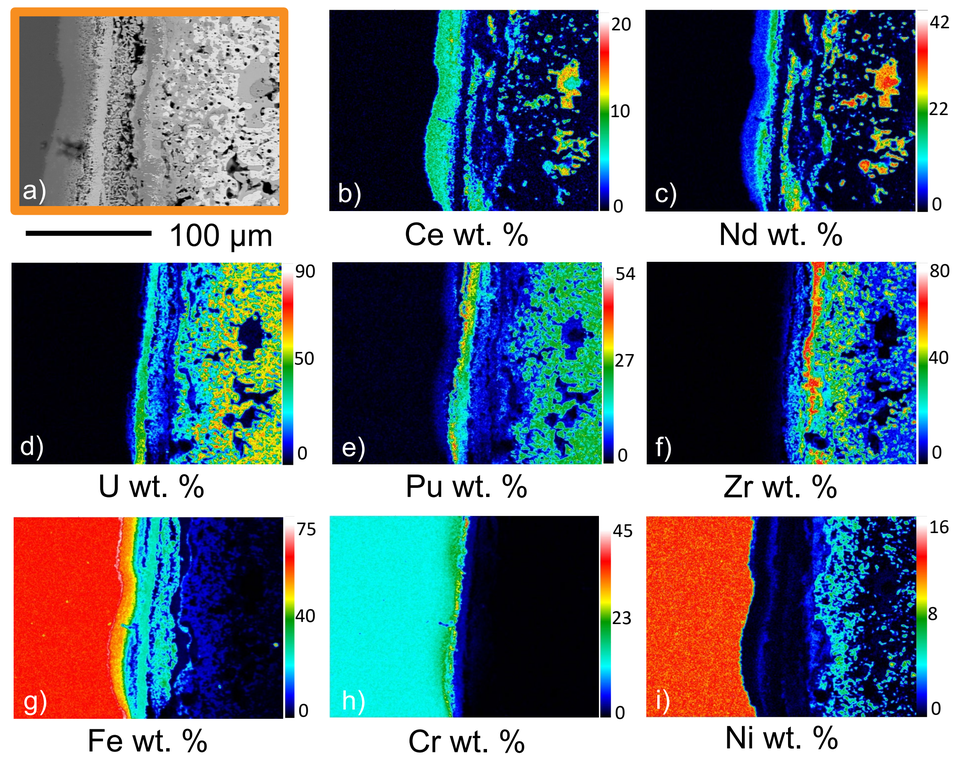

Fig. 3 Backscattered electron image showing fuel-cladding interface (a); X-ray maps of lanthanide fission products(b, c), fuel elements (d-f), and cladding (b, c), fuel elements (d-f), and cladding constituents (g-i) in the fuel-cladding region, showing interaction layer formation and interdiffusion at the interface.

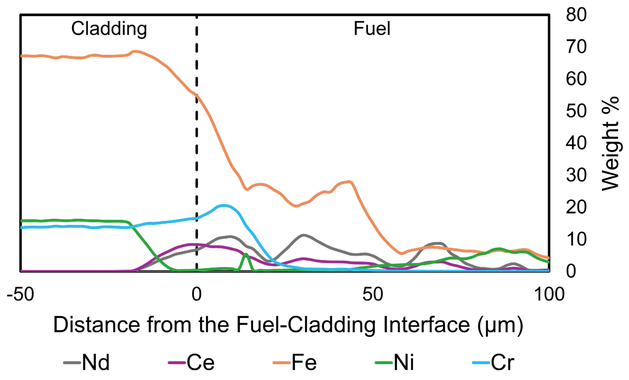

Fig. 4 Quantitative chemical traverse through FCCI region, revealing lanthanide fission products penetrating the cladding and cladding elements diffusing into the fuel matrix.

Conclusions from Preliminary Analysis

- Four distinct regions of fuel constituent redistribution observed, confirming additional complexities demonstrated in [1]
- Pu shown to redistribute, which is not included in existing fuel performance models for metallic alloys
- Fuel, fission products, and cladding element diffusion at the interaction layer and can be quantified using EPMA

Next Steps: Additional EPMA analyses have been conducted on this sample, including another cladding traverse, scans along redistribution region transition areas, and individual spot and phase measurements. Analyzed data from these comprehensive examinations will ultimately be compared to results from EPMA conducted on high burnup U-19Pu-14Zr [1] and U-19Pu-6Zr.

Acknowledgements:
This work was funded by the Advanced Fuels Campaign.

References:
[1] Wright, K. E., Lecrivain, L., Pincock, C., Coleman, M., Wiscaver, P., Barker, B., ... & Aitkaliyeva, A. Exploring Constituent Redistribution in Irradiated U-19pu-14zr Fuel Via Electron Probe Microanalysis. Available at SSRN 4853919.