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Office Of Nuclear Energy
Sensors and Instrumentation
Annual Review Meeting

FCRD Advanced Fuels Campaign
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Idaho National Laboratory

September 16-18, 2014

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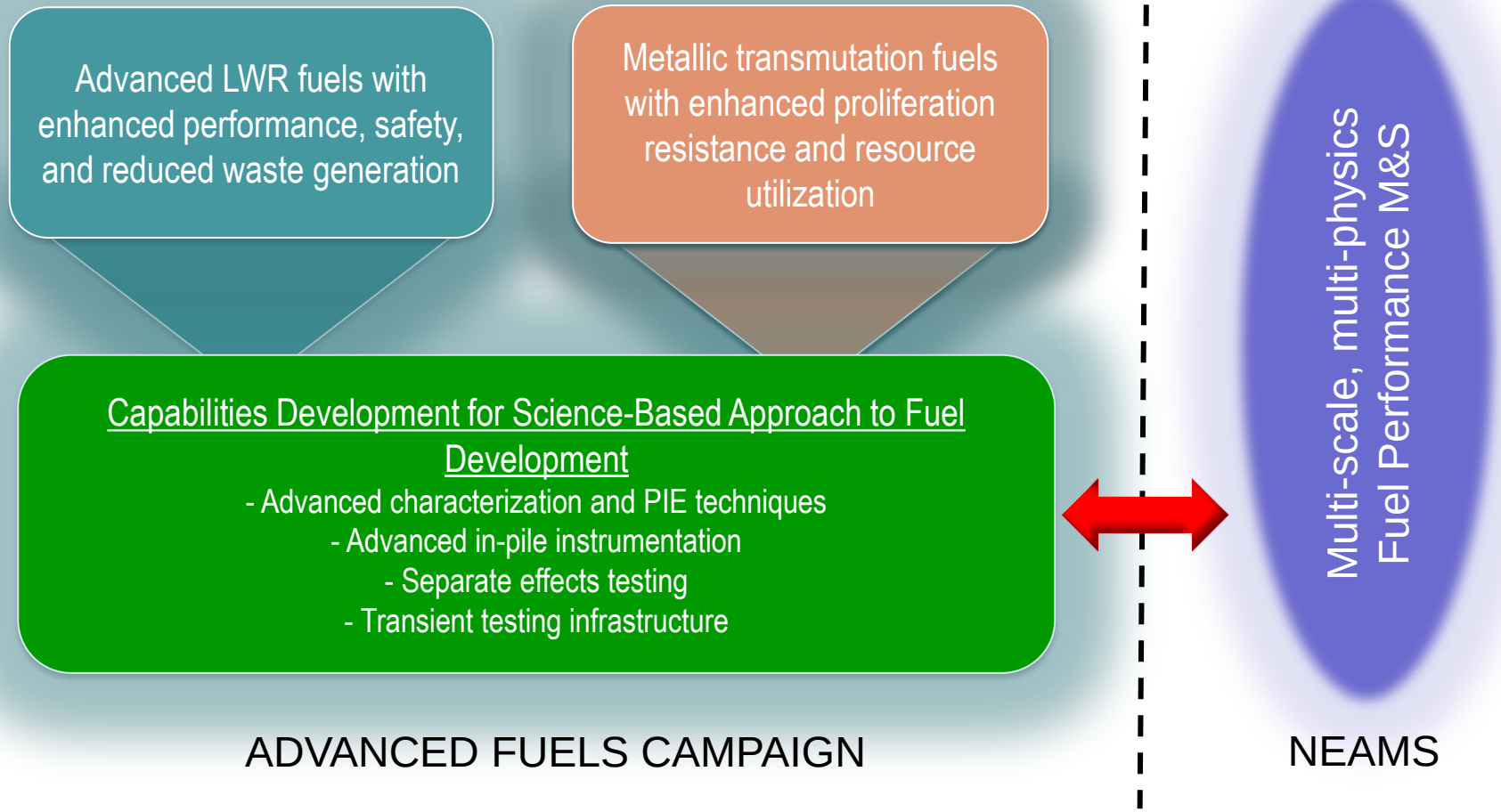
The FCRD Advanced Fuel Campaign is tasked with development of near term Accident Tolerant LWR fuel technology and performing research and development of long term resource enhancement options.



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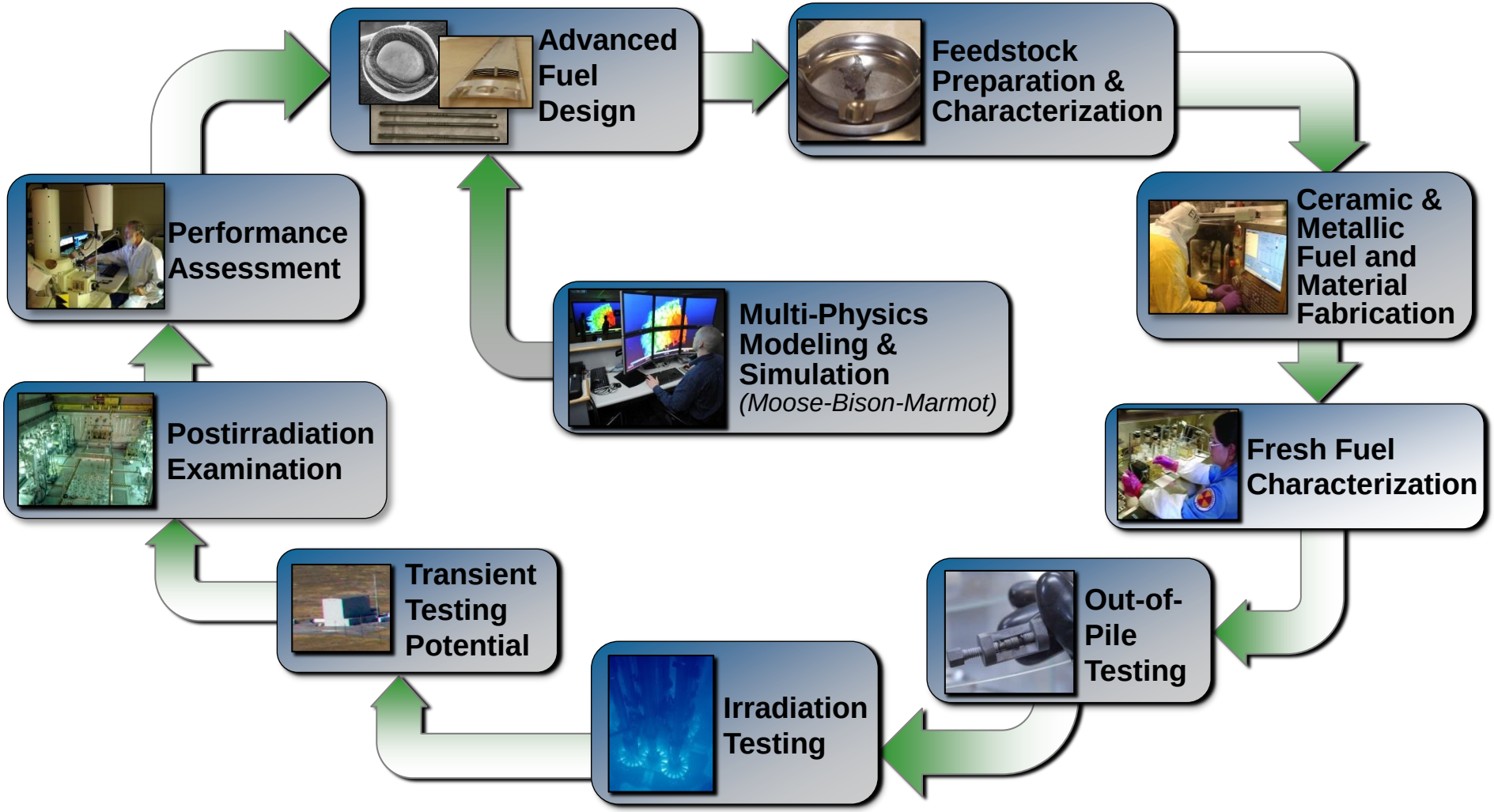
Fuel Development Life Cycle



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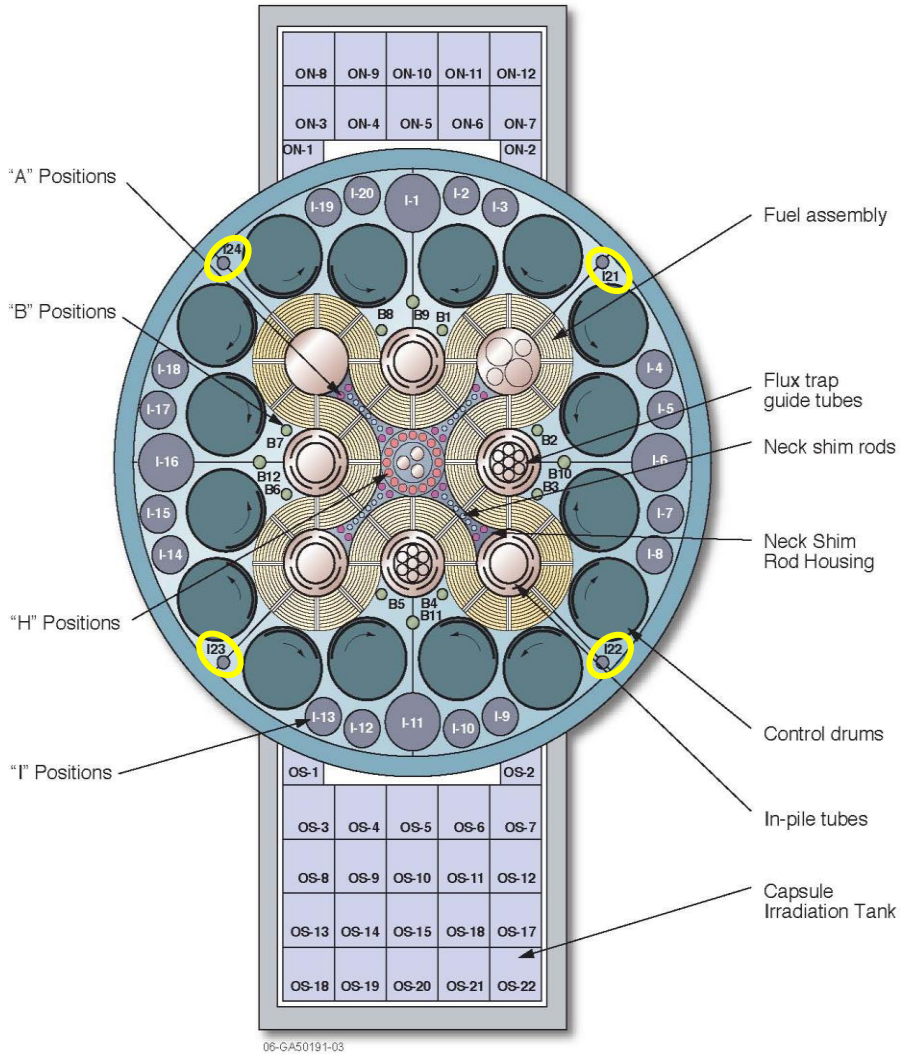
ATF-1 Irradiation Experiments in ATR

- **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



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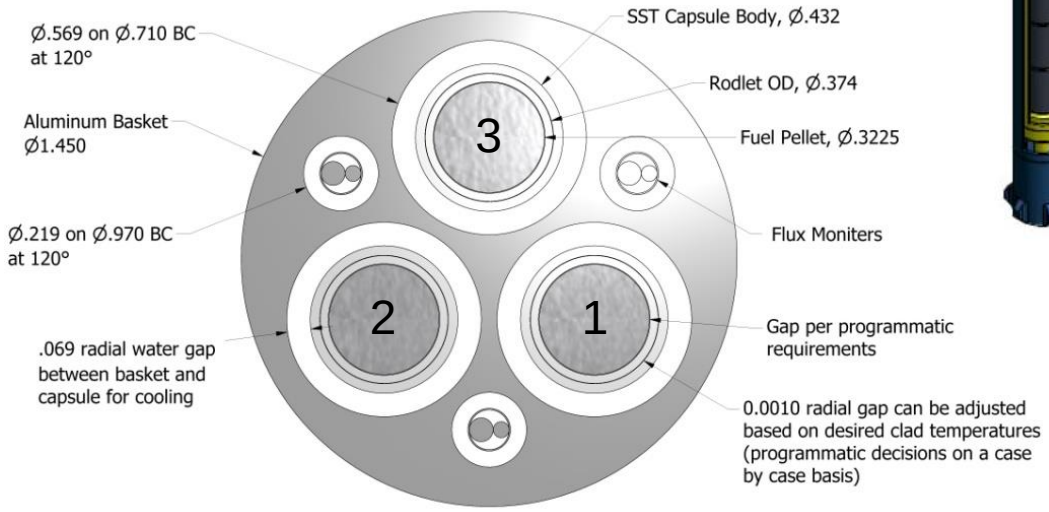
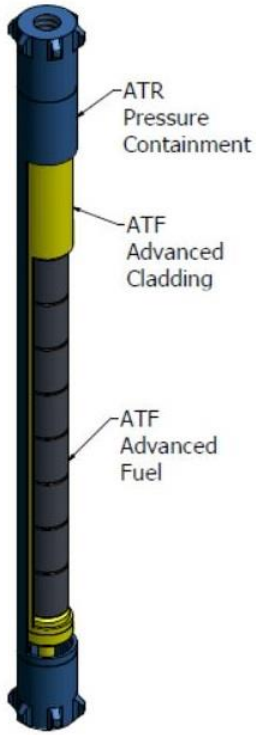
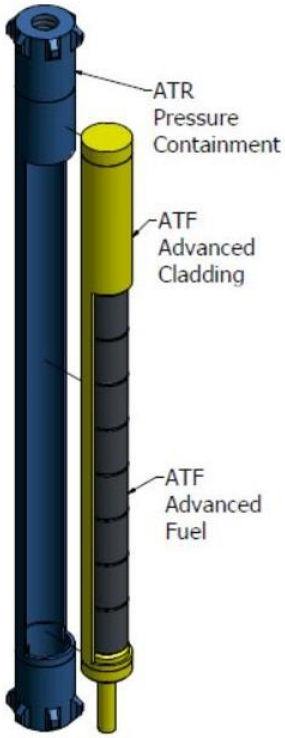
ATF-1 Design

- **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.





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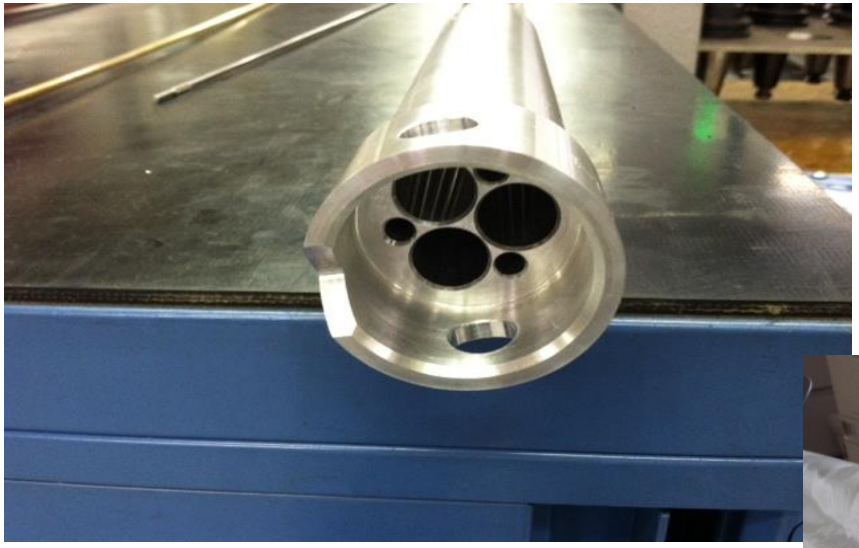
ATF-1 Basket



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

- Flux wire holders

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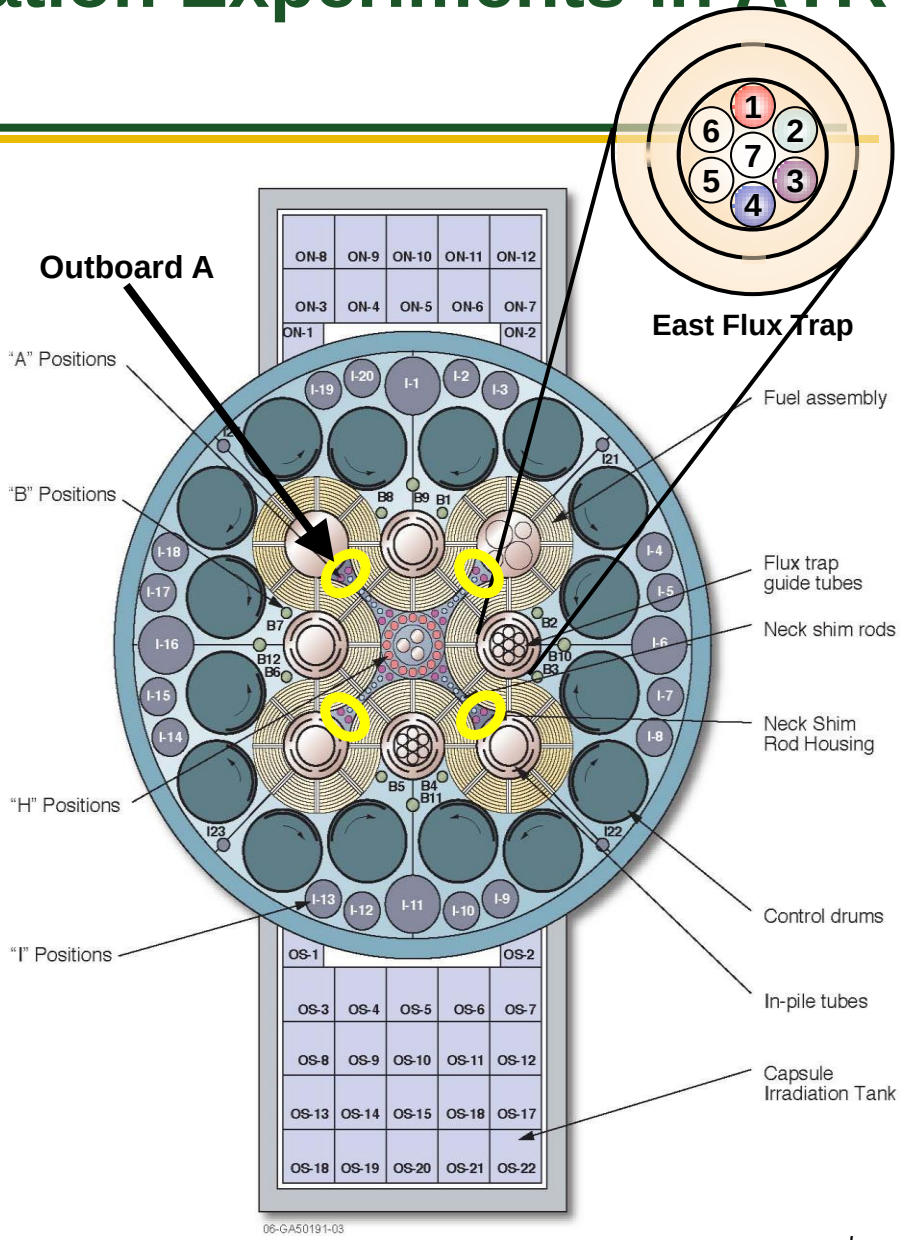
AFC Irradiation Experiments in ATR

- **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)



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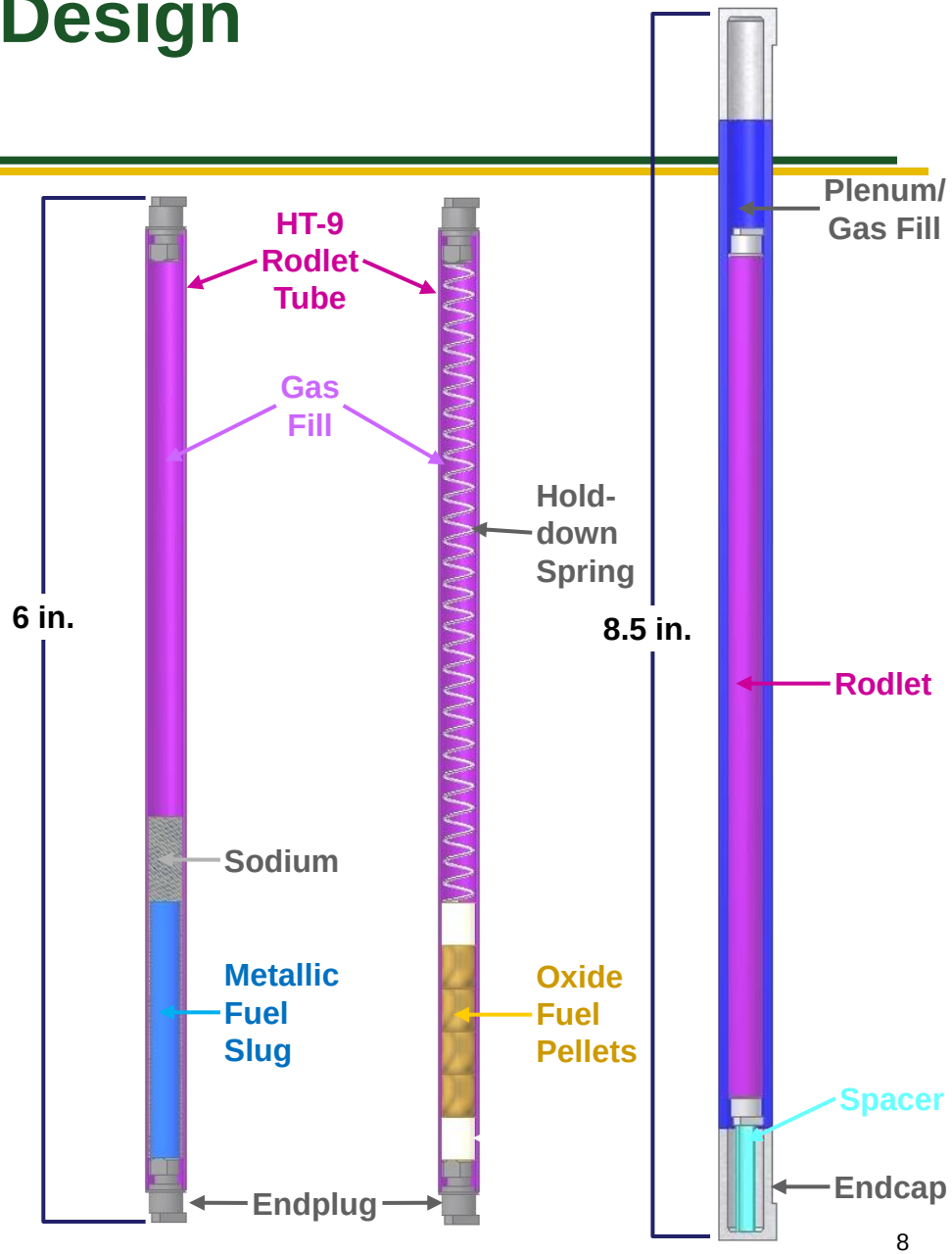
AFC-OA Design

- **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**



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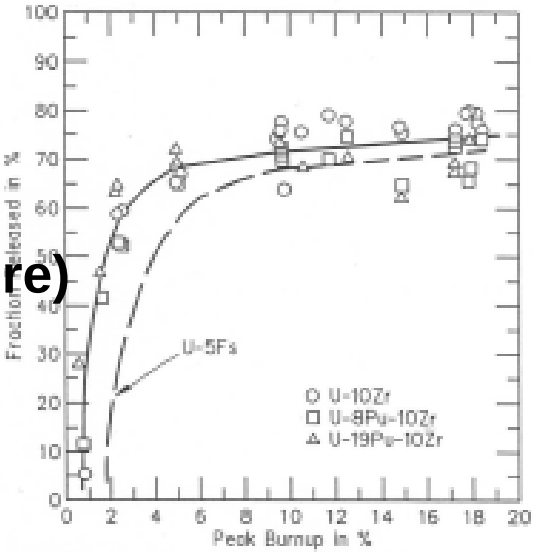
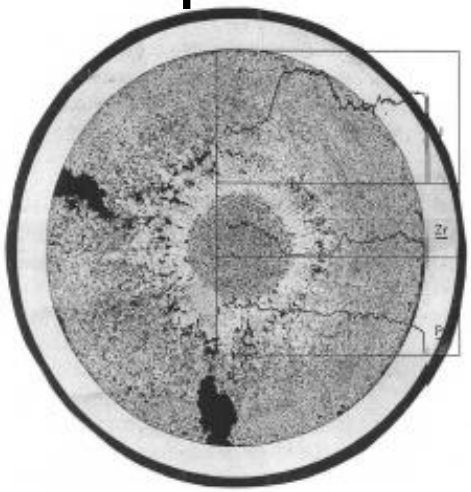
Fuel Performance Phenomena

- **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



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



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.

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

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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

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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

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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

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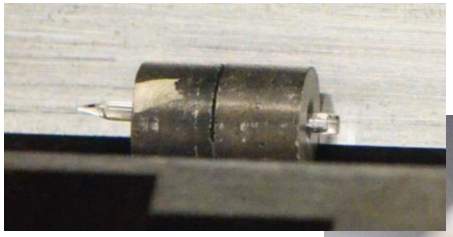
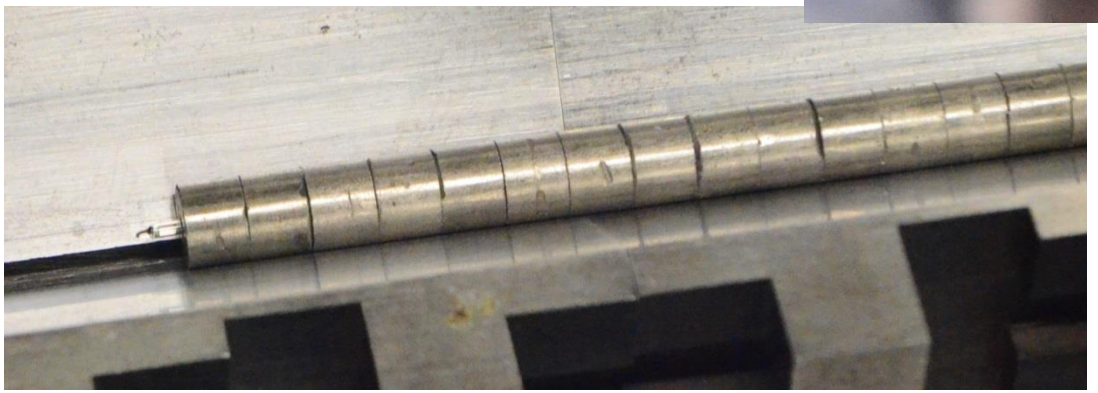
Current Instrumentation

- **Melt Wires**
  - ATF-1
  - inserted inside dU insulator pellets
- **Flux Monitors**
  - ATF-1 basket
- **SiC Temperature Monitors**
  - planned use in future ATF-1 experiments





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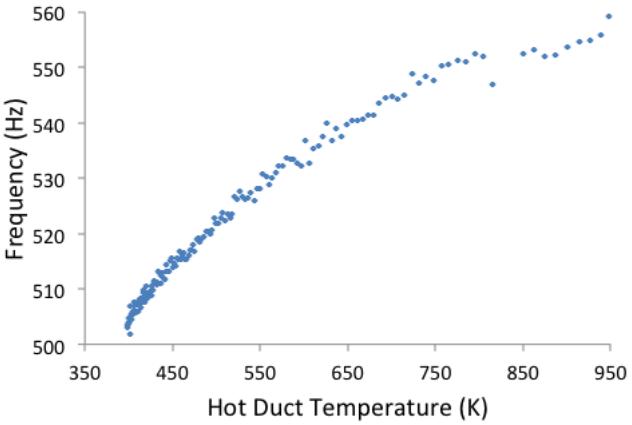
Wireless Sensing via Sound and Thermoacoustics

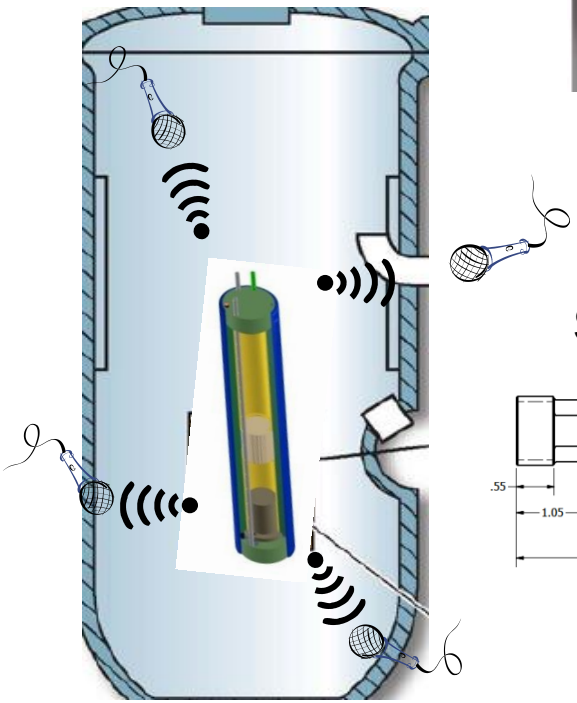
Fission Gas

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

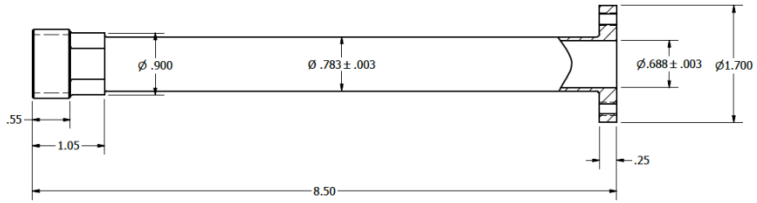
Microstructure

High Temperature





Set-1 Capsule Resonator



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Activities

- **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

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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

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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***

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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

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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**