

The TerraPower logo features the company name in a dark blue, sans-serif font. Above the text is a green graphic element consisting of a curved line that starts as a thin arc and ends as a thicker, more pronounced arc, resembling a stylized wave or a protective shield.

TerraPower™

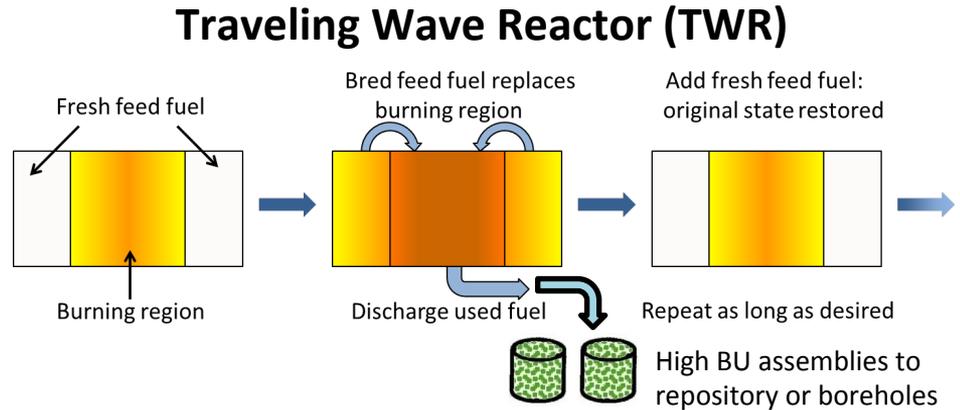
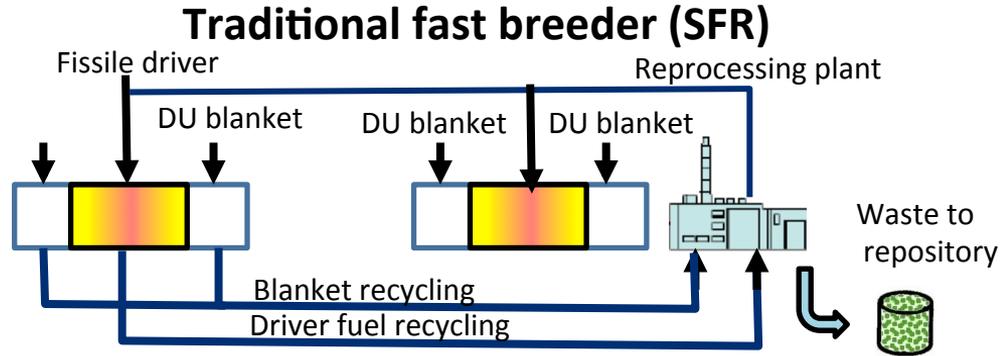
Fuel Development, Testing, and Schedule for the Traveling Wave Reactor

Kevan Weaver

**DOE-NRC Second Workshop on Advanced Non-LWR Reactors
North Bethesda Marriott, June 7-8, 2016**

The Traveling Wave Reactor

- First breeds fissile Pu-239 in U-238 feed fuel
- Unlike in a traditional SFR, TWR fuel is directly used after breeding, without a reprocessing step
 - Once-through fuel cycle with 30x uranium utilization of LWRs
- Requires:
 - An excellent neutron economy – judicious use of structural materials
 - High burnup fuels and irradiation resistant materials



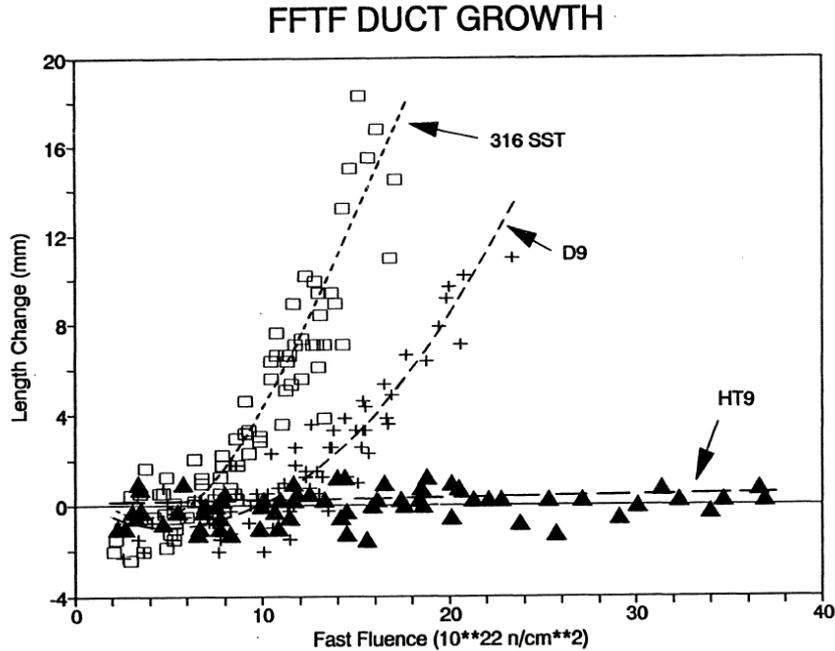
Main Focus Areas for Fuels and Materials

- Historic data and archived material
 - Forms basis for material choice
- Understand fuel/material behavior
 - Use information to optimize material, and benchmark predictive codes
- Fabrication
 - Supply chain development
- In-pile and out-of-pile testing
 - Heavy ion and neutron irradiations
- Post irradiation examination

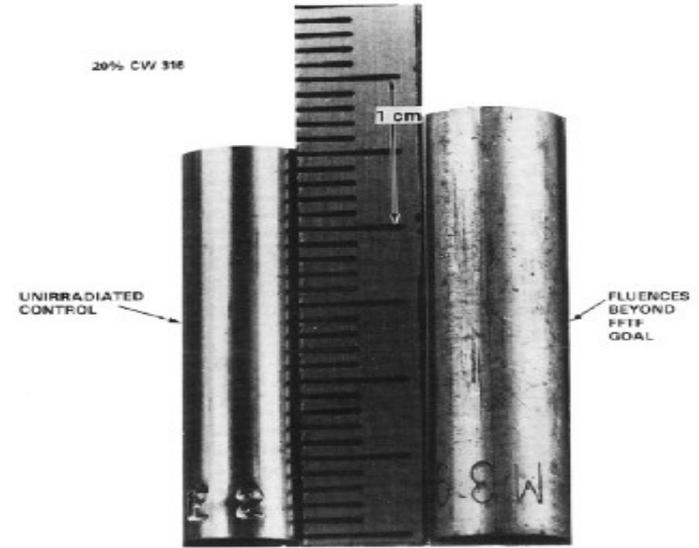
U.S. Fast Reactor Fuel Experience

- Clad and structural materials
 - Stainless steel (austenitic, ferritic-martensitic)
- Ceramic fuel
 - Oxide (UO_2 and MOX)
 - High melting temperature, low conductivity
 - Carbide (UC)
 - High melting temperature, high conductivity
 - Nitride (UN)
 - High melting temperature, high conductivity
- Metal fuel
 - Uranium metal
 - Low melting temperature, high conductivity
 - Uranium metal alloys (U-Fs, U-Zr, U-Mo, etc.)
 - Moderate melting temperature, high conductivity

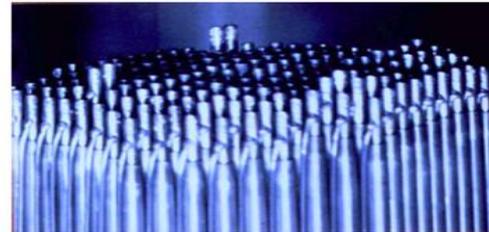
F/M Performance Advantages



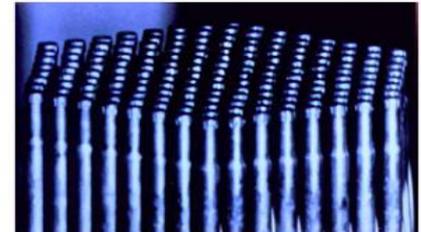
AL Pitner et al., Rpt. # WHC-SA-1967-FP, Oct. 1993



FFTF Fuel Pin Bundles



Stainless steel, swelling



HT-9, no swelling

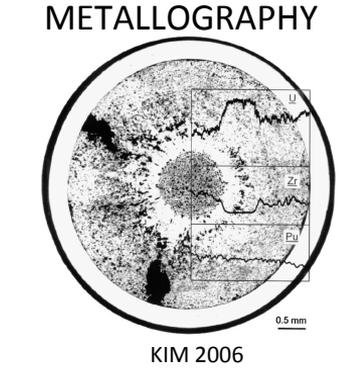
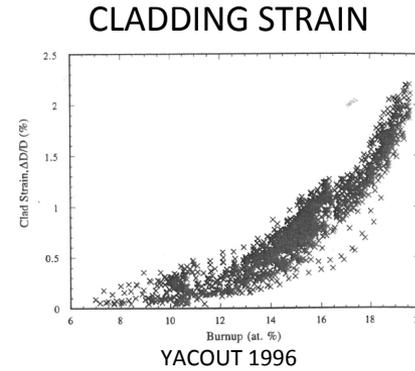
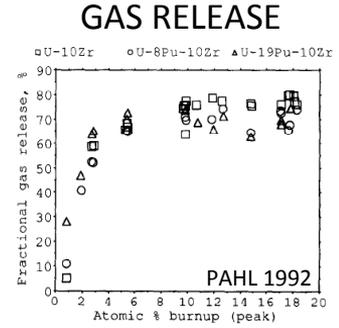
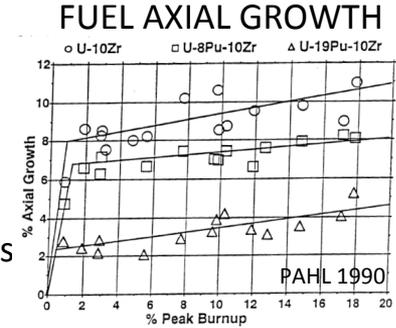
US DOE Metallic Fuel Pin Data and New PIE on FFTF Metallic Fuel Assemblies

- Fuel Pin – U-10Zr alloy sodium bonded in steel cladding

Schematic of fuel element



- EBR-II and FFTF fuel pin irradiation test data from INL and PNNL
- TerraPower sponsors new PIE at INL on FFTF metal fuel assemblies
 - Profilometry, fission gas release, neutron radiographs, gamma scan, metallography, etc...
- Data used to understand fuel performance and to benchmark models
- Data supports licensing case



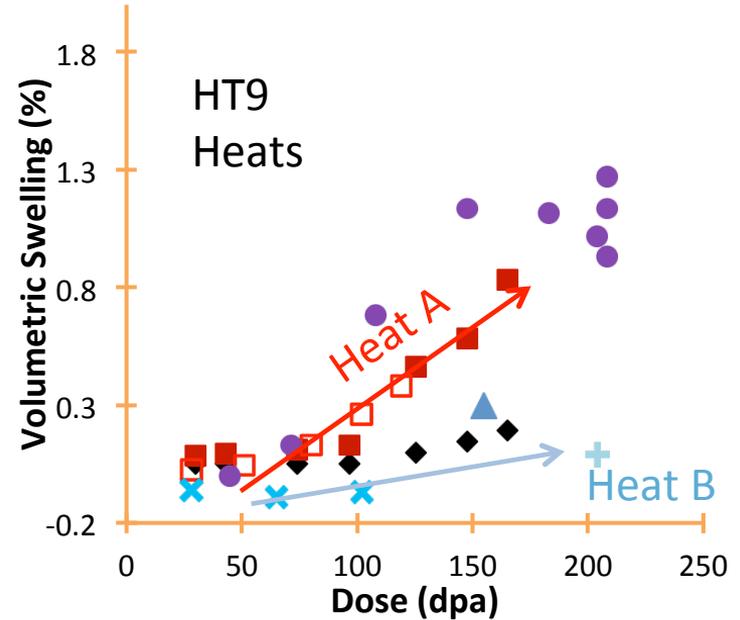
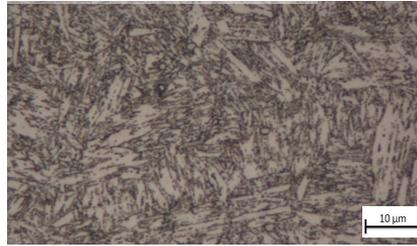
Advanced HT9 Development

- Why did different HT9 heats result in different swelling behavior?
- Exhaustive review of archive (unirradiated) HT9 and performance data
- Identified optimal microstructure features and processing
- Commercial fabrication of advanced HT9 for irradiation testing

**Poor structure
(heat A)**



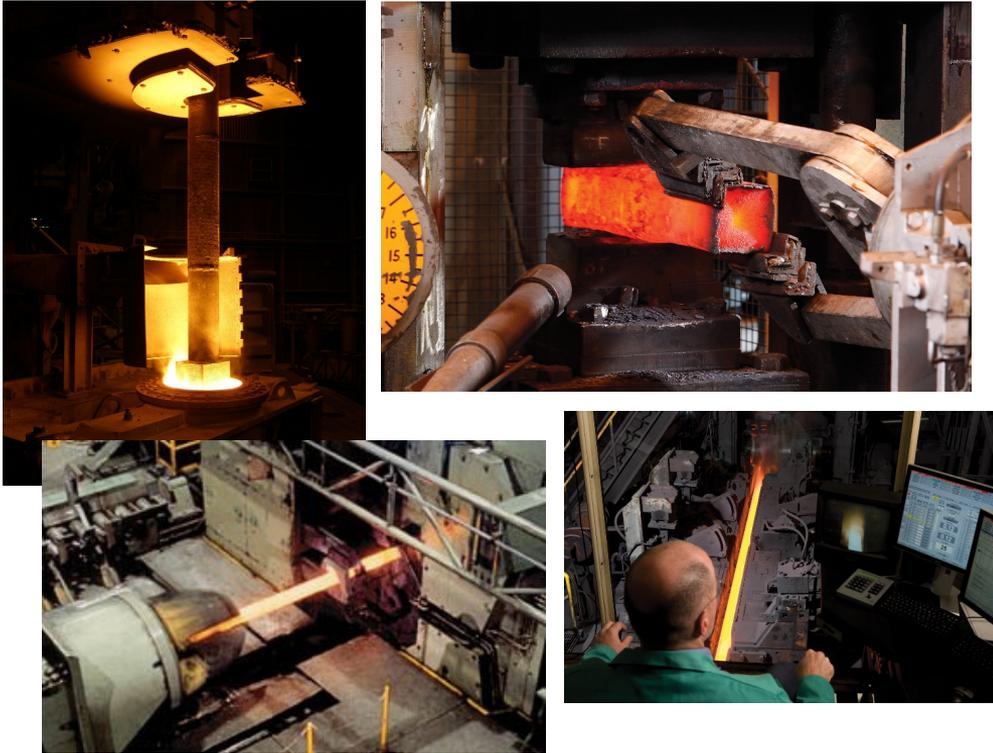
**Good structure
(heat B)**



HT9 Fabrication and Processing



Commercial Fabrication of HT9



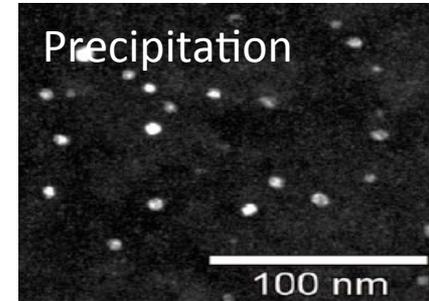
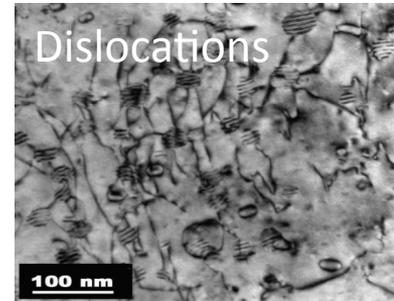
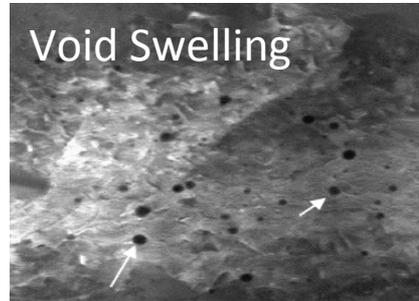
- Three orders for commercial-sized ingots
 - Kobe Steel (3 tons)
 - Carpenter Steel (5 tons each)
- Product to be used for:
 - Fabrication of fuel test pins
 - Fuel assembly mockups, thermal-hydraulic testing
 - Materials test programs

Proof of Fabrication

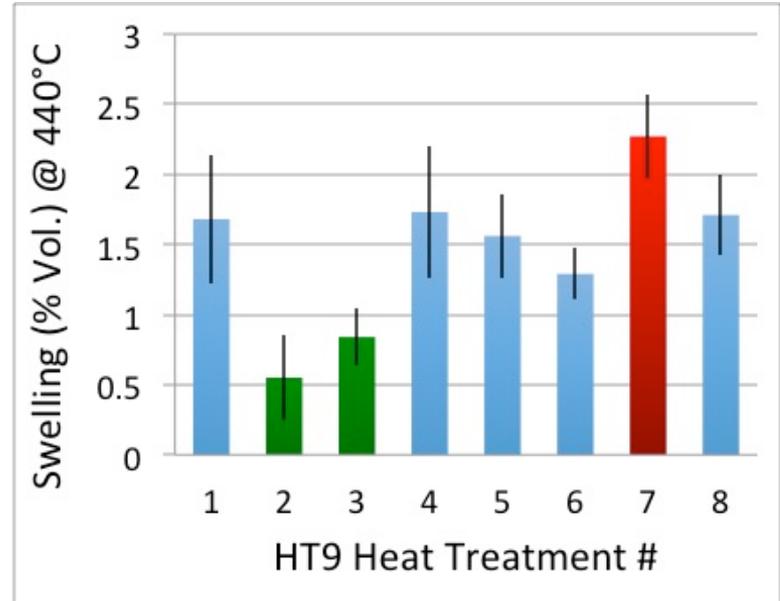
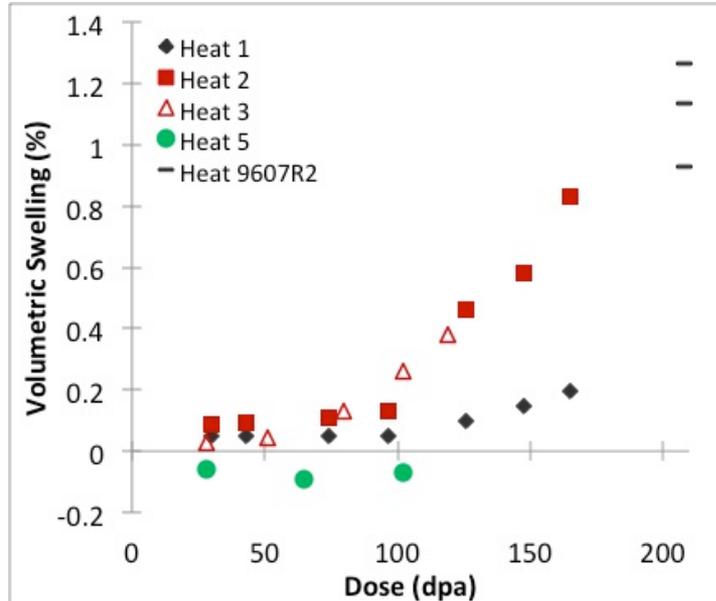


Heavy Ion Irradiation Program

- Program Objectives: Provide qualitative (head-to-head) information on radiation effects in short time frames; and establish a correlation between heavy ion and neutron irradiation
- Benchmark material :
ACO-3 duct from FFTF,
155 dpa @ avg. 443°C
- Fe²⁺ irradiation of archive
ACO-3, 188 dpa @ 460°C
- Irradiation-induced
microstructure features
are similar, including
dislocations, G-phase, α' ,
voids



Both Neutron and Ion Irradiations Show Importance of Optimized Heat Treatment



Neutrons (previous irradiations)

Ions

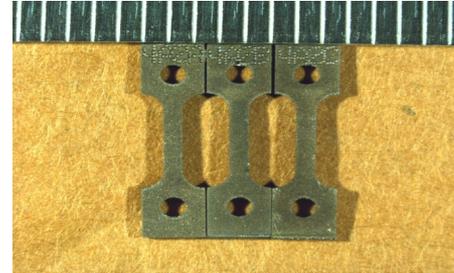
BOR-60 Materials Test, TP-1 and TP-2

Goals Include: Irradiate HT9 to 280 dpa by 2019, provide data on optimized production process HT9

- Rigs 1 and 2 inserted into BOR-60 Dec 24, 2013.
 - 360 and 400°C
 - New TerraPower Optimized Material (>350 specimens).
 - DOE Pre-Irradiated (~150 specimens)
 - Temperature maintained by gamma heating



Pressurized Tube



ACO-3 Tensile



TEM Capsule

Assembled Suspension with 16 sample/monitor holders



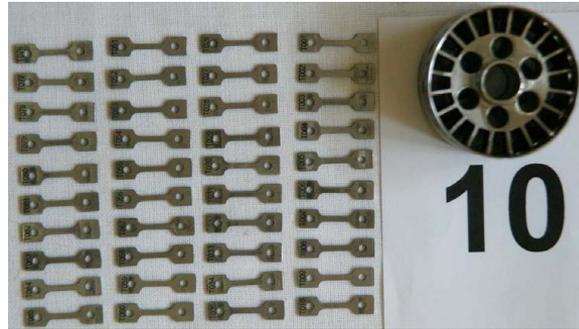
Container with Assembled Suspension Inside

Lower Section interfaces with below core low pressure sodium plenum

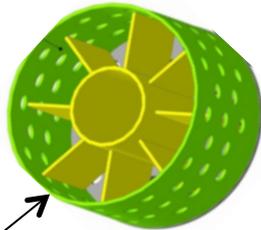
BOR-60 Materials Test, TP-3, TP-4, TP-5 (High Temperature Rigs)

Goals Include: Irradiate HT9 to 280 dpa by 2019, provide data on optimized production process HT9

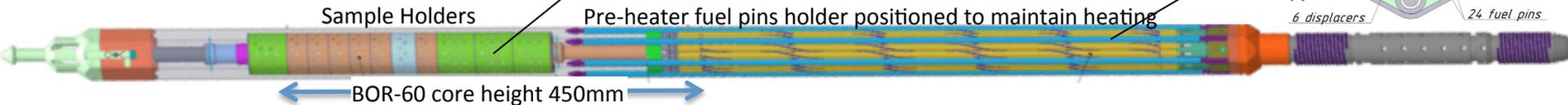
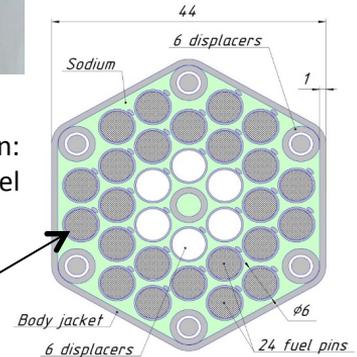
- Rigs 3,4,5 inserted in Mar & May 2014
- 450, 500, 625°C
- New TerraPower Optimized Material (>750 specimens).
- DOE Pre-Irradiated (~100 specimens)
- Temperature maintained by pre-heater fuel.
- First irradiated samples (Rigs 1 and 2) to discharged in 2014 (10 dpa) and replacement samples inserted.



Sample Holder for TP-3, 4, 5

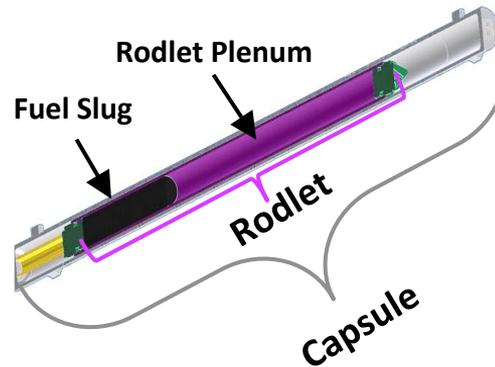
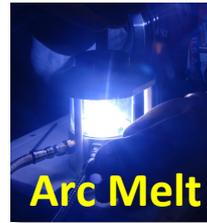


Cross-section: Pre-heater fuel



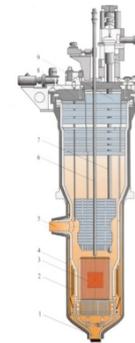
Fuel Fabrication at INL and Irradiation Testing in the ATR

- Purpose: Quickly examine a variety of advanced fuel concepts for commercial TWR design
- Fuel slugs fabricated at Idaho National Laboratory (INL)
- Five specimens, Five capsules
- Inserted into Advanced Test Reactor (ATR) Fall 2013
- 5at% burnup by year end 2014
- Follow on testing in progress

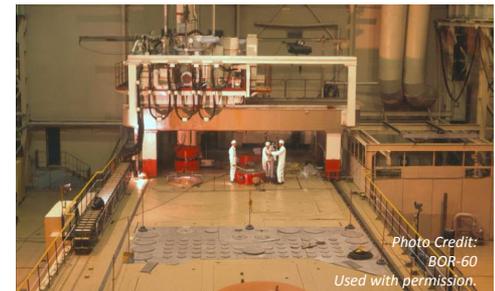


Fuel Pin Irradiation Testing in Russian BOR-60 Fast Reactor at RIAR

- BOR-60 Fuels Irradiation Program intended to provide qualification for TWR prototype and commercial fuel designs
- Three test rigs, ~60 fuel pins
- Testing will be parametric and prototypic by design
 - Benchmark fuel pin models
 - Connect with metallic fuel database
 - Demonstrate advanced fuel pin performance
- Lab-scale fuel pin factory at INL (EFF) using commercial processes
 - Construction, testing → now
 - Fuel pin fabrication begins → early 2017
- Test inserted into BOR-60 → Q4 2018



BOR-60 FAST REACTOR



TWR FUEL QUALIFICATION

Global Integration Network

Supplies product
Supplies results

