

NASA CERCER Development TDM Presentation

November 2022

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Outline



CERCER Fuel Development

- Background
- Primary objectives of CERCER development activities
- ➤ Major Accomplishments for CERCER fuel development
 - Fabrication of prototypic CERCER fuel compact
 - Sirius-2C TREAT Experiment
 - ZrC/UN diffusion interaction
 - Task 1.9 CERCER fuel compacts with varied fuel loadings
- Near-Term Outputs
- Look Ahead
- Main Take Aways



Radiological SPS system. Image from Thermal Technologies



CERCER Fuel Development

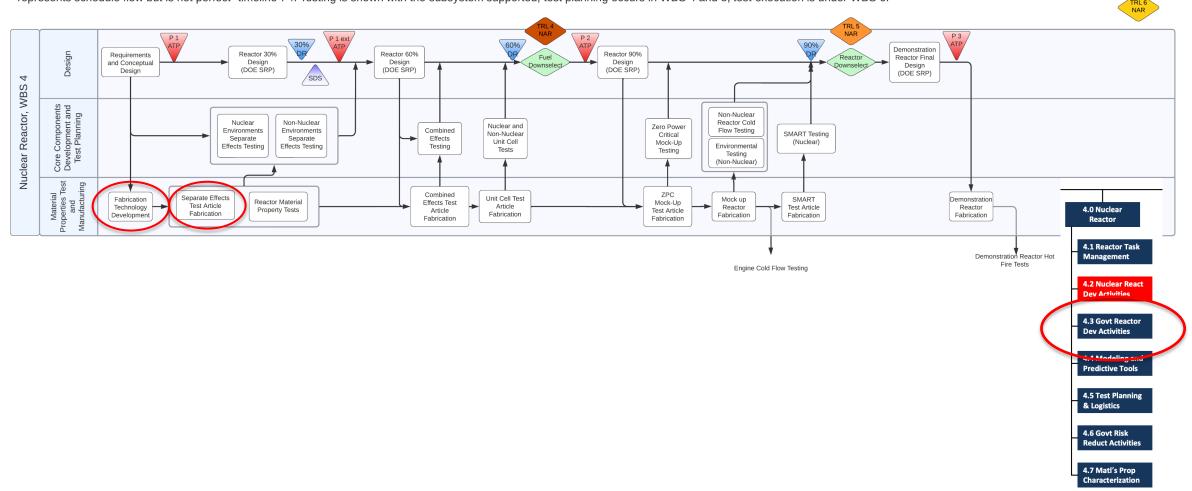




Nuclear Thermal Propulsion Technology Maturation Plan

Updated 10/24/2022

Notes: 1. Boxes indicate when a task begins and do not denote duration. 2. Only hardware integration denoted with arrows, other modeling and subsystem integration analysis will occur throughout. 3. Diagram functionally represents schedule flow but is not perfect "timeline". 4. Testing is shown with the subsystem supported, test planning occurs in WBS 4 and 5, test execution is under WBS 6.



CERCER Background



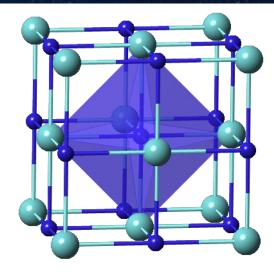
Benefits of CERCER Development

CERCER composition → ZrC & UN.

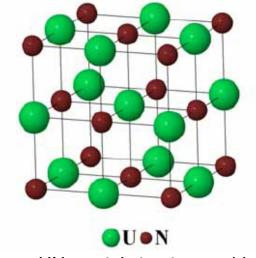
- ZrC is a high temperature metal carbide capable of sustained temperatures at and above 3000 K
- ZrC does not have the neutronic penalty of refractory metals, i.e. W
 & Re
- > ZrC is able to sustain hot hydrogen exposure at high temperature

<u>Industry Tie In</u>

➤ CERCER development aligns with fuel concepts being explored by General Atomics (GA) and Ultra-Safe Nuclear Corporation (USNC)



ZrC crystal structure; cubic



UN crystal structure; cubic

CERCER Background



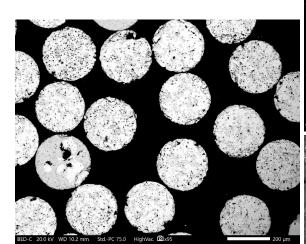
Primary Objectives of CERCER Development

Task 1.6

- ➤ Develop sintering parameters and demonstrate fabricability of CERCER prototypic fuel compacts, i.e. precision machining and flow channel fabrication path
- Fabricate fuel compacts with angular UN and spherical UN kernels
- Develop an understanding of ZrC and UN phase interactions

Task 1.9

- Fabricate fuel compacts with varying fuel loadings
 - Fuel loadings of 5 vol% up to 50 vol% UN
- Compacts to be used for follow-on thermal and mechanical testing to gain test data on compositions



SEM images of UN kernels

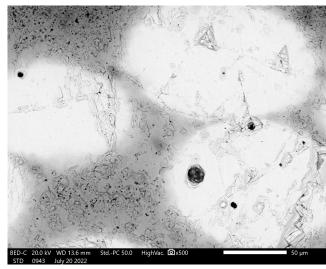


2022 Major Accomplishments

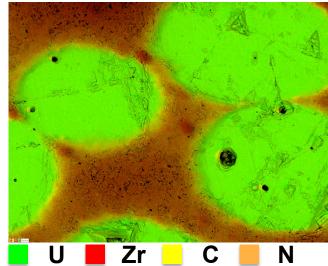


CERCER Fuel Development

- Process development of prototypic CERCER fuel compacts to extend our fabrication knowledge of this fuel form
- ➤ Fabrication of a CERCER fuel compact for testing/experimentation in the TREAT facility
- Better understanding of ZrC & UN interactions and phase stability
- Fabrication of fuel compacts with varied fuel loadings to be used to gather test data on CERCER compositions



SEM & EDS images of ZrC/UN microstructure

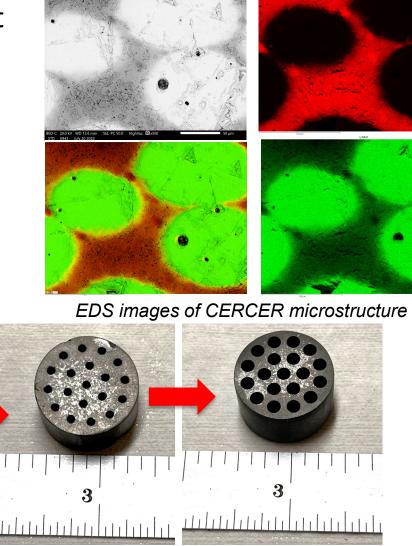


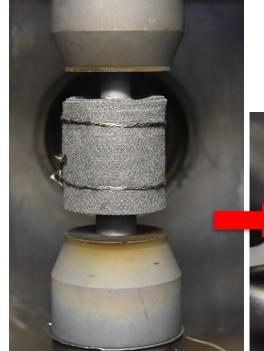




Zr

- Investigation of ZrC & UN as a composite fuel has not been undertaken to date
- Developed the process flow to fabricate a prototypic CERCER fuel compact with flow channels





Task 1.6 - Fabrication of Prototypic CERCER Fuel

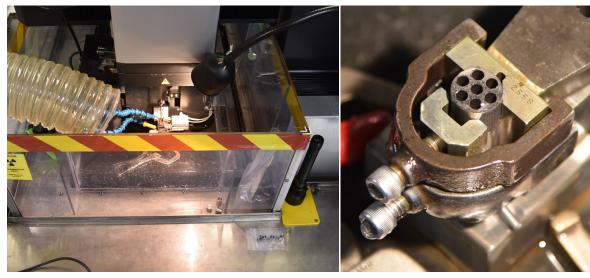




- Developed machining processes to meet precise dimensions and placement of flow channels
 - Developed grinding, lapping and hole drilling methodologies
 - Established EDM hole drilling and EDM wire processes to accurately machine CERCER fuel compacts
- Analyzed resulting fuel microstructure to better understand impact from sintering
- Creates pathway for fabrication of CERCER compacts for later testing of prototypic fuel compacts, e.g. NTREES & Sirius
 - Provides guidance to industrial partners pursuing CERCER and metal carbide fuel concepts



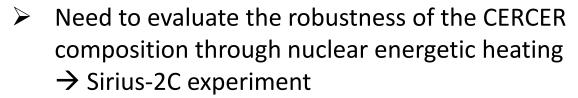
EDM Small Hole Drilling Machine



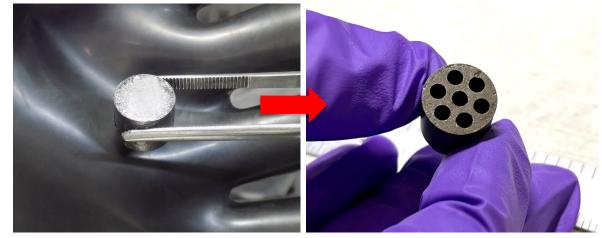
Fuel compact in the EDM Small Hole Drilling Machine

Sirius-2C TREAT Experiment

4* 5* NASA



- Third experiment in the Sirius-2 series of TREAT experiments
- First reactor experiment with CERCER fuel
- Used established processes to successfully fabricate fuel compact for TREAT experiment
- Provides test data on irradiation of CERCER fuel



Sirius-2C CERCER fuel compact



Fully machined Sirius-2C CERCER fuel compact





Sirius-2C CERCER fuel compact integrated into the experiment capsule hardware

4* Fuel Development Accomplishment

5* Materials & Testing Accomplishment

Understanding of ZrC & UN Interaction





- > There is indication that the ZrC & UN system has the potential to form various phases
- Carried out a series of high temperature experiments to better understand the CERCER matrix and fuel phase interactions
 - Interaction region observed to form between ZrC & UN

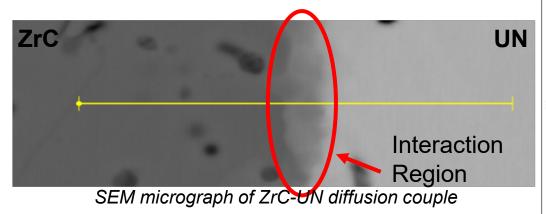


2000-



ZrC & UN disks loaded in graphite dies for diffusion experiments in the SPS

UN



EDS line scan of interaction region

Understanding of ZrC & UN Interaction





High resolution analysis used to better identify structure and composition of interaction region

APT results

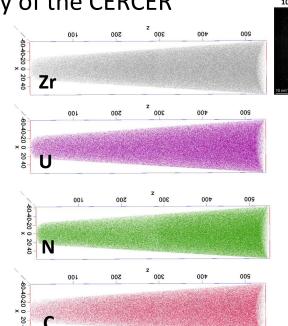
- TEM shows cubic structure → UN, ZrC, UCN & U,Zr(C,N) phases are all cubic
- Atom Probe Tomography (APT) provides clearer picture on elemental composition of interaction region
- Found to be equal parts U, Zr, N, & C

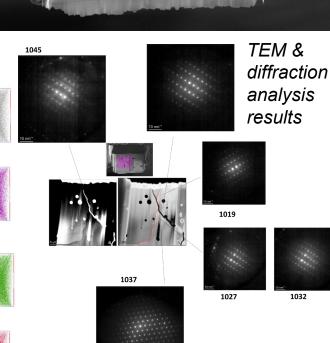
Gains insight on the high temperature phase stability of the CERCER

composition and address the need for coatings

ZrC Cone 1	APT Cone
Interaction Region UN \$\frac{\text{VIN}}{\text{3.25.24 PM}} \text{12.00 kV} \text{1000 x} \text{16.6 mm} \text{100 kV} \text{1000 kV}	© SEM micrograph

ements	At. %
Zr	29.929
U	24.897
С	24.751
N	29.929
Interaction Region Composition	





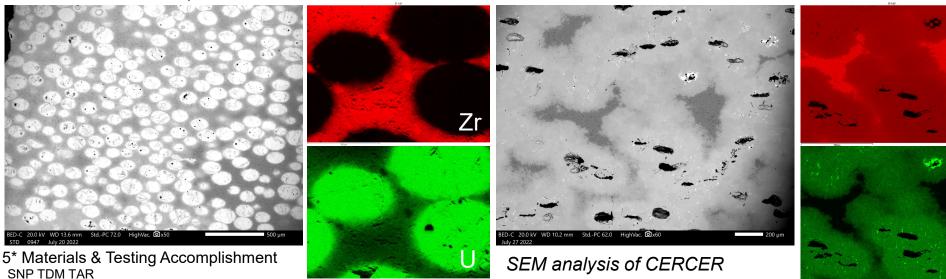


Task 1.9 – CERCER Compacts with Varied Fuel Loadings

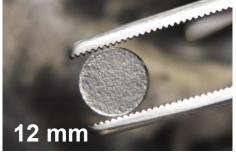


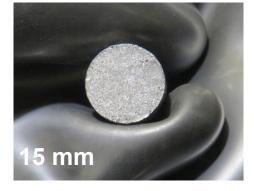


- Fabrication of different sized fuel compacts for follow-on testing
 - To generate test data for different UN concentrations in a ZrC matrix
- Fuel compacts fabricated with varying fuel loadings
 - 5 vol% UN up to 50 vol% UN
- Matrix fuel interactions are observed to vary with fuel concentration
 - Dissolution of kernel observed through sintering, possible indication for need to continue development of coatings for fuel kernels
- Provides test data to better inform on the effects of fuel concentration as CERCER development continues









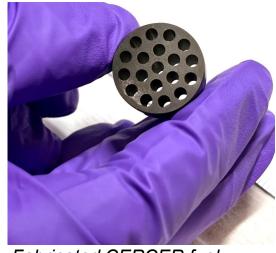
Fuel compacts for testing

Outputs



Near-Term Outputs

- ➤ Task 1.6 Fabrication of CERCER fuel
 - Finalize prototypic 19 flow channel fuel compacts with UN kernels
 - Provide fuel compacts for external coating studies
 - Demonstrate full size fuel compact fabrication, i.e. 91 flow channel specimen
- ➤ Task 1.9 VolMax of CERCER
 - Deliver fuel compacts for follow-on testing
 - Finalize fabrication of Group 4 specimens for testing in CFEET (work ongoing)
 - Fabricate fuel compacts with ZrC coated UN kernels



Fabricated CERCER fuel comapacts. (above) Task 1.6 activities (below) Sirius-2C fuel compact

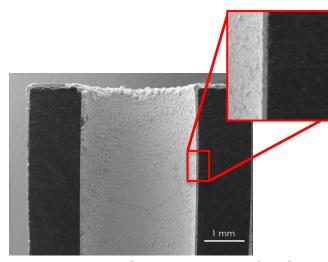


Look Ahead

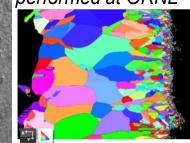


Future Work

- Post-irradiation examination (PIE) of Sirius-2C fuel will provide feedback on CERCER development and performance for both Government and Industry efforts
- Through continued experimentation, evaluate the effects of the ZrC coating of UN kernels on the interactions with the ZrC matrix to better inform on kernel coating activities
 - Evaluate other coating materials, e.g. carbon
- Provide fueled CERCER compacts for exterior coating activities with ORNL
 - Perform testing of CERCER compacts with ZrC exterior coating to inform on full compact coating activities



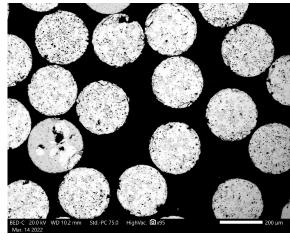
SEM analysis of ZrC coatings on carbon substrate. Work performed at ORNL



Main Take Aways



- Machining processes have been established for the CERCER composition
 - This will contribute to future prototypic fuel compact fabrication, e.g. PRIME-2 (Sirius-5) fuel compacts
- Understanding ZrC & UN interactions can provide a clearer picture on the need for kernel coatings & the effects of high temperature on the composite
- > Testing of fuel compacts with varied fuel loadings will better inform on thermomechanical properties and provide test data on the ideal fuel loading
- Exterior compact coatings can provide additional protection of the fuel from the effects of hydrogen at operating conditions.
 - Test data can steer the government development activities and provide input to industry partners



SEM image of UN fuel kernels fabricated at BWXT



40 mm CERCER fuel compact from Task 1.9 activities





Questions?

