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Process Development for Advanced Complex Nuclear Oxide Fuels

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Abstract

Oxide nuclear fuel processing has the ability to convert long-lived actinide waste into short-lived fission products through fast reactors. Research is needed to improve the overall efficiency of this process to ensure it is a viable and sustainable option. Boise State University (BSU) worked in collaboration with others to synthesize, consolidate, and characterize complex surrogate oxide systems for use as advanced nuclear fuels. The objective of this work was to demonstrate the atmosphere affects on the final composition and density of the final fuel. The scope of this work included the identification of surrogate fuel compositions (target fuels, mixed oxide (MOX) fuels, and transuranium (TRU)/MOX fuels), acquisition and characterization of the initial starting powders, the synthesis and characterization of surrogate fuel compositions and the study of atmospheric effects on the sintering of the aforementioned fuel compositions. The microstructures of the fuels were characterized using electron microscopy, optical microscopy, and density determinations.

Disciplines

Engineering

BOISE STATE UNIVERSITY College of Engineering
Department of Materials Science & Engineering

Process Development for Advanced Complex Nuclear Oxide Fuels

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Abstract

Oxide nuclear fuel processing can convert long-lived actinide waste into short-lived actinide fission products using Next Generation Nuclear reactors. This work included the identification, synthesis, and characterization of initial powders for surrogate fuel composition fabrication of complex oxide fuels (target fuels, mixed oxide (MOX) fuels, and transuranic/mixed oxide (TRU/MOX) fuels). The microstructures and densities of the sintered pellets were characterized to investigate the effects of sintering atmosphere.

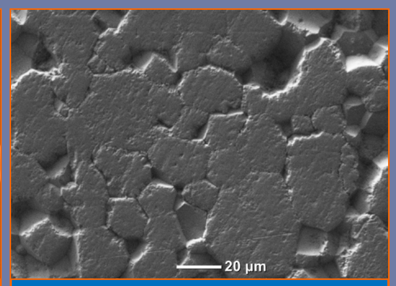
Introduction

The project objective was to develop viable processing methods to create complex oxide nuclear fuels. These fuels are considered a major contribution to goals set by the Global Nuclear Energy Partnership (GNEP) and the Advanced Fuel Cycle Initiative (AFCI). The expectation is to use oxide fuels to reduce high volume radioactive waste by transmutation (reprocessing and burn-up) of transuranic materials.

$97CeO_2$-$3Dy_2O_3$ Initial starting powder

$(3)UO_2$ $(3)CeO_2$ $(2)HfO_2$ Green fuel pellets

$(3)UO_2$ $(3)CeO_2$ $(2)HfO_2$ Sintered fuel pellets



$97CeO_2$-$3Dy_2O_3$ Sintered fuel pellet

Specific oxide powders were selected as surrogates for complex fuel compositions containing uranium dioxide. The use of surrogates allow for more complete and in-depth studies while decreasing safety risks and experimental costs. The powders were cold pressed into pellets prior to sintering in different atmospheres. The densities and microstructures of the fuels were characterized using several techniques.

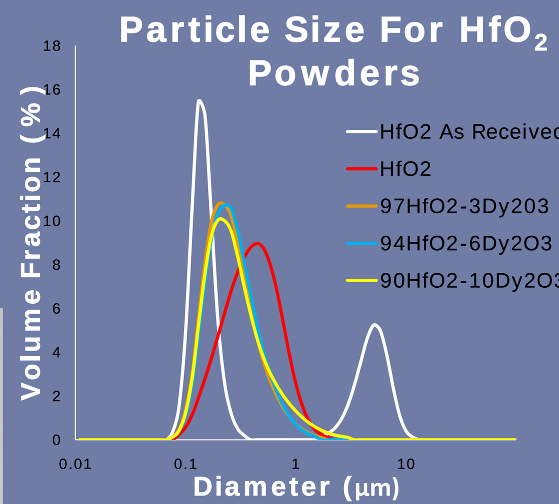
Powder Synthesis Flowchart

Powder homogenization
- Ball milled in a high energy ball mill
- 2 hours at 500 rpm in isopropyl alcohol (IPA)
- Reduction of particle size distribution

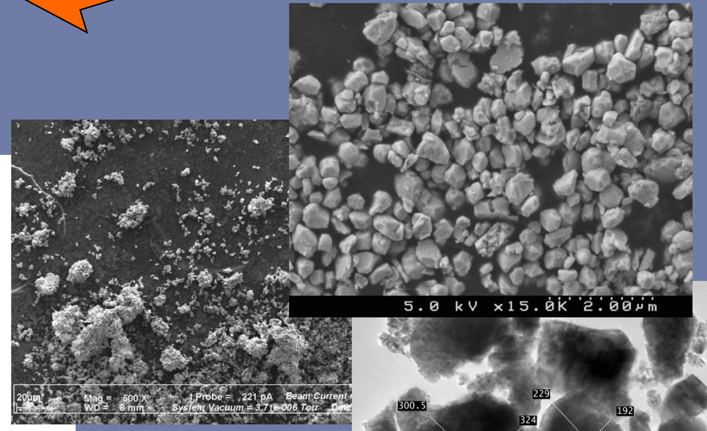
Heat treat
- 6 hours in lab air at 1200°C

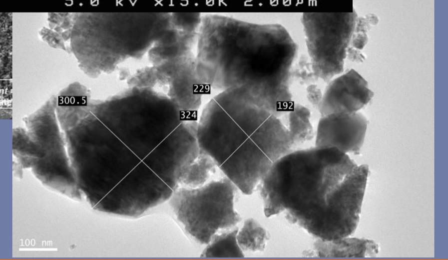
Particle size reduction
- Ball milled in a high energy ball mill
- 2 hours at 500 rpm in IPA

Particle Size Analysis
- Multi wavelength particle size analyzer

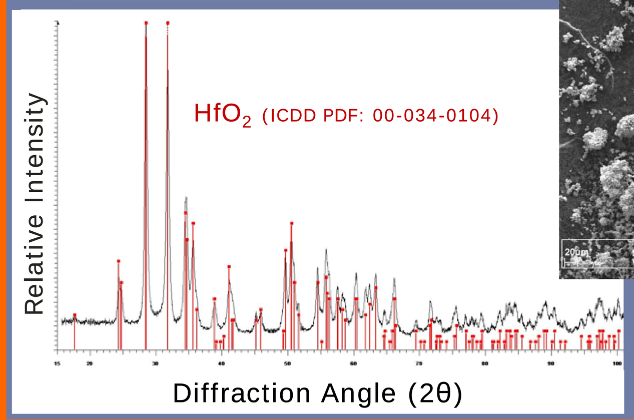


Electron Microscopy
(SEM & TEM)





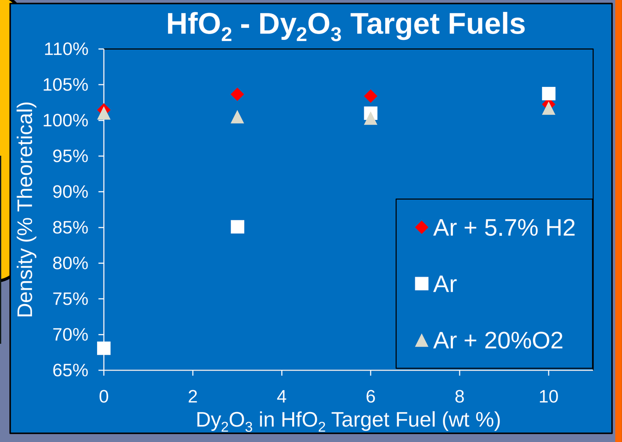
X-Ray Diffraction



Microstructural Characterization

Densities determined using two methods:
- Geometric
- Archimedes

Theoretical Density (g/cm³)
- UO_2 → 10.97
- HfO_2 → 9.68
- Dy_2O_3 → 7.80



Section and mount pellets
- Low speed cutting saw
- Mounted in conductive molding compound

TRU/MOX Pellet sintered in Ar + 20%O_2

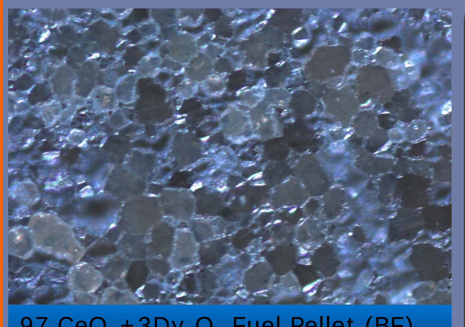
MOX Pellet sintered in Ar + 20%O_2

Polish
- Grinding with SiC paper
- Polish with diamond slurry (1μm)

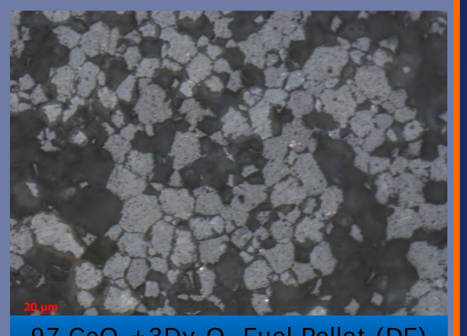
D-UO_2 Pellet sintered in Ar + 6%H_2

MOX Pellet sintered in Ar + 20%O_2

Optical Microscopy
- Darkfield (DF)
- Brightfield (BF)
- Differential Interference Contrast (DIC)

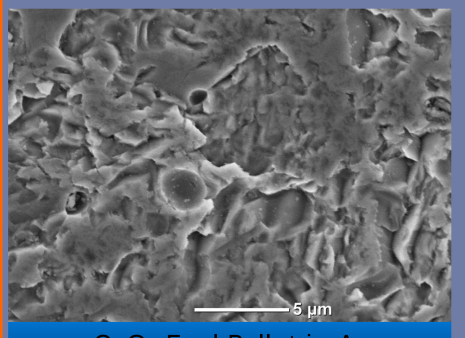


97 CeO_2+3Dy_2O_3 Fuel Pellet (BF)

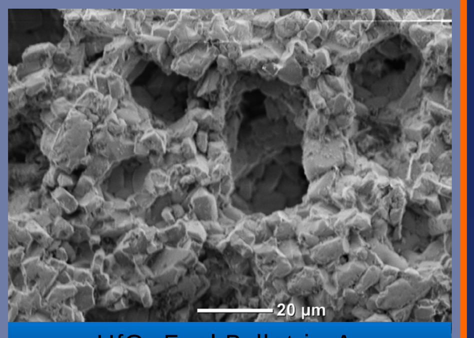


97 CeO_2+3Dy_2O_3 Fuel Pellet (DF)

Scanning Electron Microscopy



CeO_2 Fuel Pellet in Ar



HfO_2 Fuel Pellet in Ar

Surrogate Fuel Compositions

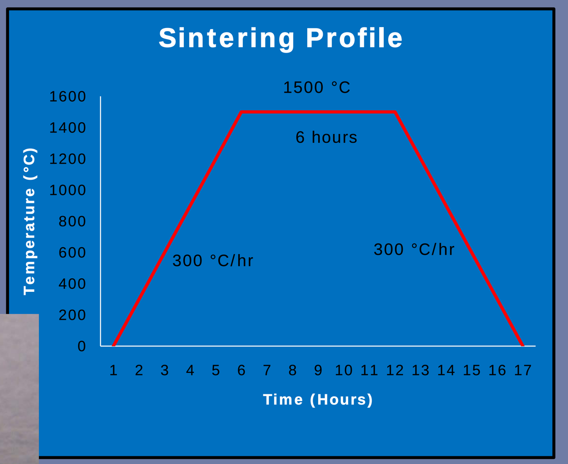
Proposed Actinide Fuels (wt%)	Surrogate Fuels (wt%)
UO_2	Depleted UO_2 (U-238) or HfO_2
UO_2 + 3 Am_2O_3	D-UO_2/HfO_2 + 3 Dy_2O_3
UO_2 + 6 Am_2O_3	D-UO_2/HfO_2 + 6 Dy_2O_3
UO_2 + 10 Am_2O_3	D-UO_2/HfO_2 + 10 Dy_2O_3
MOX Fuels	
UO_2 + 20 PuO_2	D-UO_2/HfO_2 + 20 CeO_2
UO_2 + 30 PuO_2	D-UO_2/HfO_2 + 30 CeO_2
TRU/MOX Fuels	
UO_2 + 20 PuO_2 + 3 Am_2O_3 + 2 NpO_2	D-UO_2/HfO_2 + 20CeO_2 + 3 Dy_2O_3 + 2 MnO
UO_2 + 30 PuO_2 + 5 Am_2O_3 + 3 NpO_2	D-UO_2/HfO_2 + 30CeO_2 + 5 Dy_2O_3 + 3 MnO

Fuel Pellet Fabrication

Cold Press Fuel Pellets
Homogenous powders were pressed into fuel pellets at 225 MPa using a 5 mm die in a hydraulic press. All of the D-UO_2 powders and pellets were handled in an argon atmosphere glovebox.

Sinter Fuel Pellets
Three pellets of each composition were placed in a controlled atmosphere, high temperature, alumina tube furnace. The pellets were sintered in three different atmospheres with the same furnace profile.

UHP atmospheres (**3**) x Compositions (**20**) = **60** Total Fuel Compositions
Ar, Ar+20% O_2, Ar+6% H_2 (water saturated)



Storage
All pellets were stored in a vacuum desiccator to maintain pellet composition stoichiometry.

Vacuum Desiccator

MOX fuel pellet directly after furnace run

Conclusions

Complex oxide fuels were identified, synthesized, sintered, and characterized. Variances in sintering conditions were investigated and the final fuel forms were compared to actinide fuels.

Acknowledgments

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