Transient Testing of Advanced Fuel and Cladding Material Concepts Under Conditions Relevant to DBA and BDBA Scenarios

K. Linton[a], M. N. Cinbiz[a], N. Brown[b,a], Y. Yan[a], K. Terrani[a]

a) Oak Ridge National Laboratory b) Department of Mechanical and Nuclear Engineering, Pennsylvania State University

In-Cell & Ex-Cell Severe Accident Test Station (SATS)

Objectives: Provide a platform for evaluation of advanced fuel concepts under postulated **design basis accident (DBA)** and **beyond design basis accident (BDBA)** conditions. Replicate and optimize already demonstrated **Loss-of-Coolant Accident (LOCA)** Integral Test System while providing a wide range of conditions (temp, pressure, gas flow rate, etc.) in-core during BDBAs.

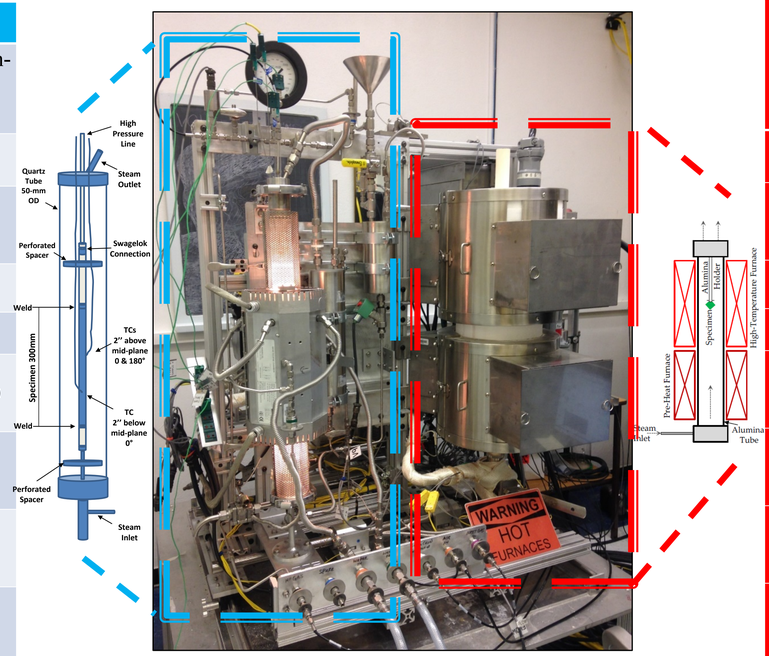
Integral LOCA Testing

One of NRC's central regulations used in nuclear plant licensing deals with postulated loss-of-coolant accidents (10 CFR 50.46). The in-cell LOCA integral tests are designed to investigate the performance of current and advanced irradiated fuels, which undergo ballooning and rupture under LOCA conditions.

High Temperature Furnace (BDBA)

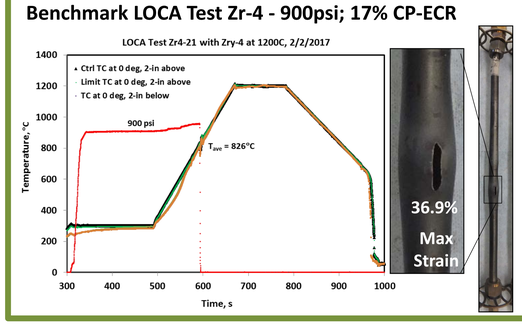
Candidate fuel cladding materials can be exposed to severe accident conditions well beyond LOCA test conditions. The system is capable of exposing samples to rapidly flowing steam at temperatures of at least 1700°C.

	DBA Module	
	LOCA Integral Test	Oxidation-Quench Test
Sample Spec	Fueled Rod	Defueled Rod
Sample Segment (mm)	~200 - 300	~25 - 50
Pressure (MPa)	~8, max 20	.1
Max Temp (°C)	1200	1200
Heating Rate (°C/min)	5	5; max 20
Steam Flow Rate (mg/cm2.s)	~5.7	~5.7
Gas Environment	Steam or Ar	Steam or Ar
Quench (°C)	@ 20-800	@20-800



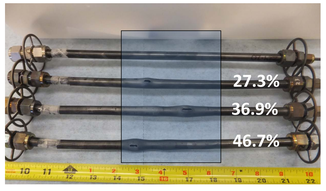
	BDBA Module
	High Temperature Test Station
Sample Spec	Rod or Coupon w/3mm hole
Sample Segment (mm)	~25 - 50
Pressure (MPa)	.1
Max Temp (°C)	1700
Heating Rate (°C/min)	10; max 25
Steam Flow Rate (mg/cm2.s)	3.0-7.0
Gas Environment	Steam or Ar
Quench (°C)	None

Benchmark LOCA Test Zr-4 - 900psi; 17% CP-ECR

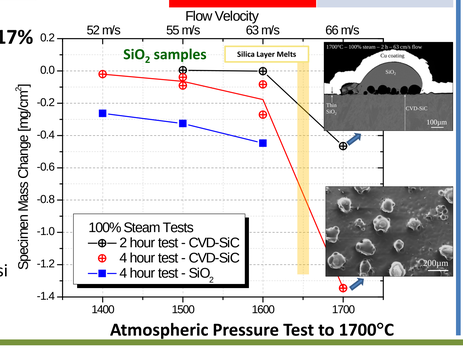


Benchmark LOCA Tests at 1200°C for CP-ECR = 17%

- 4 benchmark LOCA tests conducted at 1200°C for 0, 600, 900 and 1200 psi
- All samples ruptured in middle 4" section



Internal Pressure
← 0 psi
← 600 psi
← 900 psi
← 1200 psi



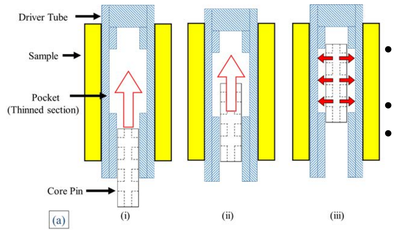
Ex-Cell Reactivity-Initiated Accident Tube Burst Test

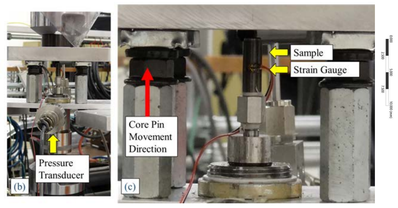
Objectives: Develop a separate effects test device to understand cladding material response to the low-temperature pellet cladding mechanical interaction (PCMI) phase of a **Reactivity-Initiated Accident (RIA)**. Support restart of the Transient Reactor Test Facility (TREAT) by providing experimental data for model development and informing design of in-core integral effects testing.

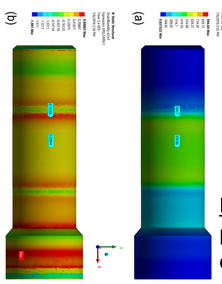
High Strain Rate PCMI Test Device

Based on enhanced version of EPRI device (Yueh et al. JNM 2016, Yueh JNM 2017)

- Simulates PCMI Phase of RIA
- Driver Tube Filled with Hydraulic Oil
- Movement of Core-Pin Pressurizes Oil
- Oil Expands Driver Tube
- Driver Tube Strains Sample







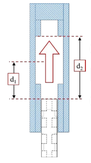
Reactivity-Initiated Accident (RIA)

RIA is postulated design basis accident (DBA) in an LWR typically in the form of control-rod-ejection in PWR or control-rod-drop in BWR. During the first phase of RIA, the fuel pellet thermally expands. To ensure RIA effects of candidate cladding materials are acceptable, tests are necessary to determine their appropriate safety limits and failure mechanisms.

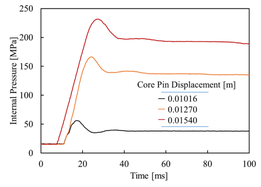
Driver tube designs are optimized to proposed cladding dimensions for cladding candidate materials.

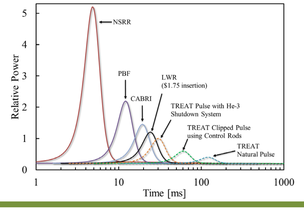
Controlling Pulse Width

PCMI tests are conducted to determine the failure strain (%) of a sample. However, the pulse width and rate of fuel temp. increase will help determine the strain rates (%/sec.) which will inform the strain rate that should be targeted for a particular test.



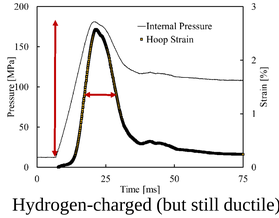
Core-Pin Displacement Controls Pulse



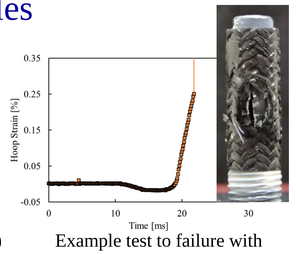


Transient test reactors do not produce a prototypic LWR RIA pulse width (driven by neutron generation time), so PCMI separate effects testing can augment in-situ testing and benefit from RIA condition pulse width calculations.

Demonstration with Zirlo, SiCf/SiC-m, and FeCrAl Samples

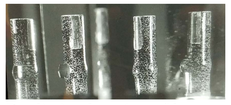


Hydrogen-charged (but still ductile) ZIRLO

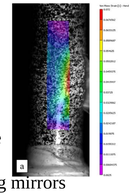


Example test to failure with SiC-f/SiC-m

Three Dimensional Strain Using DIC



Predicting location of hoop failure strain can be overcome by three dimensional Digital Image Correlation (DIC) using mirrors to view all sides of the sample.



Speckle pattern and the region-of-interest for the strain measurements.