INL/MIS-23-75304-Revision-0

Performance of the HERA Pre-Hydrided Experiments

November 2023

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Advanced Fuels Campaign

Performance of the HERA Pre-Hydrided Experiments

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U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

HERA Work Plan Overview

High-Burnup Experiments in Reactivity-Initiated Accidents (HERA) program being executed under the NEA FIDES program

1. Six RIA tests with pre-hydrided cladding and oversized UO_2 pellets at different pulse widths

2. Four RIA tests with actual high burnup material

3. Modelling and Simulation Exercise

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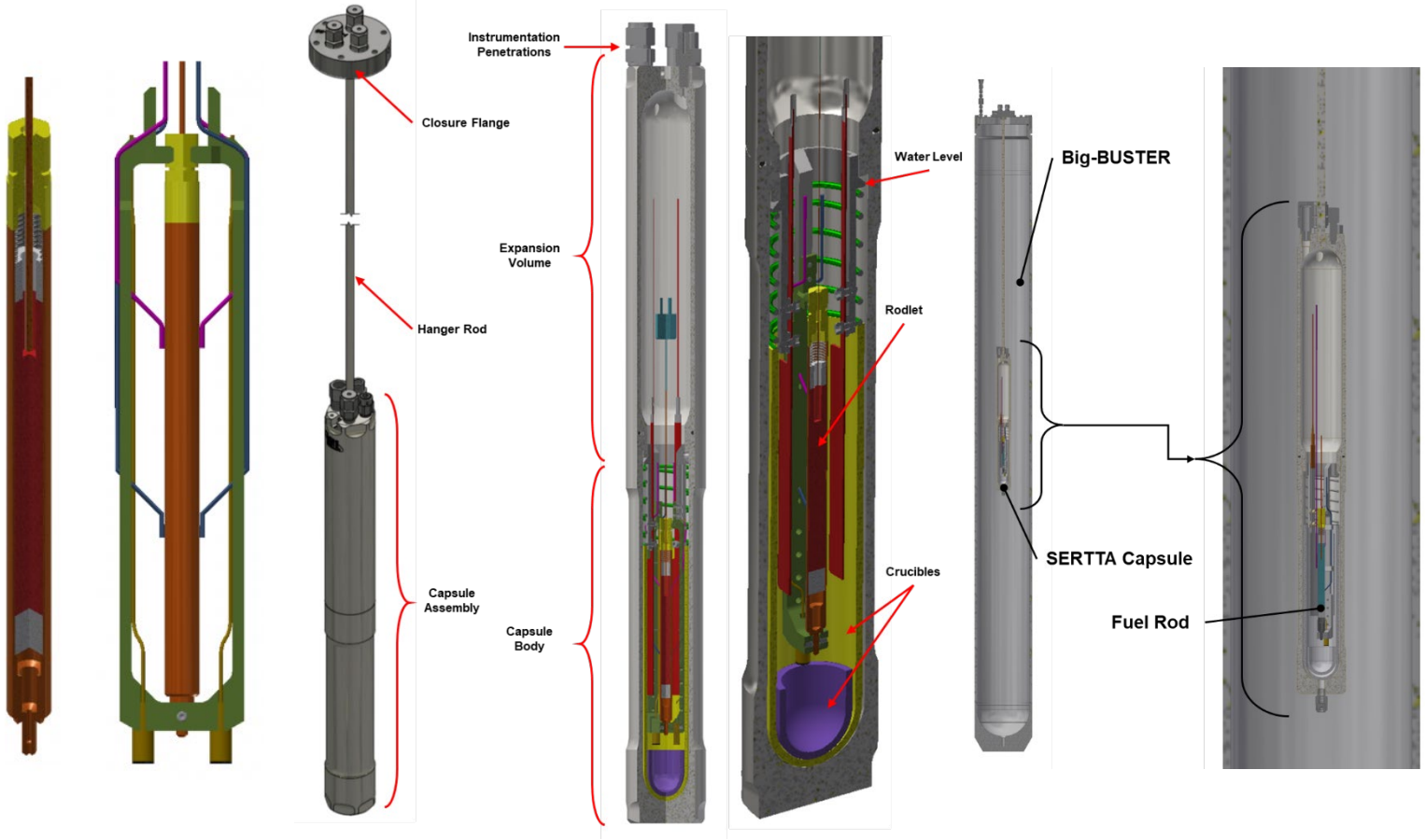
HERA Experiments Status

- High-Burnup Experiments in Reactivity-Initiated Accidents (HERA) program being executed under the NEA FIDES program
  - Six RIA tests with pre-hydrided cladding and oversized UO2 pellets at different pulse widths
    - Study effects of pulse width on simulated high-burnup rodlets
  - Four RIA tests with actual high burnup material
    - Experiment will be performed in the TWIST capsule (currently finalizing design for this capsule for RIA experiments)
  - Modelling and Simulation Exercise
- To-date 4 experiments have been performed
  - 2 at NSRR and 2 at TREAT
  - Last 2 experiment in TREAT planned in April 2024

Test Number	Test Reactor	Pulse Width (ms)	Target Enthalpy (J/g)
HERA-PreH-1	NSRR	5-10	650
HERA-PreH -2	NSRR	5-10	725
HERA-PreH -3	TREAT	90	650
HERA-PreH -4	TREAT	90	650
HERA-PreH -5	TREAT	90	725
HERA-PreH -6	TREAT	90	725

Current Capsule Design

- Modifications from previous experiments
  - Removed heater (all experiments start from RTP)
  - Added a fuel centerline TC
  - 4 integral junction cladding TC
  - Electro-impedance boiling detector
  - Fiber-optic based pressure transducer
- Recently transitioned experiments from the BUSTER to Big-BUSTER containment pipe



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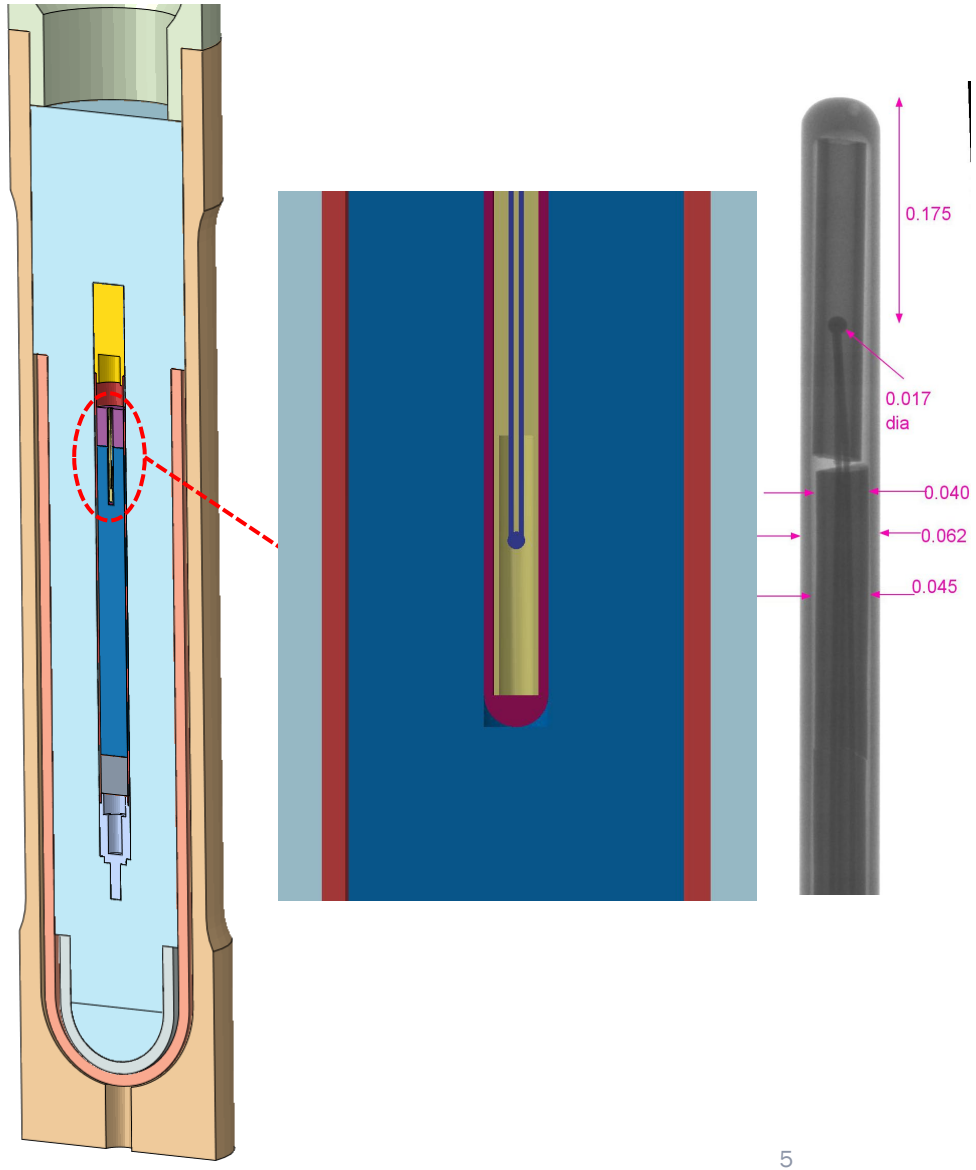
HERA Validation Experiments

- Leveraged multiple transients with other experiment programs
  - Cal capsule included 4 transients of increasing energy depositions
  - Utilized fuel centerline thermocouple data to perform thermal validation

Test Number	Test Reactor	Pulse Width (ms)	Target Enthalpy or Energy Deposition* (J/g)
MSERTTA-aLEU-UO2-1A-Cal	TREAT	~90	220*
MSERTTA-aLEU-UO2-1B-Cal	TREAT	~90	494*
MSERTTA-aLEU-UO2-1C-Cal	TREAT	~90	607*
HERA-Cal-1	TREAT	~90	705*
HERA-Zr-1	TREAT	~90	650 (734*)
HERA-PreH-1	NSRR	5-10	650
HERA-PreH-2	NSRR	5-10	650
HERA-PreH-3	TREAT	90	650
HERA-PreH-4	TREAT	90	650
HERA-PreH-5	TREAT + He-3 Clip	~50**	650
HERA-PreH-6	TREAT + He-3 Clip	~50**	650

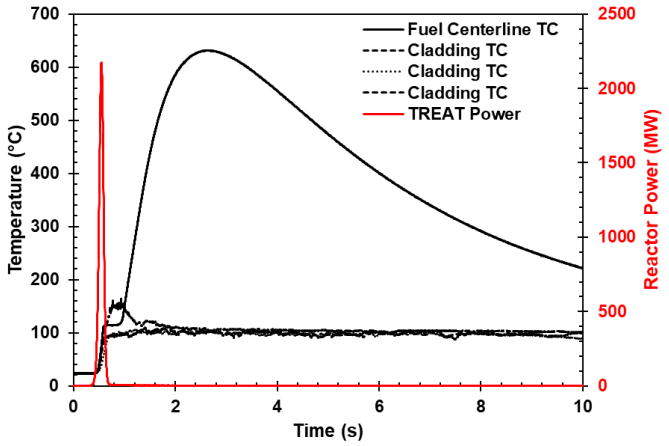
** Will be increased to >90ms if both TREAT experiments at 90ms experience PCMI

- Detailed ABAQUS model of the capsule, water, fuel rod, and fuel centerline temperature thermocouple was created
  - CT scan of TC provided detailed dimensions and construction
  - Coupling factor for fuel modified until reasonable agreement between model and experiment were met

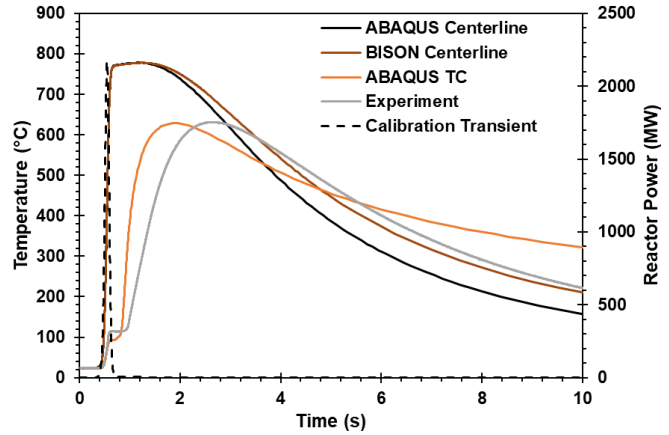


HERA CAL-1A

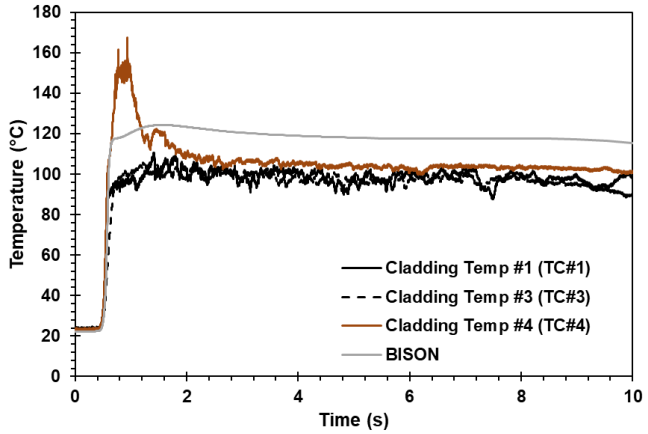
- 240 MJ TREAT transient
  - 98 ms FWHM pulse
  - Estimated 220 J/gUO_2 energy deposition
- Experiment results compared to BISON and ABAQUS predictions assuming best estimate coupling factors
  - BISON model thermal-hydraulics BCs loosely coupled from RELAP5-3D
- Coupling factor from MCNP6.1 neutronic calculations results in less than 0.5% difference in measured vs. predicted thermocouple temperature prediction
  - Differences in time of peak
  - TC measures ~150°C lower than predicted peak fuel centerline temperature
- Performed same analysis for 4 calibration experiments
  - All experiments showed less than 1% difference in measured vs. predicted



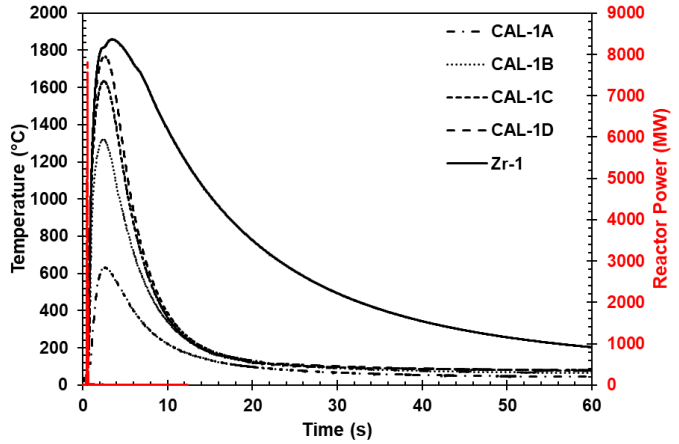
Experiment cladding and fuel thermocouple results



BISON and Abaqus modeling predictions compared to fuel thermocouple



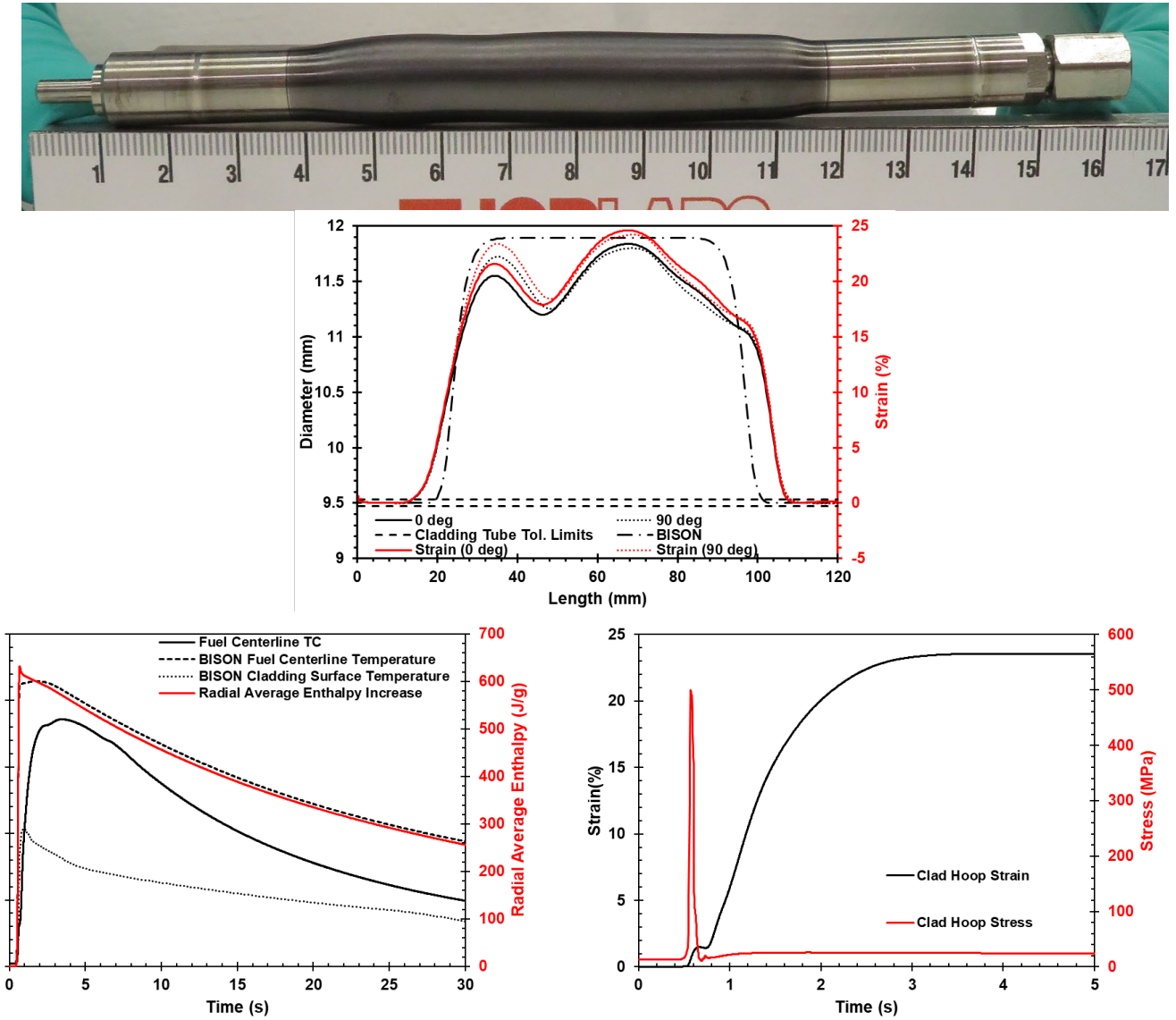
Cladding thermocouple measurements with BISON prediction



Fuel thermocouple results for all experiments

HERA-Zr-1

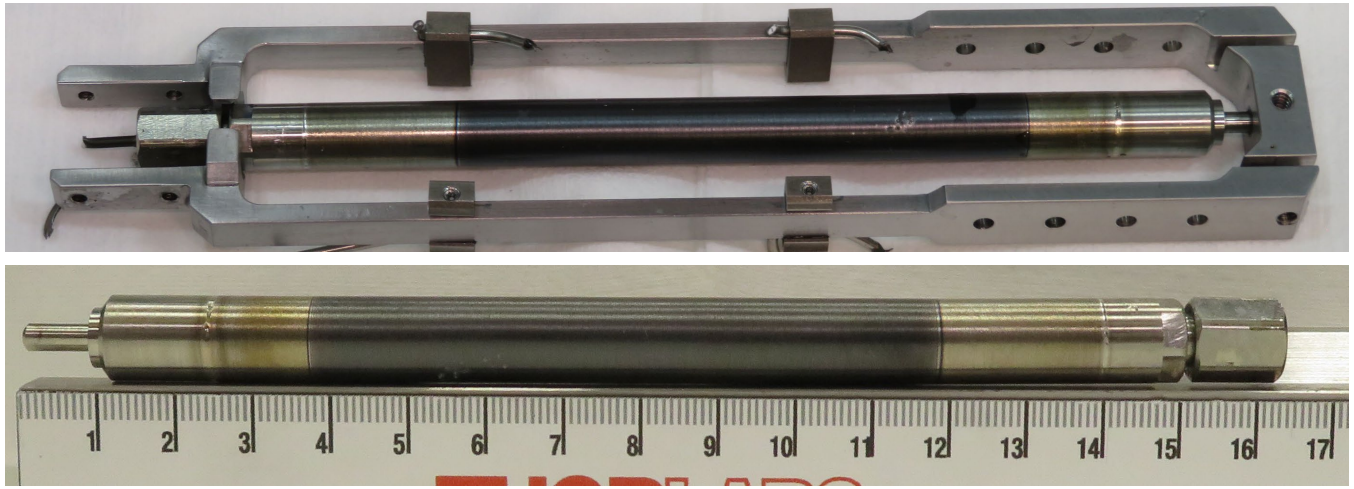
- The validated coupling factor from 4 previous tests used to design a transient that would target 650 J/gUO_2 peak radial average enthalpy rise
  - HERA-Zr-1 rodlet has oversized pellets similar to the pre-hydrided rodlets
- BISON simulations used to determine a 795 MJ (740 J/gUO_2) would achieve 650 J/g PRAER
- Transient resulted in 789 MJ (735 J/gUO_2)
  - 89 ms FWHM
  - BISON simulations predict 633 J/g PRAER
  - Peak fuel temperature of 2145°C
  - Predicted peak cladding temperature of 1032°C
  - Peak cladding hoop strain of 23.6% (peak 24.6% measured)



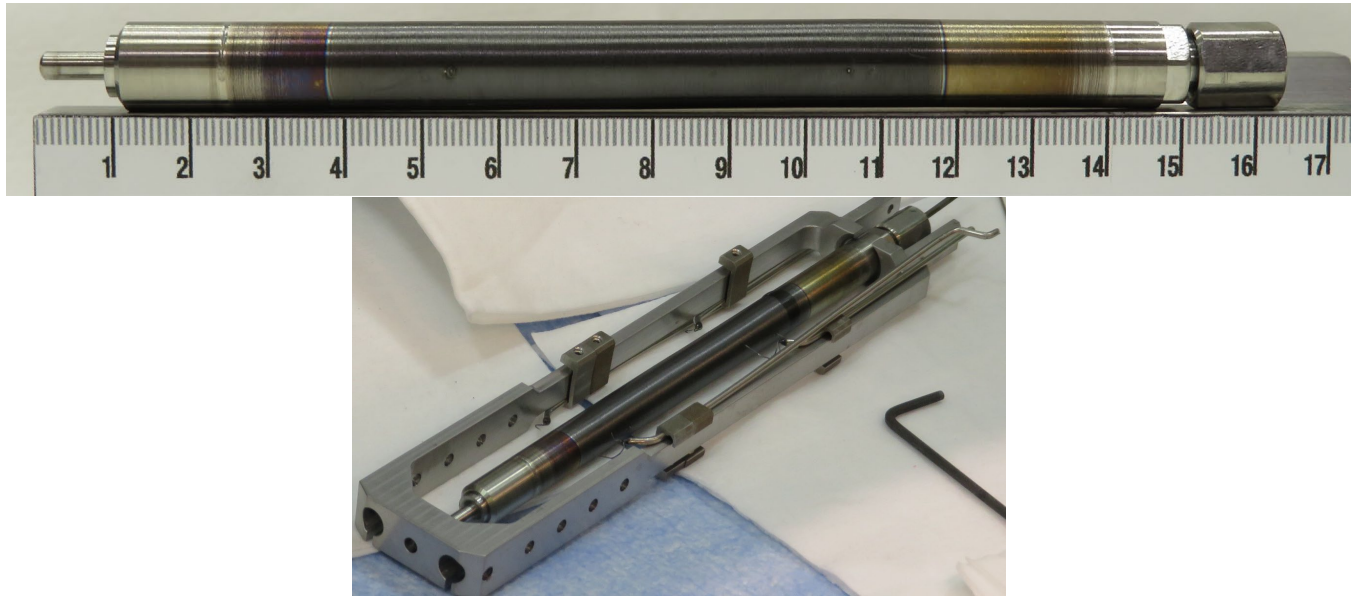
BISON predictions of the as-run transient compared to PIE profilometry

HERA Results Summary

- HERA data protected under the FIDES agreement
- Cladding contained ~400 ppm hydrogen
- HERA PreH-3 transient 858 MJ (798 J/g)
  - ~700 J/g peak radial average enthalpy
  - 1.2% final hoop strain
- HERA PreH-4 transient 707 MJ (658 J/g)
  - Transient undershot the target
  - ~580 J/g peak radial average enthalpy
  - 0.7% final hoop strain
- HERA PreH-1 (NSRR) targeted 625 J/g peak radial average enthalpy
  - No failure detected
- HERA PreH-2 (NSRR) targeted 725 J/g peak radial average enthalpy
  - No failure detected



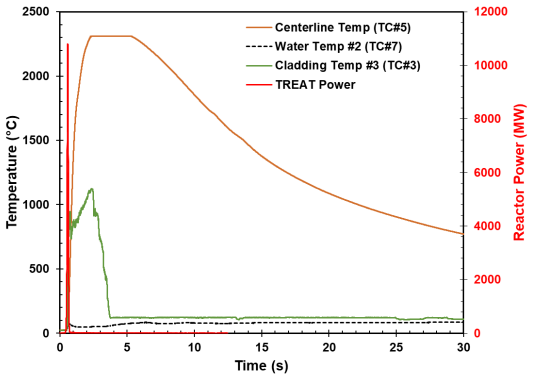
HERA PreH-3 rodlet following irradiation, no failure detected

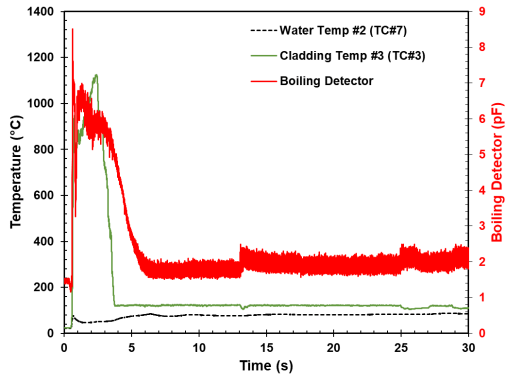


HERA PreH-4 rodlet following irradiation, no failure detected

CCZ RIA

- The NSUF-Chromium Coated Zr (CCZ-RIA) experiment
  - Will investigate thermal, mechanical and irradiation response of Cr-coated zirconium alloy (Zr-alloy) claddings under RIA conditions in comparison with uncoated Zr-alloy cladding
  - Cr coatings deposited by two different methods
    - Cold spray (CS)
    - Physical Vapor Deposition (PVD)
- Performed two experiments to date (CCZ-Zr-2 and CCZ-Zr-3)
- CCZ-Zr-3 deposited ~1000 J/gUO_2
- Exceeded temperature limit of Type C thermocouple >2310°C
- Cladding TC and boiling detector indicate DNB occurred





Transient Test ID	Experiment ID	Cladding	Fuel Diameter (mm)	Rodlet Fill Gas	Rodlet Plenum Pressure (MPa)	Capsule Fill Gas	Capsule Pressure (MPa)	Test Objectives		
								Specimen energy deposition target (J/g)	Step Insertion[1] (dk/k)	Test Purpose
NSUF-CCZ-1	CCZ-Zr-3	Zr-4	UO2-8.2	Helium	2	Helium	0.1	1000	4.2% Clipped	Moderate Enthalpy Burst
NSUF-CCZ-2	CCZ-Zr-2	Zr-4	UO2-8.2	Helium	2	Helium	0.1	1150	4.2% Clipped	High Enthalpy
NSUF-CCZ-3	CCZ-CS-1	Cold Spray Chrome Coated Zr-4	UO2-8.2	Helium	2	Helium	0.1	1150	4.2% Clipped	High Enthalpy Burst
NSUF-CCZ-4	CCZ-CS-2	Cold Spray Chrome Coated Zr-4	UO2-8.2	Helium	2	Helium	0.1	1000	4.2% Clipped	Moderate Enthalpy Burst
NSUF-CCZ-5	CCZ-CS-3	Cold Spray Chrome Coated Zr-4	UO2-8.2	Helium	0.1	Helium	0.1	1150	4.2% Clipped	High Enthalpy Oxidation
NSUF-CCZ-6	CCZ-PVD-1	PVD Chrome Coated Zr-4	UO2-8.2	Helium	0.1	Helium	0.1	1150	4.2% Clipped	High Enthalpy Oxidation
NSUF-CCZ-7	CCZ-PVD-2	PVD Chrome Coated Zr-4	UO2-8.2	Helium	2	Helium	0.1	1000	4.2% Clipped	Moderate Enthalpy Burst
NSUF-CCZ-8	CCZ-PVD-3	PVD Chrome Coated Zr-4	UO2-8.2	Helium	2	Helium	0.1	1150	4.2% Clipped	High Enthalpy Burst

[1]**NOTE**: *Step insertion values are subject to change and will be determined for each transient by TREAT Reactor Engineering using input from the PI.*

Experiment Results for CCZ-Zr-3

Look Ahead on High Burnup Tests

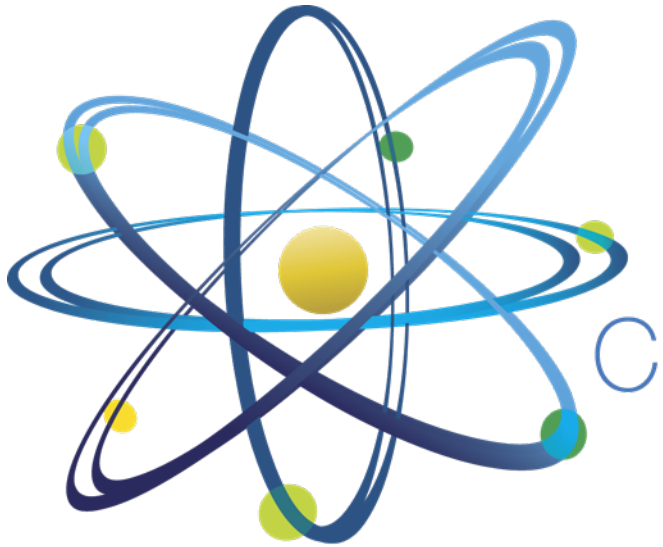
- Finalizing design modifications to the TWIST capsule for high-burnup HERA tests

- December 2023 – Previously Irradiated fuel (HBU and ATF) arrive in INL hotcell
- August 2024 – TWIST system calibration transients with fresh fuel
- December 2024 – First Test on Previously irradiated fuel
- April 2026 – Final Test on Previously irradiated fuel
- December 2025 – Complete PTE of previously irradiated fuel

Summary

- Leading a joint project under the NEA FIDES framework
- Performed 4 of 6 pre-hydrided cladding and oversized fresh fuel tests
  - 2 at NSRR and 2 at TREAT
  - Post transient examinations on the TREAT rods has begun
  - 2 remaining tests at TREAT
  - No tests so far have experienced failure
- Will be performing 4 tests on pre-irradiated high-burnup and ATF rods in the TWIST capsule
- Started experiments for the NSUF CCZ-RIA campaign

Questions?



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