Facilities and Potential Intermediate-Term ATF Development

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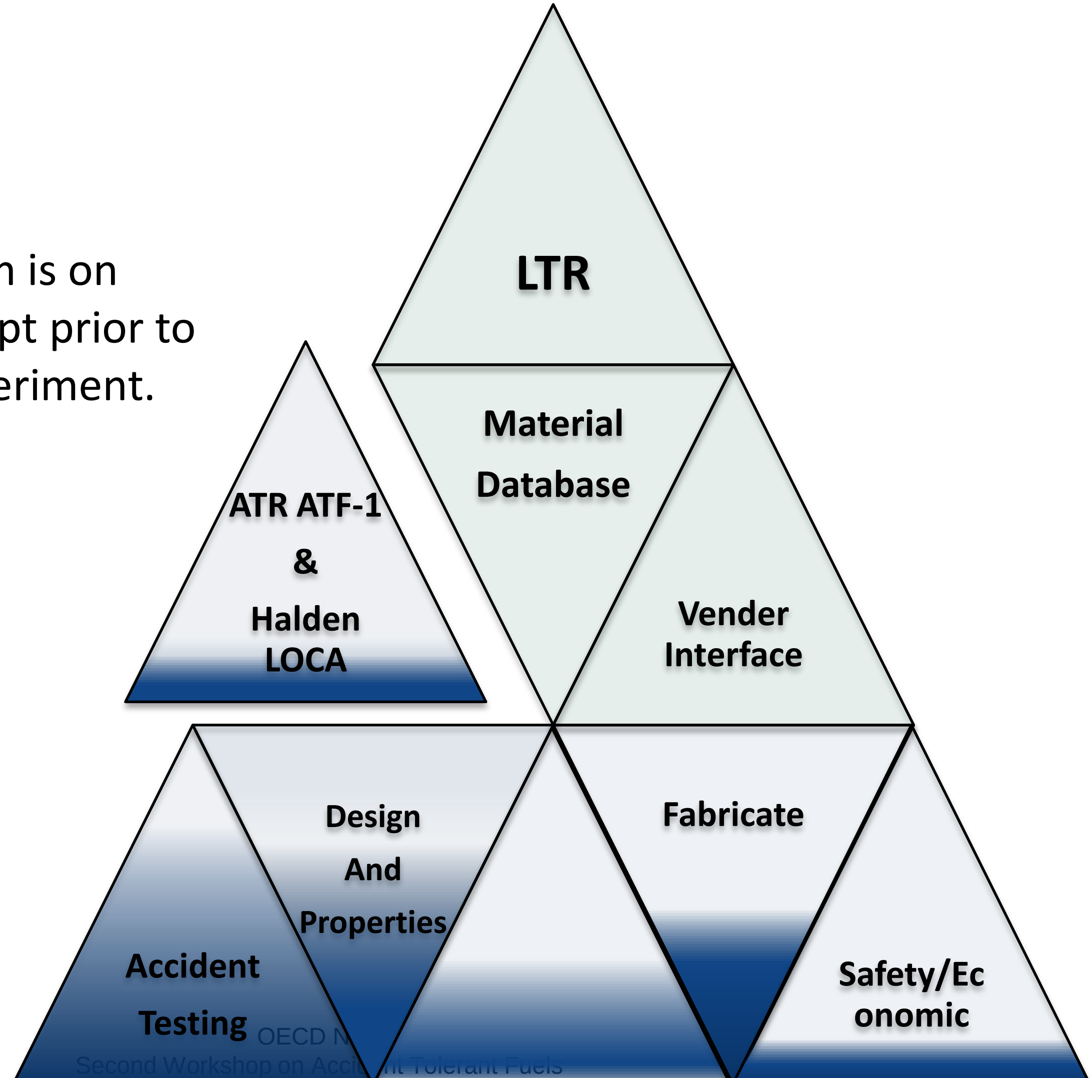
Near-Term Direction of US ATF Program

- Near-term emphasis of program is on key technologies proving a concept prior to irradiation in ATR : the ATF-1 experiment.



ATR ATF-1 Experiment at Idaho National Laboratory

PLN-4444
Revision: 0
Effective Date:

Irradiation Testing of Accident Tolerant Fuels in the ATR

(The ATF-1 Test Series)

Fuel Cycle Research & Development
Advanced Fuels Campaign

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Prepared for
U. S. Department of Energy
Office of Nuclear Energy

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FCRD-FUEL-2011-xxxxxx

A number of concepts have indicated a desire to be included in ATF-1 experiment: ~ July 2014.

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

ATR ATF-1 Experiment at Idaho National Laboratory

ATF Development Lead	Fuel	Anticipated Fuel Enrichment	Cladding	Coating	Desired Irradiation Conditions: PICT (°C)	LHGR (W/cm)	Burnup (GWd/MT)	# of Rodlets in Initial Insertion
ORNL	FCM-UO2, UN	19.70%	Zircaloy	n/a	350-450	180-280	10, 30, 50	21
	UO2	4.96%	FeCrAl					
	UO_2	4.96%	SiC					
PNNL	U-10Mo U-7Mo	3-6%	MA-956	n/a	300-400	200-350	15, 30	6
EPRI / LANL	UO2	5-6%	Mo	n/a	300-360	350-500	25, 50	6
Westinghouse	UN + U3Si2	~5% for 5 to 10 kw/ft ~19% for 20 to 30 kw/ft	Zircaloy SiC	Ti2AlC and/or Nanosteel	300-400°C	195-1050	20, 40, 70	6 rodlets initial
	U3Si2	~5% for 5 to 10 kw/ft ~19% for 20 to 30 kw/ft	Zr		300-400°C	195-1050	20, 40, 70	6 rodlets initial
AREVA	UO2 UO_2+Cr_2O_3 UO_2+Cr_2O_3+SiC	<5%	Zircaloy	none	300-420	180-350	25, 50	6
General Electric	UO_2	4.9% (from GNF)	3 Different Advanced Steels	None	300-400	500 W/cm	20, 80	6 (3 alloys, 2 burnup levels)
U. Illinois	UO2	<5%	Mod. Zr	n/a				TBD
U. Tennessee	UO2	<5%	Zircaloy	Ceramics	n/a	n/a	n/a	n/a*
Georgia Tech	U3Si2	5-10% Test Nat-U, 5%, 8%	FeCrAl	n/a				TBD
CTP	UO2	assume <5%	SiC TRIPLEX	none	300 - 400	500 - 600	20, 50, 100	1 or 2

Severe Accident Test Station at ORNL

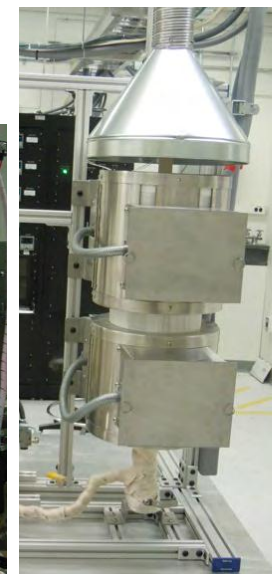
- gateway to insertion to ATF-1 -

National facility for testing new cladding concepts
- multiple "modules"
- steam to 1700°C, typically 1-10 cm/s
- pressure to 30 bar

Rubotherm TGA

"Keiser rig" high P/T ~1500°C

standard LOCA

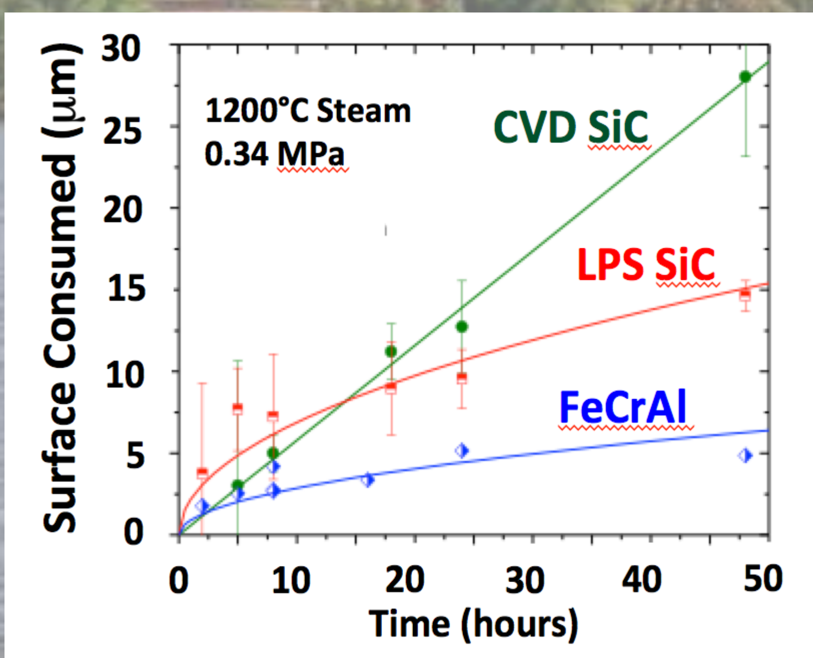


high T ~1700°C

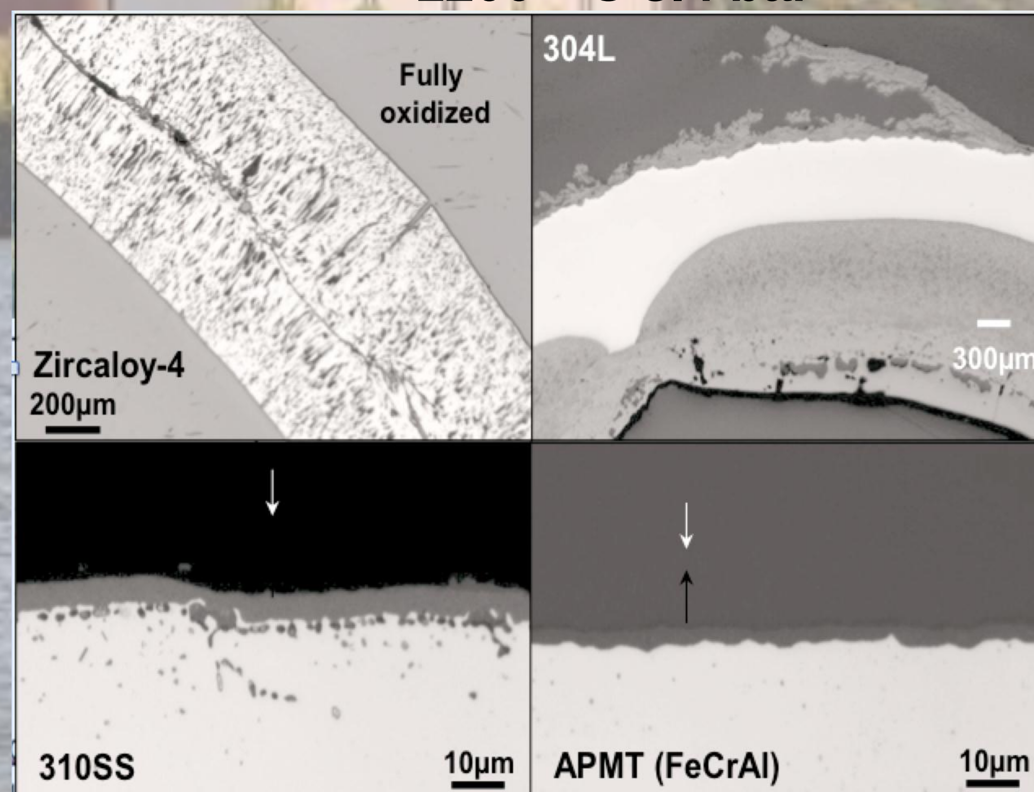
in- & ex-cell units

4

Steam Attack of Advanced Clad



1200˚ C 3.4 bar



SiC Gap Analysis and Near-Term Work

Silicon Carbide Gap Analysis and Feasibility Study

Fuel Cycle Research & Development

Prepared for
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Conclusions (focus areas):

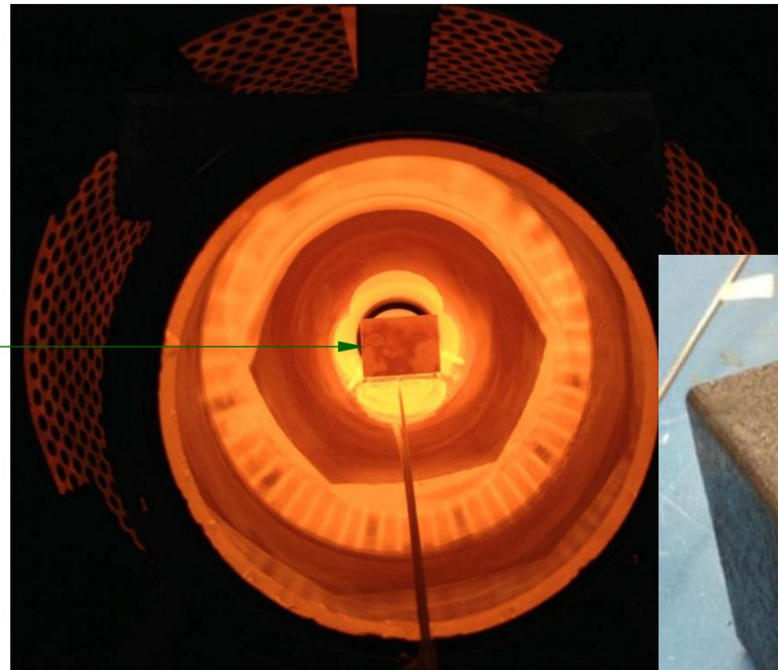
- Environmental Integrity
  - Fuel-Clad Interaction (minor work at ORNL)
  - Corrosion (MIT, ORNL, INL - 2 yr performance)
  - Steam Oxidation (nearly complete)
- Radiation Resistant Joining (complete 2015)
- Detailed Design Linked to Failure Analysis (new design required)
- Standards (long process underway)

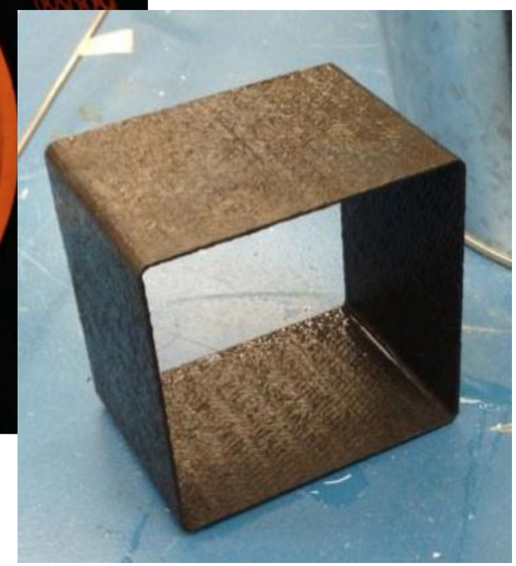
Currently, no capsule with SiC cladding is envisioned for insertion in INL ATR in the initial ATF-1 experiment.

EPRI NEET FOA on SiC Channel Box
- Thermal Shock -

Over next two years EPRI will lead a team to explore viability of a SiC channel box.
- modeling performance, irradiation creep and swelling, thermal shock, etc.

SiC/SiC composite channelbox inside infrared (IR) furnace at ~1150°C

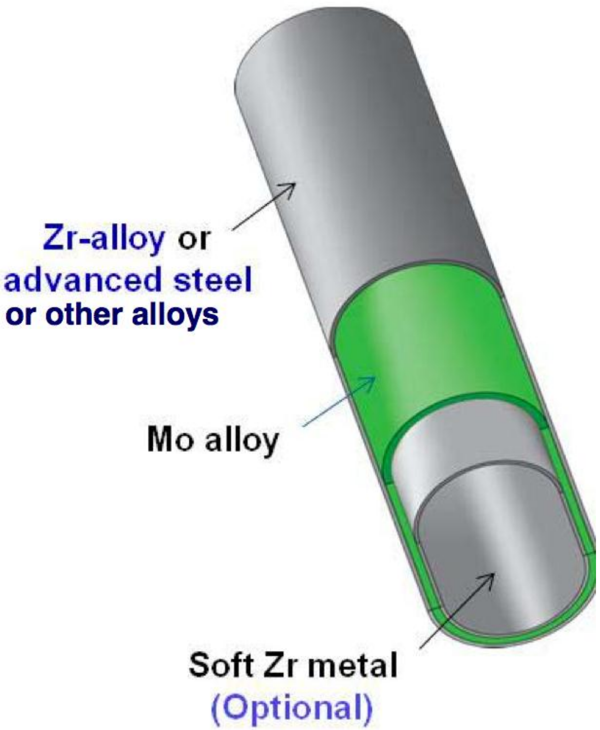




• Thermal shock viability of SiC/SiC channel box prototype successfully demonstrated.

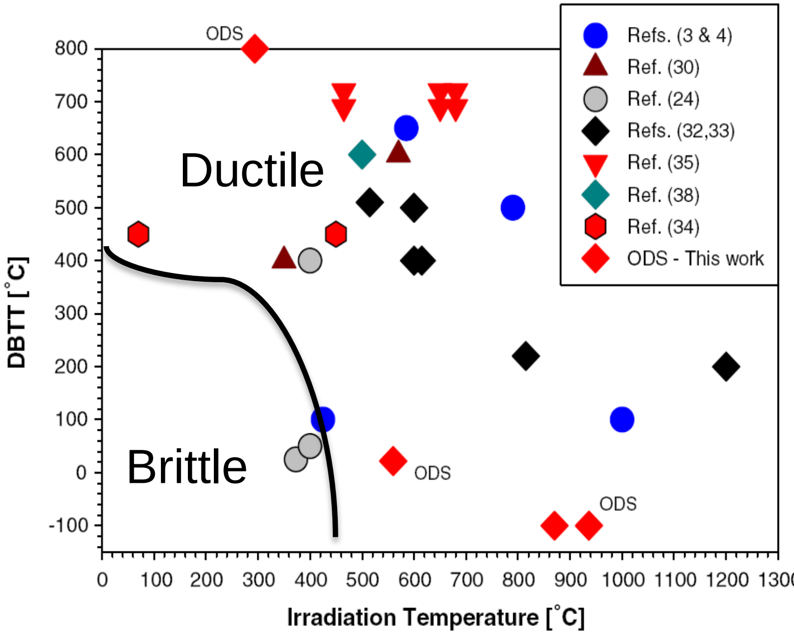
ELECTRIC POWER RESEARCH INSTITUTE

Engineered Molybdenum Clad



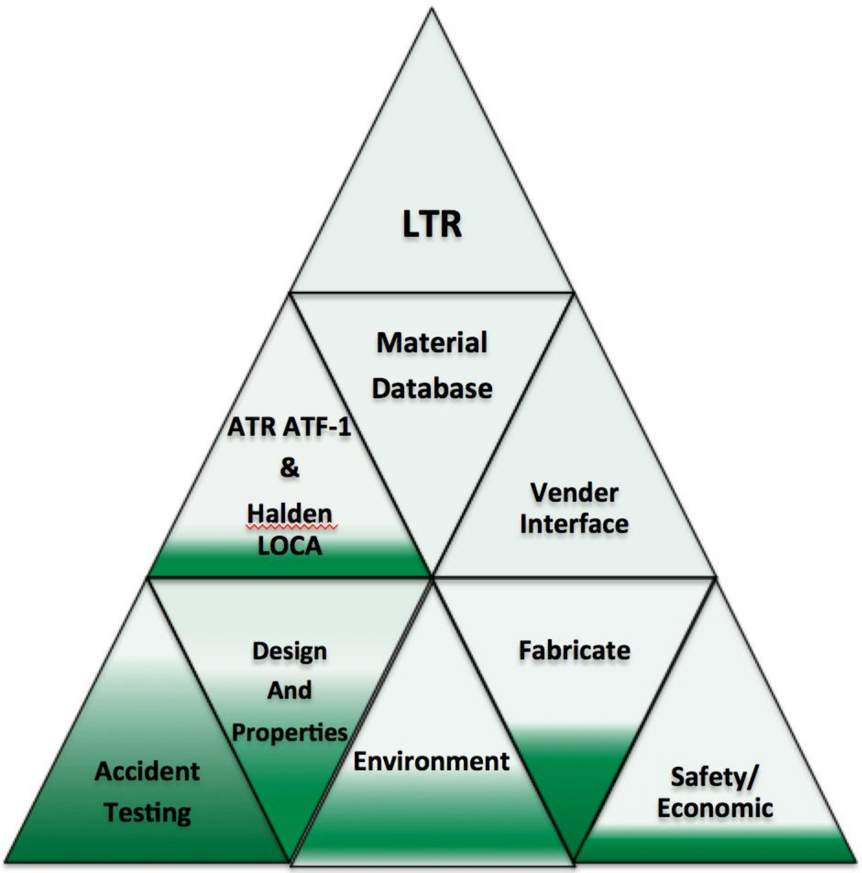
FY14-15 Focus Areas:

- Environmental Integrity
  - Fuel-Clad Interaction
  - Corrosion (EPRI-GE R&D)
  - Steam Oxidation (EPRI-LANL, ORNL)
- Radiation Resistant (required)
- Detailed core impact analysis (underway?)
- Tube and overlay forming



Advanced Steel (ATF FeCrAl) Clad

- Leading ORNL and GE Candidate for ATF-1 -

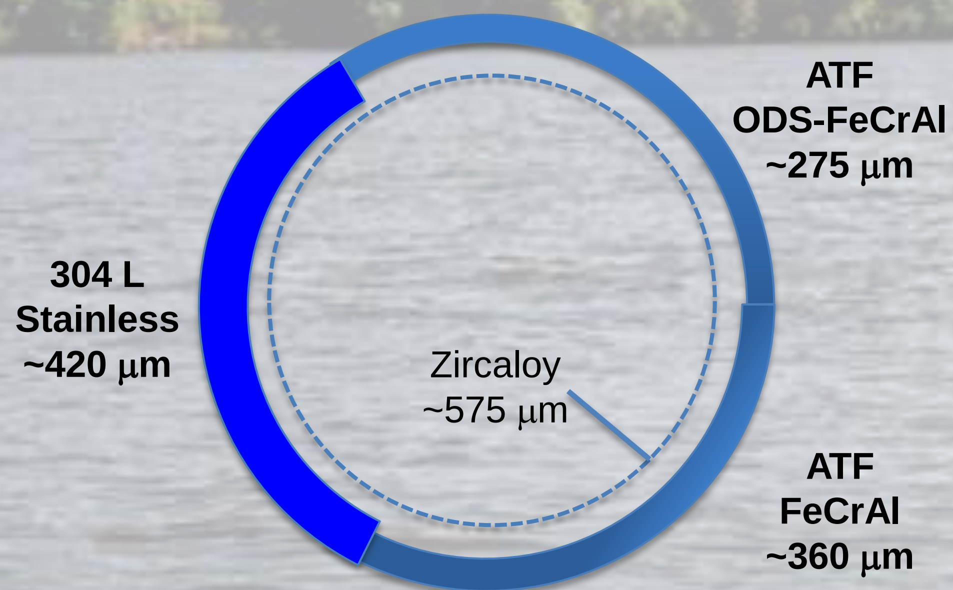


FY14-15 Focus Areas:

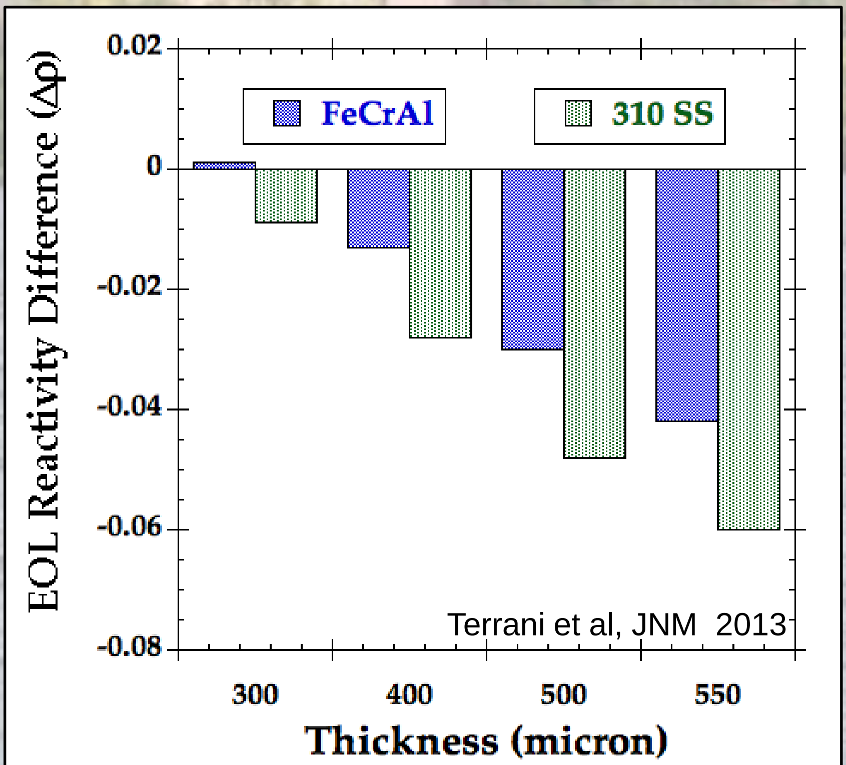
- Accident Testing (very mature for steel)
  - Model alloys complete; candidate alloy chemistry selected; kinetics understood
  - Will carry out community testing of advanced steels and steel-based coating
- Environmental Integrity
  - Fuel-Clad Interaction (purpose of ATF-1)
  - Corrosion (EPRI GE-ORNL, ORNL, EPRI-GE) necessarily requires years to complete (FY15). Initial results positive.
  - Steam Oxidation (EPRI-LANL, ORNL)
  - Radiation Embrittlement (Irradiation began in FY-13, PIE will begin FY-14, complete FY-15)
- Operational impact (enrichment penalty published and nominal). Severe accident core analysis has begun but requires expansion. (ORNL, INL)
- Thin tube drawing and welding have been carried out with positive results. Expanded program required leading to ATF-1. (EPRI, ORNL, LANL, INL, GE)
- Tritium diffusion and barrier coating research to be carried out FY-14 (ORNL)

Development of ATF FeCrAl Clad

Original 304SS clad was significantly thinner than the Zircaloy it was replaced with. Over the last four decades commercial steels have significantly improved in strength and irradiation performance, which should translate to even thinner clad. Performance of thinner cladding needs to be proven.



PWR 17X17 Core, Constant 9.6 mm Clad



Development of ATF FeCrAl Clad

Phase 1 : Model ATF FeCrAl Alloys

- Corrosion (ongoing) and Steam Attack Studies (essentially complete-published)
- Effect of Alloying Addition on Mechanical Properties (complete)
- Effect of Alloying Addition on Irradiation Embrittlement (underway)

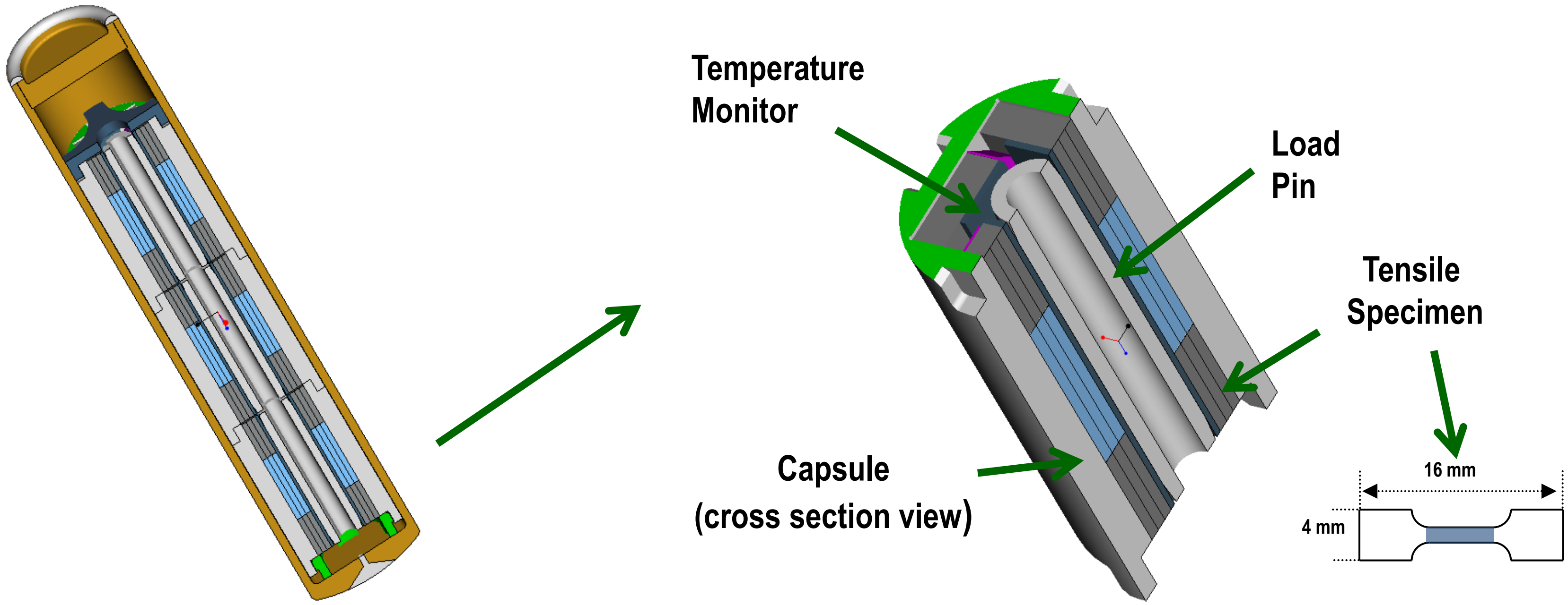
Phase 2 : Engineering ATF FeCrAl Alloys

- Grain Refinement (size, uniformity, and orientation) (underway)
- Second phase strengthening
- Tube forming and Welding

Candidate alloy selected by January 2014

Deployment: Qualification Grade Material

HFIR Irradiation Design and PIE



- 4 ORNL ATF FeCrAl candidate + 2 commercial alloys inserted to HFIR
  - Varying Cr content across selected alloys

FY2013

- Planned PIE:
  - Tensile tests at RT, 320 °C, & accident temperature to determine mechanical performance
  - SANS to determine α' volume fraction
  - Analytical electron microscopy from non-gauge section of tensile specimens

Low Dose: FY2014
High Dose: FY2015