



U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

**Office Of Nuclear Energy
Sensors and Instrumentation
Annual Review Meeting**

**FCRD Advanced Fuels Campaign
Heather J. MacLean Chichester, Ph.D.
Irradiation Testing & PIE Technical Lead
Idaho National Laboratory**

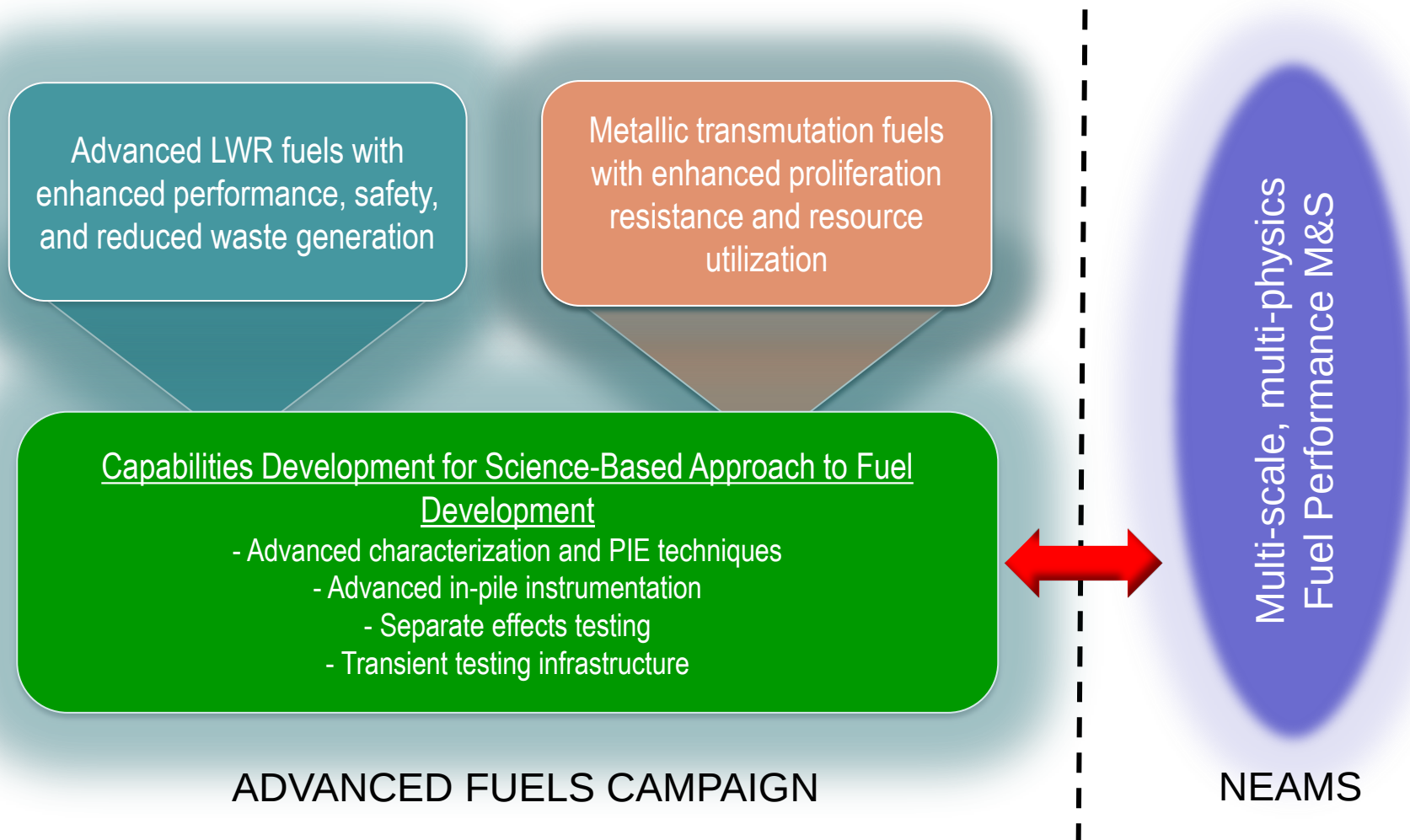
September 16-18, 2014



U.S. DEPARTMENT OF
ENERGY

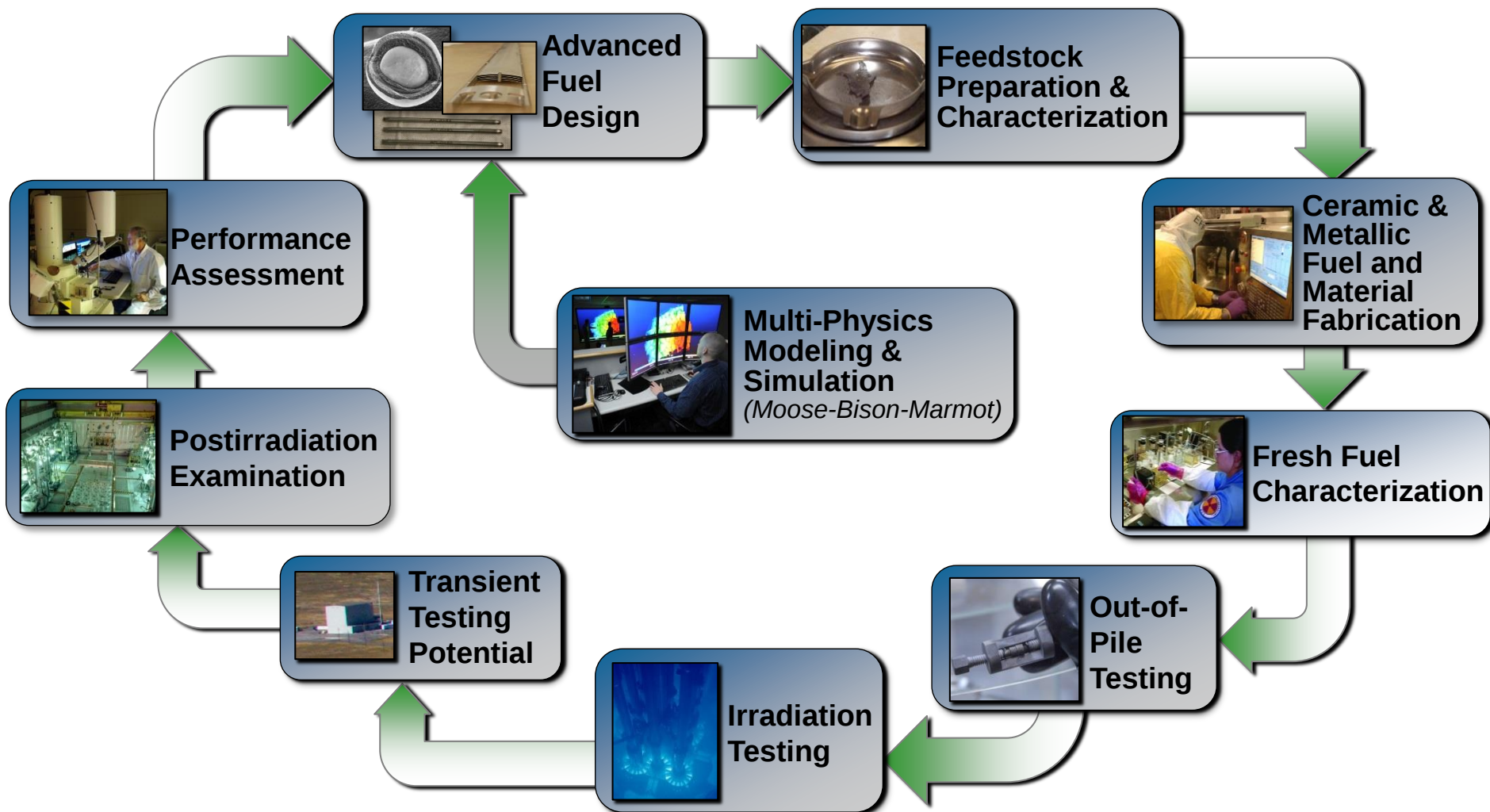
Nuclear Energy

*The FCRD Advanced Fuel Campaign is tasked with development of near term **Accident Tolerant LWR** fuel technology and performing research and development of **long term resource enhancement** options.*





Fuel Development Life Cycle





ATF-1 Irradiation Experiments in ATR

■ Experimental fuels and cladding concepts

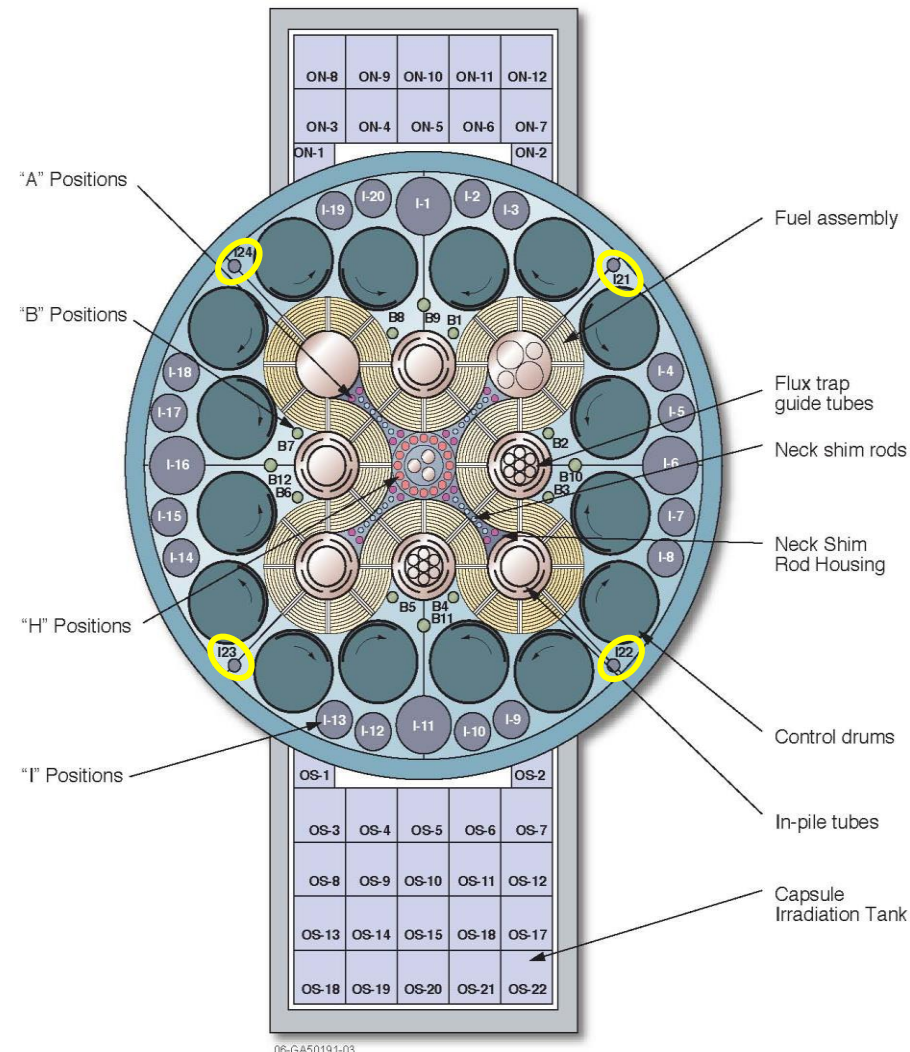
- Teams from industry, national labs, IRPs

■ Small I positions in the ATR

- 3 channels per basket
- Each channel contains vertical stack of capsules (up to 7 x 6-in. / channel)

■ Experiment safety limits

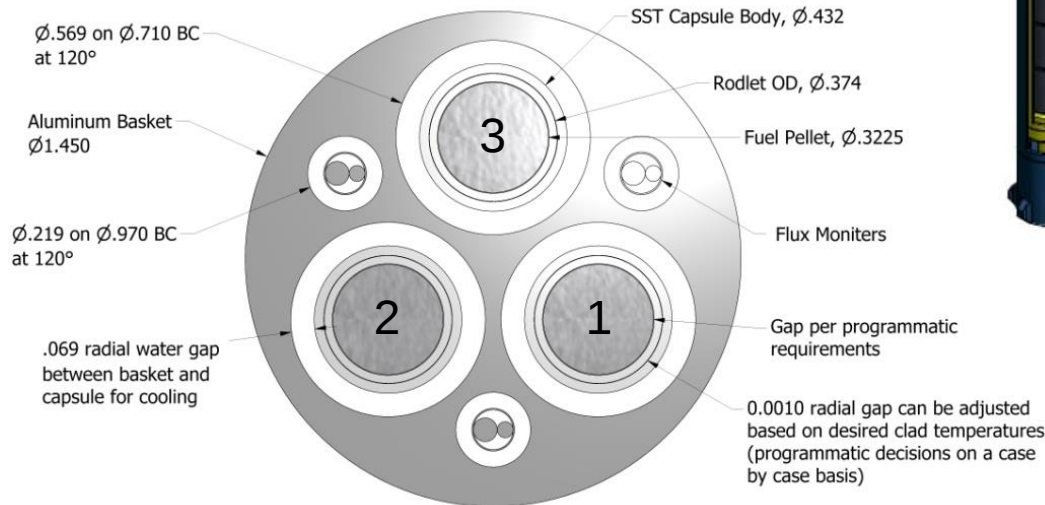
- LHGR ≤ 650 W/cm
- Capsule pressure ≤ 800 psi



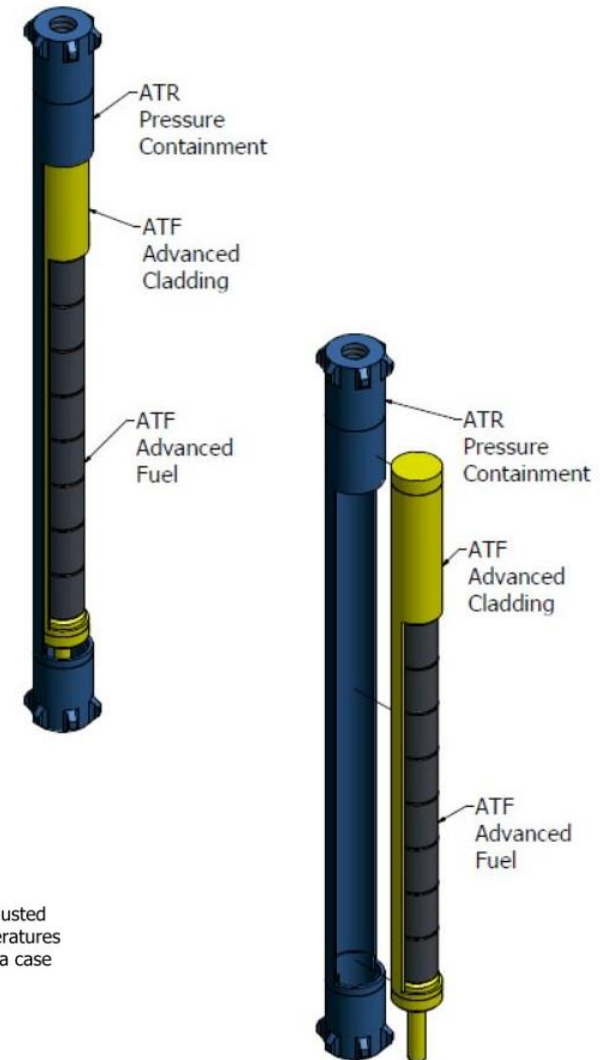


ATF-1 Design

- Double encapsulation (miniature pin in outer capsule)
- Outer capsule provides safety barrier
- Gas gap provides thermal resistance for cladding temperature
- 4 inch maximum fuel column height



All Dimensions in inches. This is an example, see program specific drawings for all dimensions.





U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

ATF-1 Basket



■ Flux wire holders

- 3 capsule channels
- 3 flux wire channels
- notch oriented toward ATR core





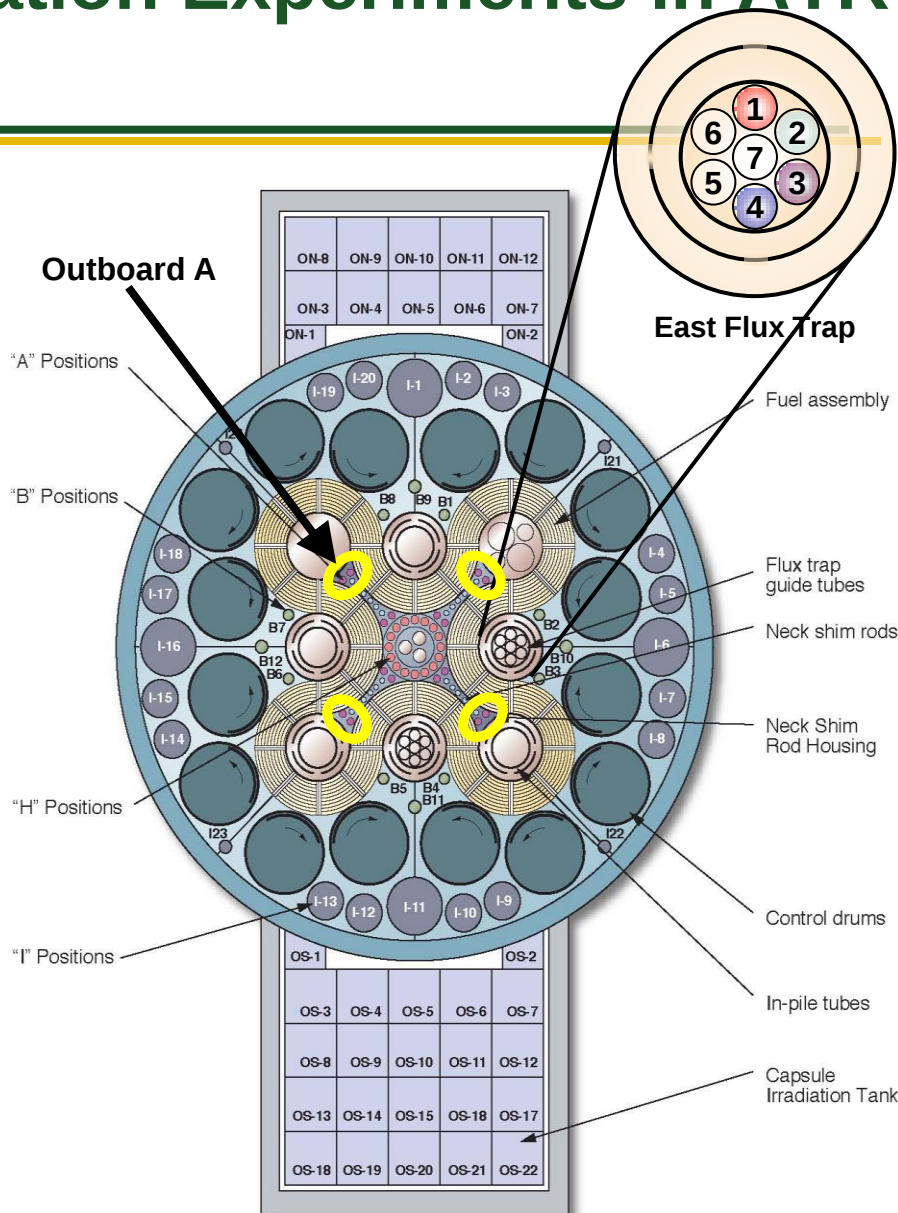
AFC Irradiation Experiments in ATR

■ Design Features

- Cd-shrouded baskets filter thermal flux
- Rodlet inside SS capsule (safety barrier)
- Gas gap provides prototypic cladding temperature
- LHGR < 500 W/cm
Target 350 W/cm
- PICT < 650°C
Target 500-550°C
- Capsule pressure < 800 psi

■ Outboard A (OA) Design

- AFC-3, 4
- Rodlets in individual capsules (axial stack of 5)





AFC-OA Design

■ Rodlet

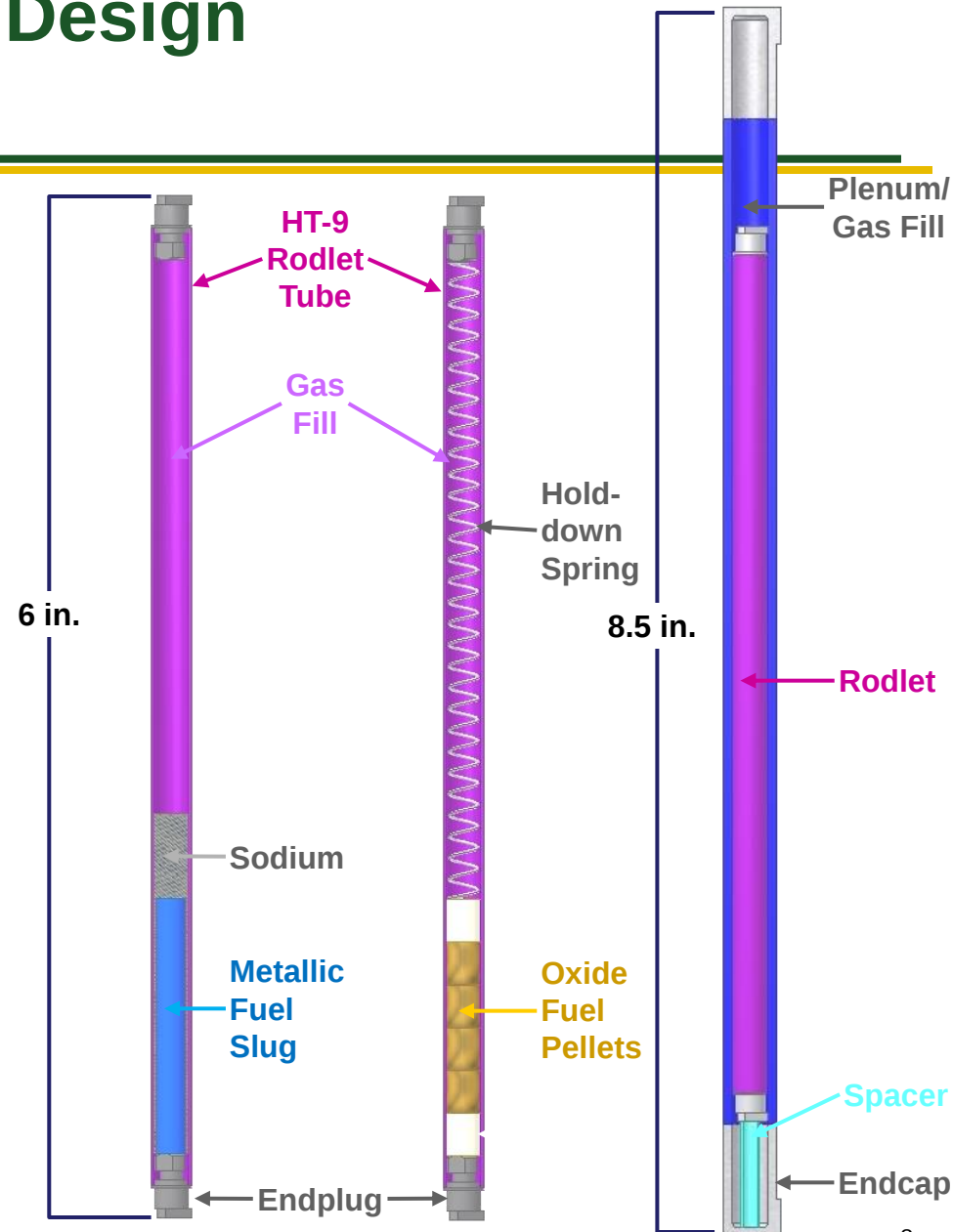
- HT-9 (SS 421) cladding
- height = 6 in. (15.2 cm)
- ID = 0.194 in. (4.93 mm)
- OD = 0.230 in. (5.84 mm)

■ Capsule

- SS 316L
- height = 8.5 in. (21.6 cm)
- ID = 0.234 in. (5.94 mm)
- OD = 0.274 in. (6.96 mm)
- 1 rodlet per capsule

■ Capsules can be inserted and removed independently

■ Redesign in progress





Fuel Performance Phenomena

■ Dimensional changes

- axial growth
- radial swelling

■ Fission gas production and release (pin pressure)

■ Fuel restructuring (zone formation)

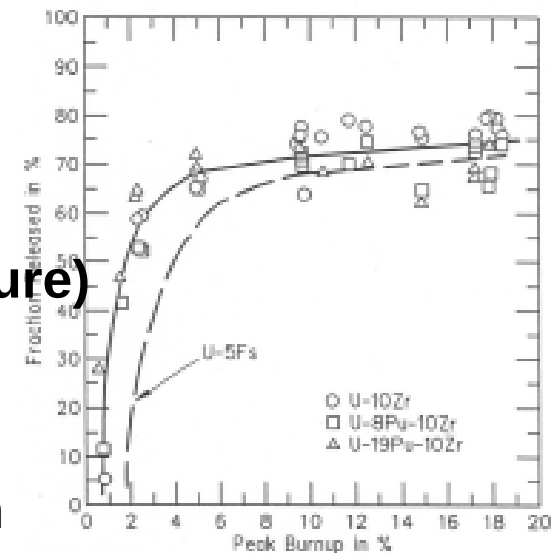
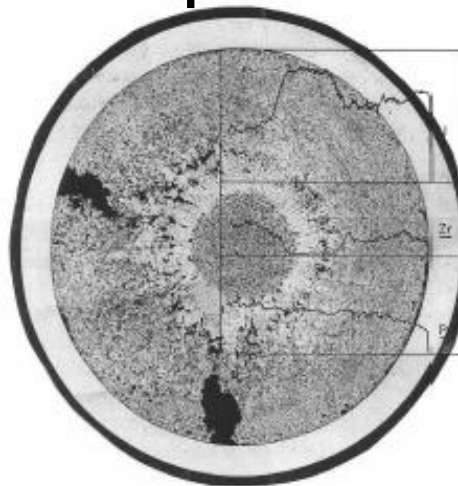
■ Constituent redistribution

■ Fuel cladding chemical/mechanical interaction

■ Performance phenomena depend on

- composition
- burnup

Transverse metallographic section from the high temperature region of a U-19Pu-10Zr element at 3 at.% burnup with superimposed microprobe scans, showing zone formation, cracking and Zr-U redistribution.



Fission gas released to plenum above fuel for various metallic fuels as a function of burnup (EBR-II irradiation)

G.L Hofman and L. C. Walters, "Metallic Fast Reactor Fuels," Materials Science and Technology Vol. 10A, 1994.



AFC Instrumentation Goals

■ Grand Challenge Fuel Development Goal

Achieve greatly increased burnup over current fast reactor fuel

■ Grand Challenge Instrumentation Goal

Measure the microstructural evolution of fuel during irradiation

■ Irradiation Experiment Measurement Goals

- Temperature: cladding, fuel
- Pressure
- Gas composition
- Dimensions: fuel, cladding
- Fuel chemistry
- Fuel microstructure
- Fuel-cladding chemical interaction



In-Situ Instrumentation Considerations

Experiment Types

■ Static Capsules

- simplest design
- most cost-effective
- accommodate wireless instruments

■ Instrumented Lead

- extensive design and handling
- accommodate wired instruments

■ Loop Experiments

- coolant environment controlled independent of ATR coolant
- accommodate wireless or wired instruments

Instrument Types

■ Wired

- only in instrumented leads and loops
- handling concerns

■ Wireless

- applicable to any experiment type

Measurement Types

■ State Point

- end of irradiation or average only
- extra data, but limited

■ Real Time

- provides more data
- detailed history of long experiments



In-Situ Instrumentation Challenges

■ Size

- experiments are about the size of a pen

■ Stability

- instruments must survive irradiation environments

■ Accessing data

- real-time, on-line data provides needed performance information

■ Complexity of experiment

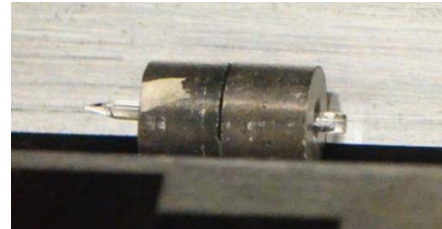
- majority of irradiation experiments will continue to use relatively simple hardware



Current Instrumentation

■ Melt Wires

- ATF-1
- inserted inside dU insulator pellets



■ Flux Monitors

- ATF-1 basket



■ SiC Temperature Monitors

- planned use in future ATF-1 experiments





Wireless Sensing via Sound and Thermoacoustics

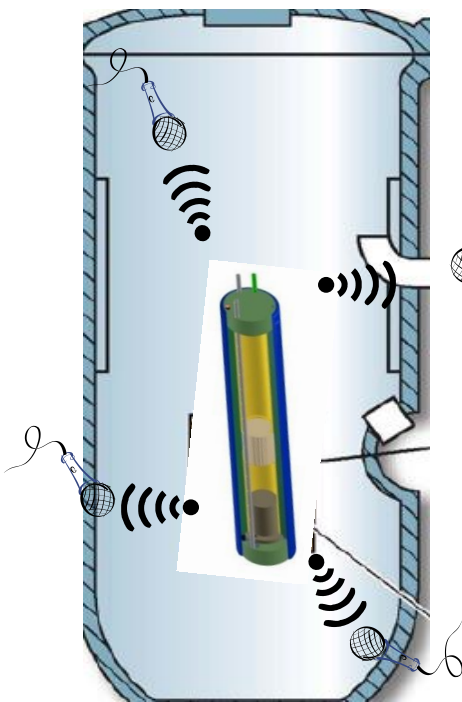
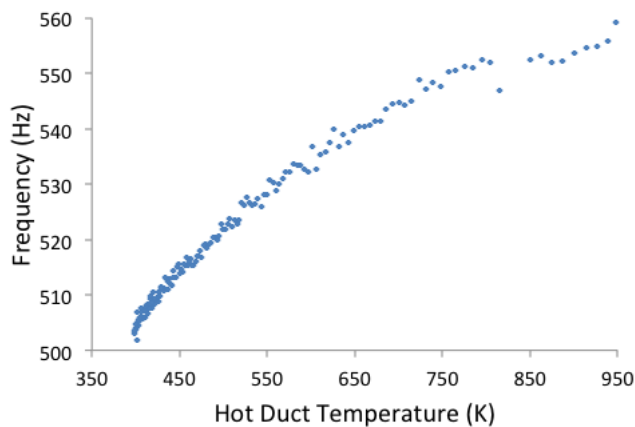
Fission Gas

Gas	Molecular Mass (a.m.u.)	Polytropic Coefficient ($\gamma = c_p/c_v$)	Ave. Freq. (Hz)	Freq. Ratio f/f_{He}	Sq. Root (Mass/ γ) Ratio
Helium	4.00	1.667	976.2	1.000	1.000
Nitrogen	28.01	1.400	315.7	0.323	0.346
(Dry) Air*	28.96	1.403	322.7	0.331	0.341
Xenon	131.29	1.667	173.0	0.177	0.175

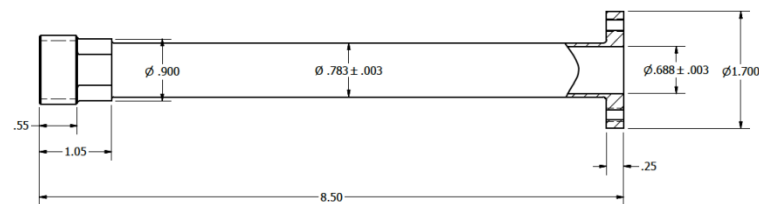
Microstructure



High Temperature



Set-1 Capsule Resonator





■ Thermoacoustic

- Wireless
 - Acoustic telemetry
 - Self-powered
- Demonstration in Breazeale Nuclear Reactor
 - Collaboration established between: INL, Penn State, Westinghouse
 - Scheduled Summer 2015
- Data acquisition and processing

■ Instrumenting ATR

- Acoustic telemetry infrastructure ready for ATR facility installation
- Current installation scheduled: September-October 2014

■ Revaluating RF sensing and other technologies

- RFID Tags
- Polymer derived ceramics



Instrumentation Activities

■ On-going

- Installing acoustic/vibrational measurement system in ATR
- Collaborating with Penn State to develop TAC sensor design for reactor testing: ATR or Penn State
- Developing a collaboration with Westinghouse

■ Planned

- Develop wireless sensors
 - Acoustic
 - RF or microwave
 - other
- Develop/use thermal sensor
 - Melt wires
 - Remote reading
 - Novel approaches
- Support TAC reactor demonstration
- Analyze ATR acoustic baseline data
- Develop TAC thermal conductivity and diffusivity measurement techniques



Accomplishments

■ Milestones

- M3: Conceptual description of promising in-pile measurement techniques, 9/30/2014
- M2: Complete report on in-pile measurement techniques, 2/1/2015
- M3: Provide thermal sensing design support and scoping report to support upcoming AFC fuel irradiations, 2/12/2015

■ *Description of milestones, deliverables, outcomes for FY14*



Technology Impact

- Provides data on fuel performance during irradiation
- Improves understanding of experiment conditions and fuel behavior during irradiation
- Improves interpretation of postirradiation examination results
- Increases the value of irradiation experiments



Conclusion

-
- **AFC is currently using flux wires and melt wires**
 - **AFC is investigating wireless instrumentation for fuel irradiation experiments**
 - increased data available for each experiment
 - improved experiment understanding and interpretation
 - **TAC demonstration planned for summer 2015**
 - **TAC infrastructure installation at ATR planned for fall 2014**