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

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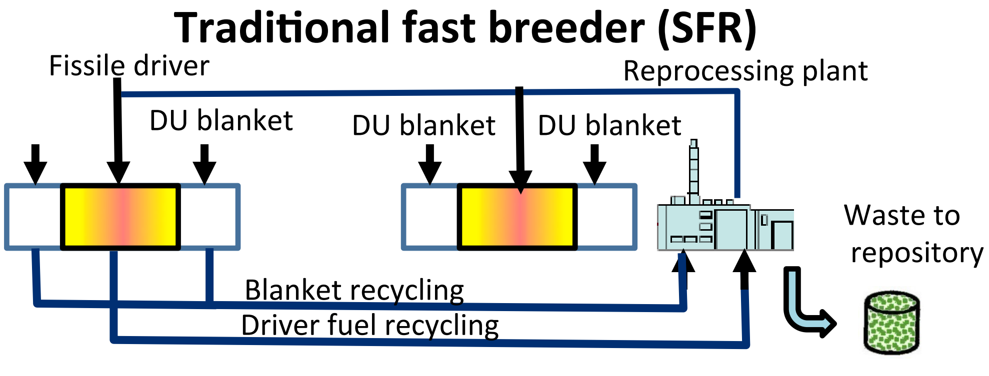
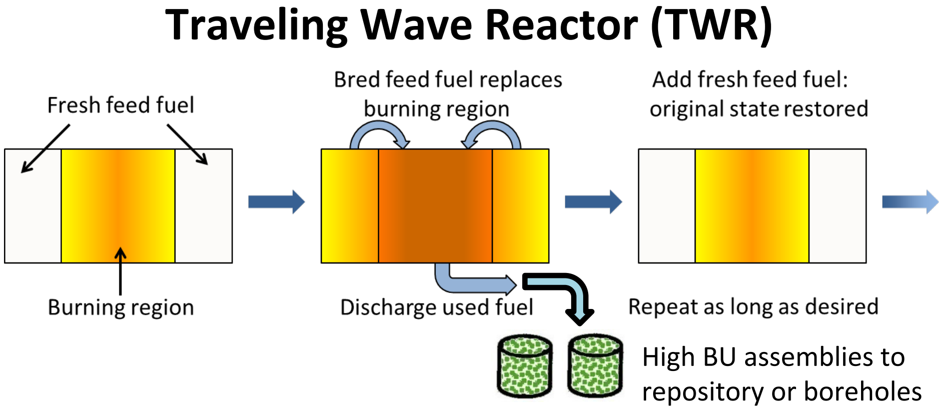
DOE-NRC Second Workshop on Advanced Non-LWR Reactors

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 (austentic, 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

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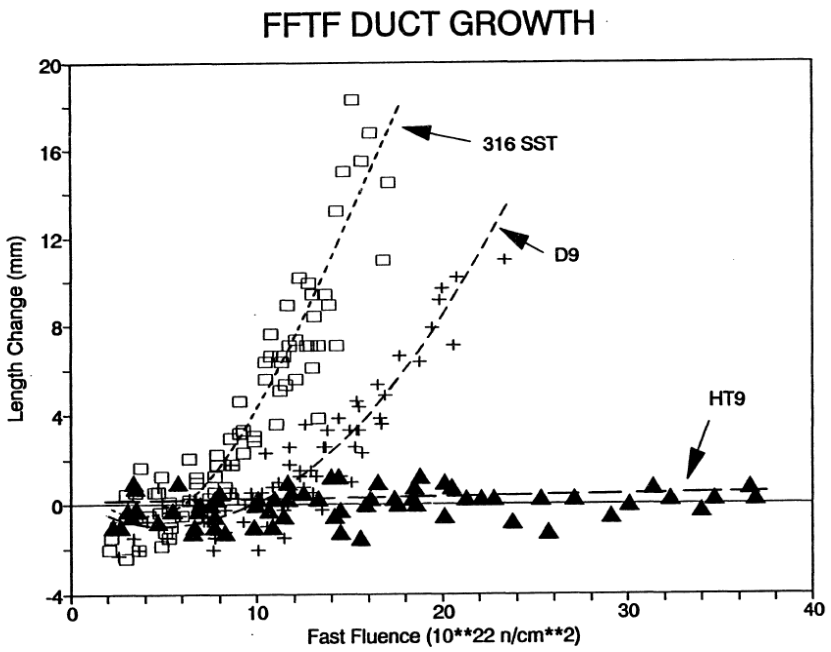
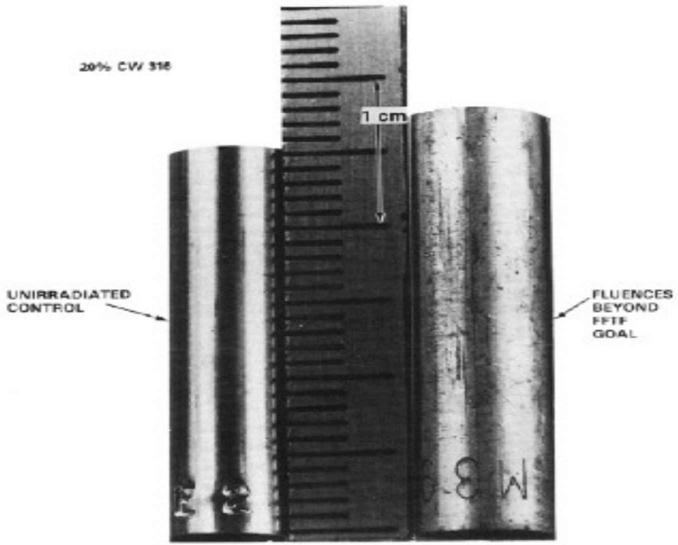
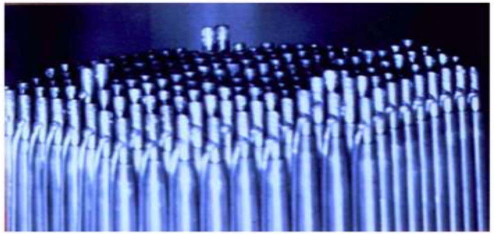
F/M Performance Advantages



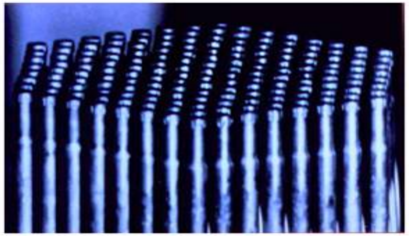
AL Pitner et al., Rpt. # WHC-SA-1967-FP, Oct. 1993



FFTF Fuel Pin Bundles



Stainless steel, swelling



HT-9, no swelling

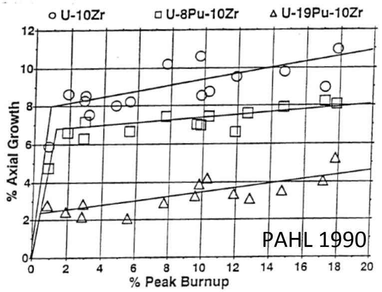
US DOE Metallic Fuel Pin Data and New PIE on FFTF Metallic Fuel Assemblies

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

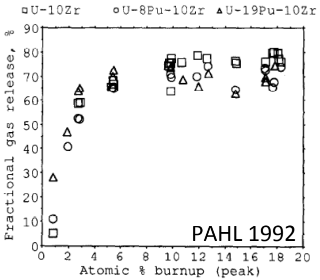
Schematic of fuel element

- 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

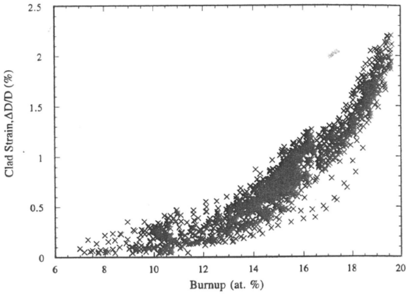
FUEL AXIAL GROWTH



GAS RELEASE

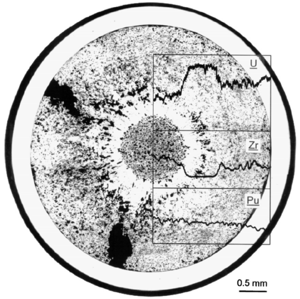


CLADDING STRAIN

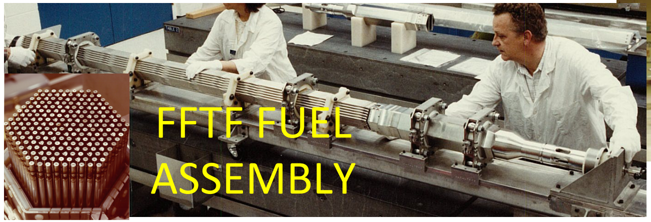


YACOUT 1996

METALLOGRAPHY



KIM 2006



HOT CELLS AT INL

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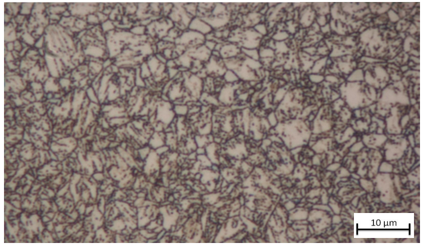
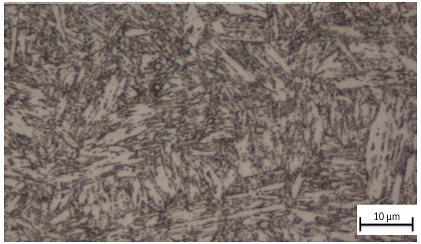
Advanced HT9 Development

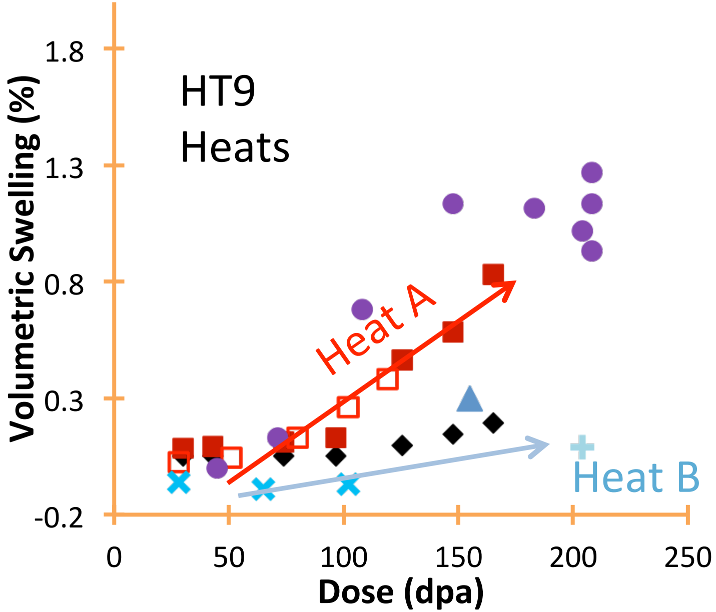
- Why did different HT9 heats result in different swelling behavior?
- Exhaustive review of archive (unirradiated) HT9 and performance data
- Identified optimal microstructure features and processing
- Commercial fabrication of advanced HT9 for irradiation testing

Poor structure (heat A)



Good structure (heat B)





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HT9 Fabrication and Processing

Double melting process

Homogenization

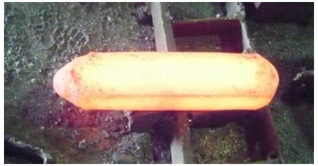
Forging

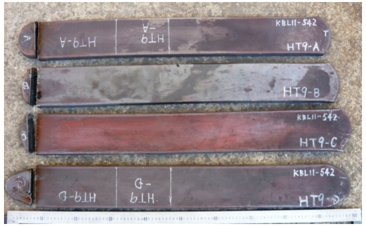
Hot rolling or extrusion

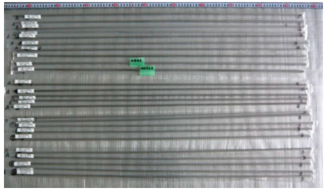
Cold rolling or drawing

Final heat treatment

KOBE STEEL







DUCT FABRICATION – VERIDIAM

Photo Credit: Veridiam Used with permission.

PIN FABRICATION – KOBE STEEL

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Commercial Fabrication of HT9

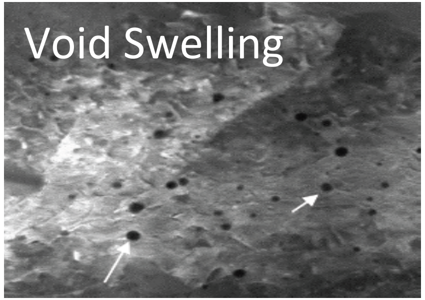
- Three orders for commercial-sized ingots
  - Kobe Steel (3 tons)
  - Carpenter Steel (5 tons each)
- Product to be used for:
  - Fabrication of fuel test pins
  - Fuel assembly mockups, thermal-hydraulic testing
  - Materials test programs

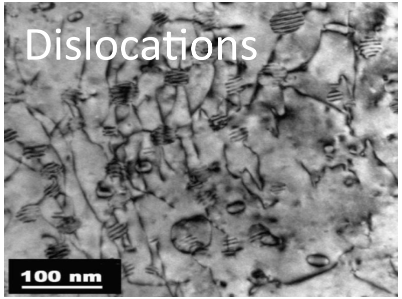
Proof of Fabrication

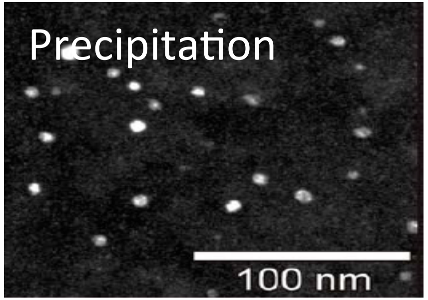
Heavy Ion Irradiation Program

- 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

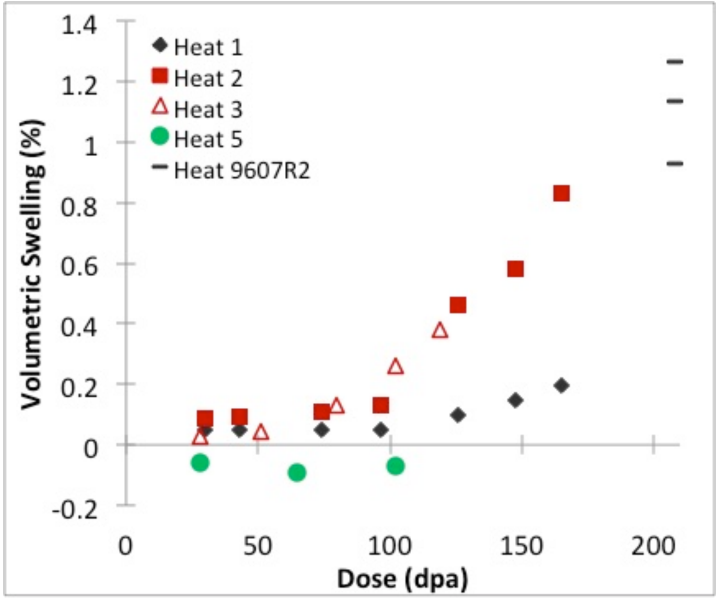
- Benchmark material : ACO-3 duct from FFTF, 155 dpa @ avg. 443°C
- Fe^{++} irradiation of archive ACO-3, 188 dpa @ 460°C
- Irradiation-induced microstructure features are similar, including dislocations, G-phase, α', voids



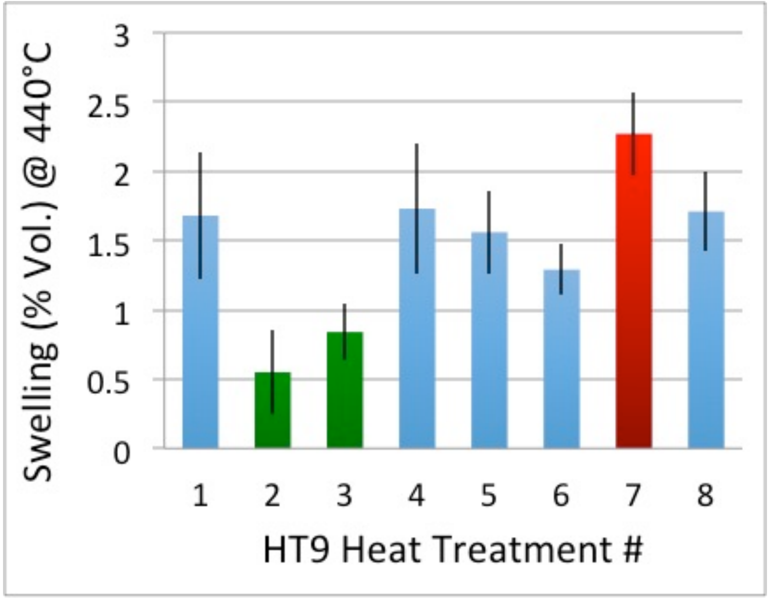




Both Neutron and Ion Irradiations Show Importance of Optimized Heat Treatment



Neutrons (previous irradiations)



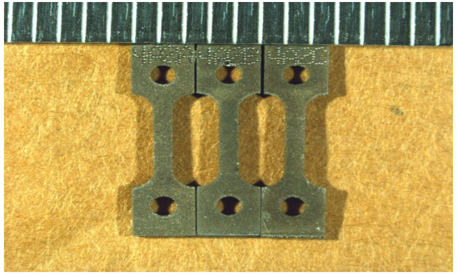
Ions

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

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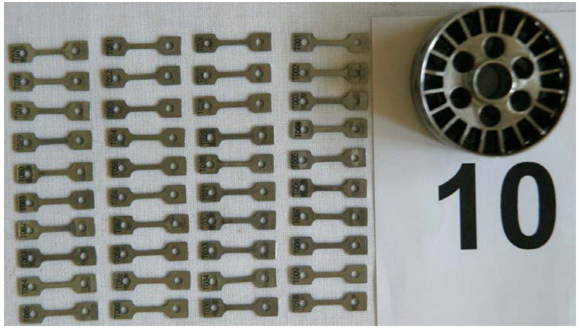
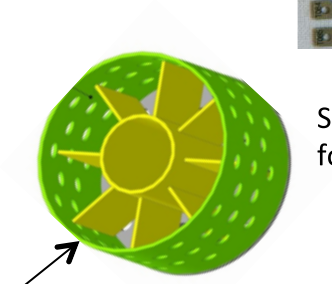
BOR-60 Materials Test, TP-3, TP-4, TP-5 (High Temperature Rigs)

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

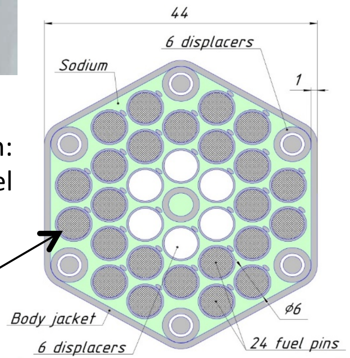
- Rigs 3,4,5 inserted in Mar & May 2014
- 450, 500, 625˚C
- New TerraPower Optimized Material (>750 specimens).
- DOE Pre-Irradiated (~100 specimens)
- Temperature maintained by pre-heater fuel.
- First irradiated samples (Rigs 1 and 2) to discharged in 2014 (10 dpa) and replacement samples inserted.

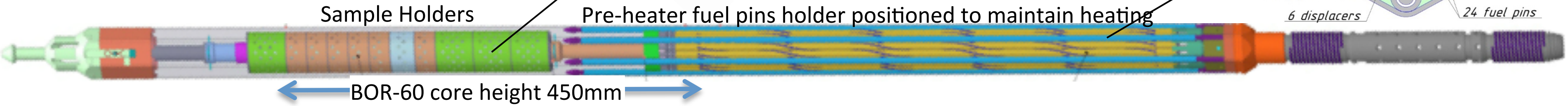




Sample Holder for TP-3, 4, 5

Cross-section: Pre-heater fuel





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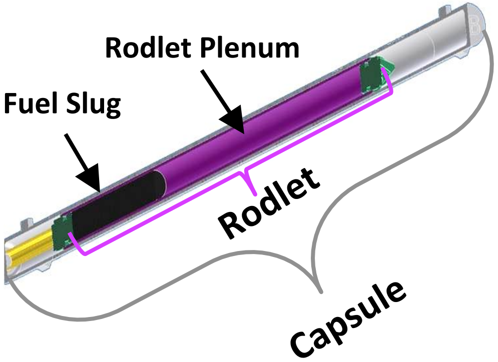
Fuel Fabrication at INL and Irradiation Testing in the ATR

- 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



ATR Specimen Insertion

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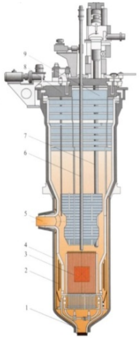
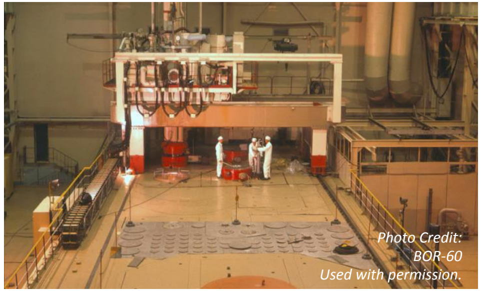
Fuel Pin Irradiation Testing in Russian BOR-60 Fast Reactor at RIAR

- 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





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TWR FUEL QUALIFICATION

Global Integration Network