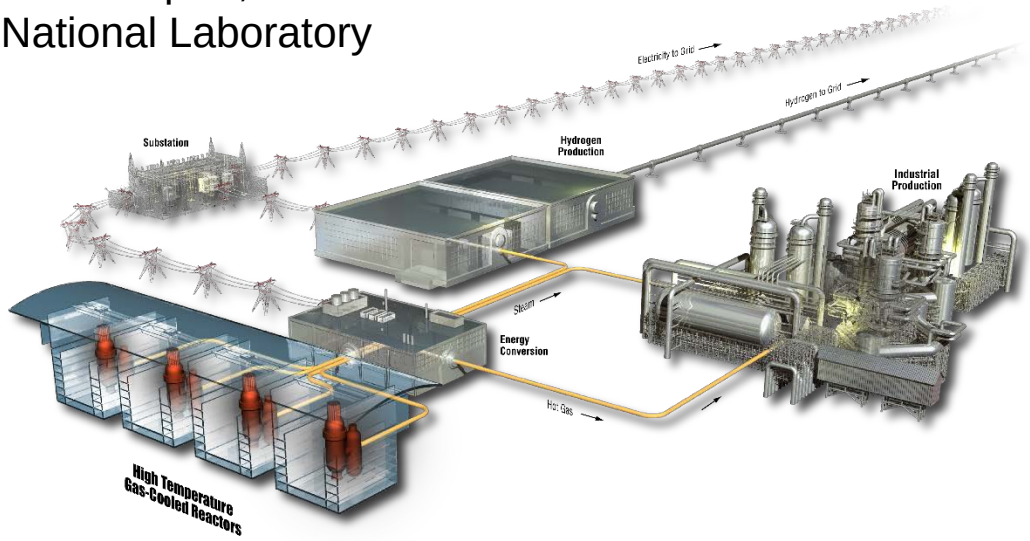
The Advanced Gas Reactor TRISO Fuel Irradiation Experiments

ART Program Review Meeting
Idaho Falls, Idaho

Michael Davenport, ART Irradiation Technical Lead
Idaho National Laboratory



www.inl.gov

Idaho National Laboratory

Objectives for the Irradiation of AGR-5/6/7

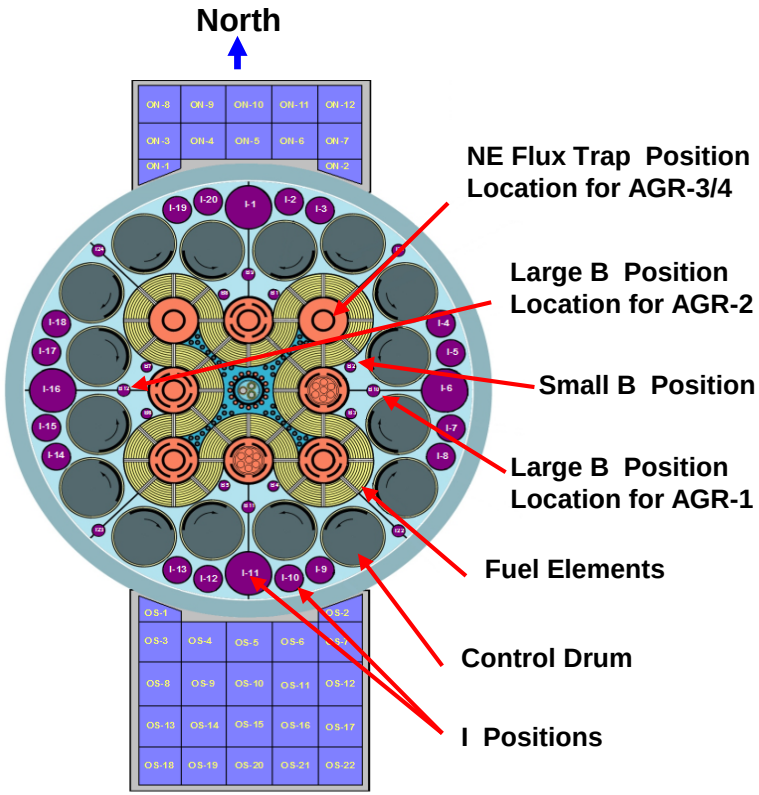
- Irradiate reference design fuel containing low-enriched UCO TRISO fuel particles to support qualification (AGR-5/6)
  - demonstrate compliance with statistical performance requirements under normal operating and potential accident conditions
- Establish the operating margins for the fuel beyond normal operating conditions (AGR-7) to support plant design and licensing
- Provide irradiated fuel performance data and irradiated fuel samples for PIE and safety testing
- Support the refinement of fuel performance and fission product transport models with on-line, PIE and safety test data
- In-pile gas release, PIE, and safety testing data on fission gas and metal release from kernels will be used in the development of improved fission product transport models.

History of AGR Irradiations in ATR

AGR-1: Irradiated December 2006 through November 2009	PIE* complete
AGR-2: Irradiated June 2010 through October 2013	PIE underway
AGR-3/4: Irradiated December 2011 through April 2014	PIE underway

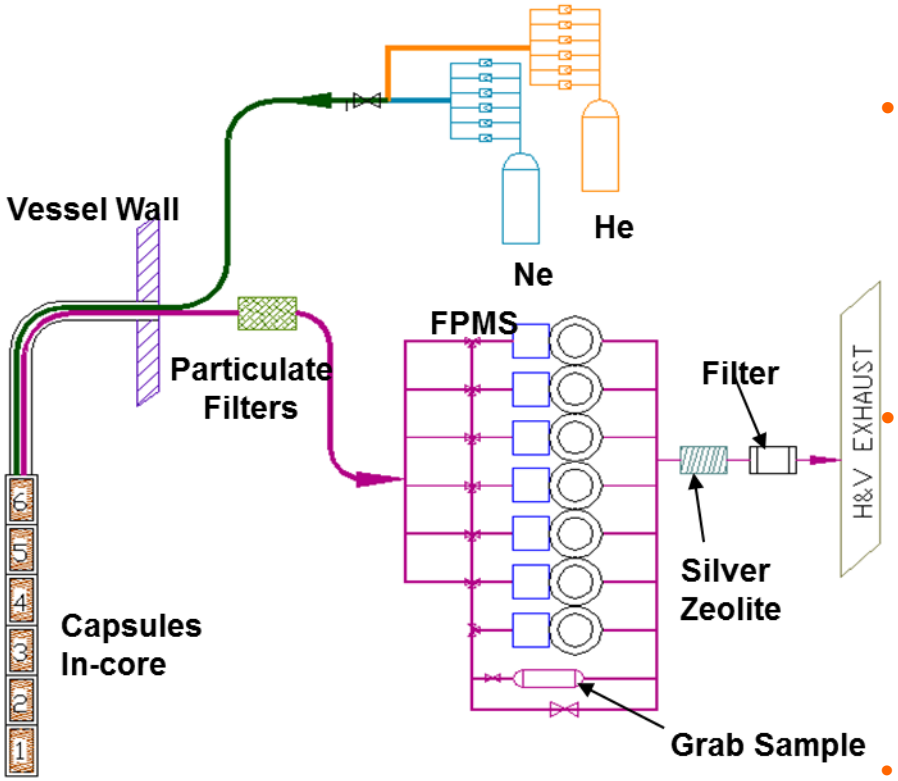
*Post Irradiation Examination

ATR Irradiation Positions



- AGR-1 and AGR-2 in large B position
  - Ø 38 mm (1.5 in.) x 1.2 m (4 ft)
  - AGR-2 in B-12 (AGR-1 in B-10)
  - Neutron flux spectrum similar to NGNP
  - Modest fuel burnup acceleration (1.5)
  - Use center vertical 0.9 m of ATR core
- AGR-3/4 and AGR-5/6/7 in NE flux trap
  - Ø 133 mm (5.25 in.) x 1.2 m (4 ft)
  - Reduce irradiation time (acceleration = 3)
  - Max. room for fission product migration
  - Min. flux gradient across experiment
  - Corner lobe allows power level control
  - Double-up experiments
    - Use full height of ATR core
  - Neutron flux spectrum modification
    - Neutron filters
    - Burnup (thermal) vs. Fluence (fast)

Temperature Control and Fission Product Monitoring Systems

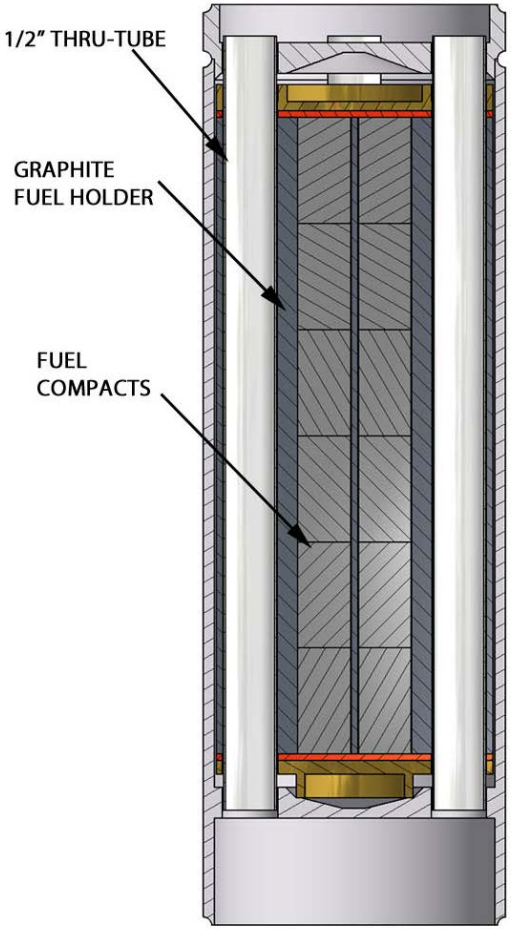


AGR Experiment Flow Path

- Individual capsule temperature control and fission product monitoring
- Temperature control system
  - Insulating gas gap in capsule
  - Helium (conductor) and neon (insulator)
  - Mass flow controllers
  - Multiple capsule thermocouples
- Fission product monitors
  - Gross gamma NaI crystal scintillation detector
  - Liquid nitrogen (LN) cooled HPGe spectrometer
  - On-line back-up spare monitor(s)
  - Grab sample capability
- AGR-3/4 gas impurities anticipated in VHTR reactor
  - 50 ppmv CO
  - 50 ppmv H2
  - 10 ppmv H2O

AGR-5/6/7Design Philosophy (Guiding Principles)

- Reuse AGR-3/4 design concepts as much as possible
- Use a few large thru-tubes rather than many small ones
  - Simplifies assembly and sealing at the slip fit
  - May allow for factory potting of thermocouples (TCs) which may reduce failures
- In the trade-off between a large number of smaller TCs vs fewer but bigger TCs, lean toward the large number
- Minimize temperatures in thru-tubes to increase TC lifetimes (try to keep <900°C)



AGR-5/6/7 Representative Capsule

Comparison of AGR Fuel

Experiment	Fuel Type	Particle Size	Enrichment	Particles/ Compact	Compact Size	Compacts/ Capsule	Capsules
AGR-1	UCO	350 µm diameter fuel kernels 780 µm diameter particles	19.8%	4,150	12.4mm x 25.4mm	12	6
AGR-2	UCO	425 µm diameter fuel kernels 850 µm diameter particles	14%	3,176	12.4mm x 25.4mm	12	3
AGR-2	UO2	510 µm diameter fuel kernels 940 µm diameter particles	9.6%	1,543	12.4mm x 25.4mm	12	3
AGR-3/4	UCO (Driver)	350 µm diameter fuel kernels 820 µm diameter particles	19.7%	1,898	12.4mm x 12.5mm	4	12
AGR-3/4	UCO (DTF)	350 µm diameter fuel kernels 400 µm diameter particles (20-25 µm PyC coating)	19.7%	20	N/A	N/A	N/A
AGR-5/6/7	UCO	425 µm diameter fuel kernels 870 µm diameter particles	15.5%	2275 (25% PF) 3442 (40% PF)	12.4mm x 25.4mm	Cap 1 = 90 Cap 2 = 32 Cap 3-5 =24	5

AGR-5/6/7 Irradiation Test Specifications

Parameter	AGR-5/6 Specification	AGR-7 Specification
Instantaneous peak temperature for each capsule (°C)	≤1800	≤1800
Time average temperature distribution goals (°C)	≥600 and <900 for about 30% of fuel ≥900 and <1050 for about 30% of fuel ≥1050 and <1250 for about 30% of fuel ≥1250 and <1350 for about 10% of fuel	Not specified
Time average, peak temperature goal (°C) (for one element)	1350 ± 50	1500 ± 50
Time average, minimum temperature goal (°C)	≤700	Not specified
Minimum compact average burnup (% FIMA)	>6 for all compacts	>6 for all compacts
Maximum fuel compact average burnup (% FIMA)	>18 for at least one compact	>18 for at least one compact
Maximum fuel compact fast neutron fluence (n/m^2, E > 0.18 MeV)	≥ 5.0×10^{25} for at least one compact and ≤ 7.5×10^{25} for all compacts	≥ 5.0×10^{25} for at least one compact and ≤ 7.5×10^{25} for all compacts
Minimum fuel compact fast neutron fluence (n/m^2, E > 0.18 MeV)	> 1.5×10^{25}	> 1.5×10^{25}
Instantaneous peak power per particle (mW/particle)	≤400	≤400

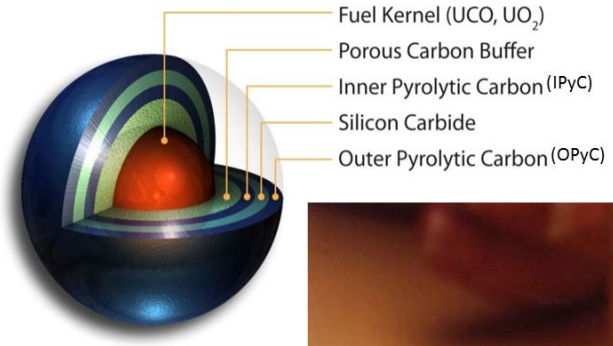
AGR-5/6/7 Temperature Distribution Objectives

AGR-5/6	
Desired fraction of particles per temperature range	Number of Particles Based on 500,000 total
30% <900°C	150,000
30% 900°C - 1050°C	150,000
30% 1050°C - 1250°C	150,000
10% 1250°C - 1350°C	50,000
Total	500,000

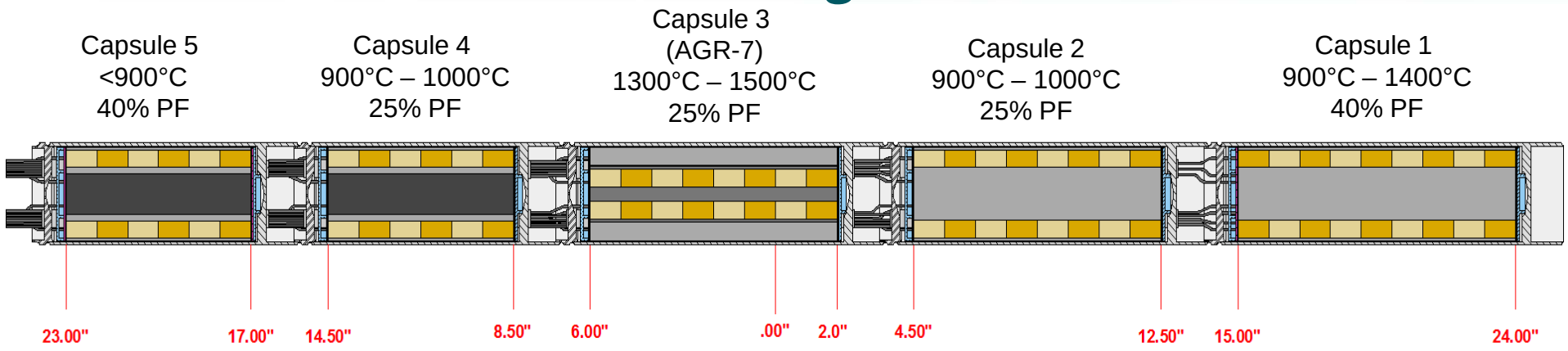
AGR-7	
Temperature Range	Minimum Number of Particles
1350°C - 1500°C	50,000

AGR-5/6/7 Fuel Details

- TRISO-coated, Uranium oxycarbide (UCO)
- Fuel particles
  - LEU 15.5% enrichment
  - 425 µm diameter fuel kernels
  - 870 µm diameter particles
- Fuel compact details
  - 194 compacts
  - 5 capsules
  - 35.7g U-235
  - 230.3g total uranium content
  - 25 and 40% packing fractions

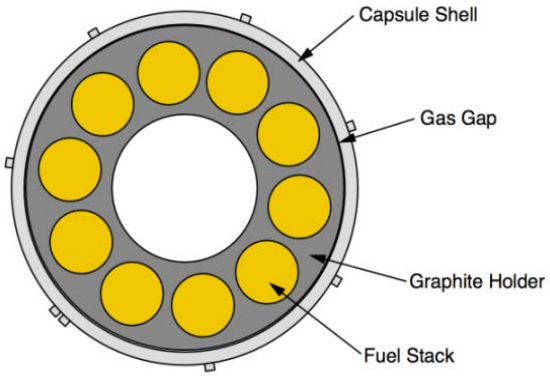


AGR-5/6/7 Test Train Design

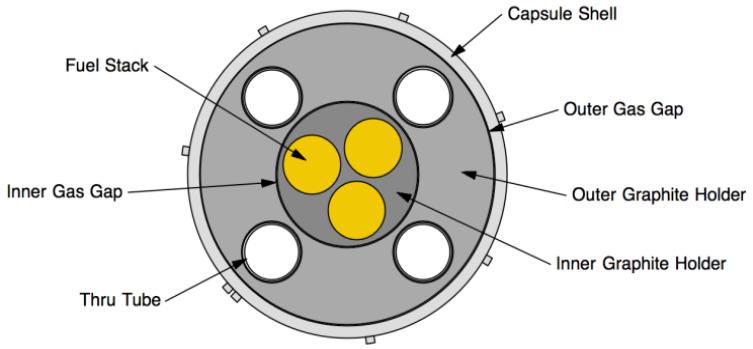


- The test train covers the center 47 inches of the core. Capsules 5 and 4 have 6 inch fuel stacks; Capsules 3 and 2 have 8 inch fuel stacks; and Capsule 1 (the bottom capsule) has 9 inch fuel stacks.
- The plenum regions between capsules have been extended compared to AGR-3/4 to accommodate bending of larger and stiffer thermocouples
- The design provides for 170 compacts (514,000 particles) in AGR-5/6 and 24 compacts (51,800 particles) in AGR-7. (There are about 3450 particles per compact in Capsules 1 and 5, and 2275 particles per compact in the other capsules.) Packing fraction values based on ATR flux profile across the core.

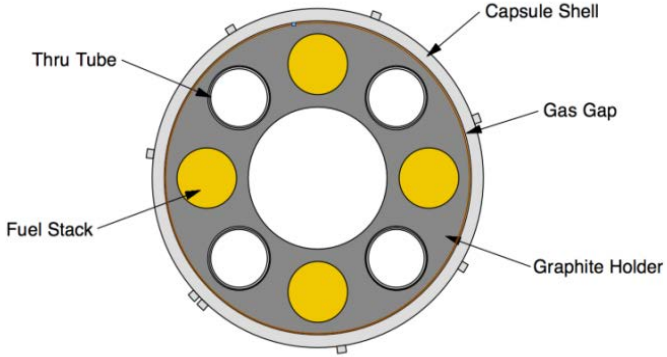
AGR-5/6/7 Capsule Cross-Sections



Capsule 1
cross-section

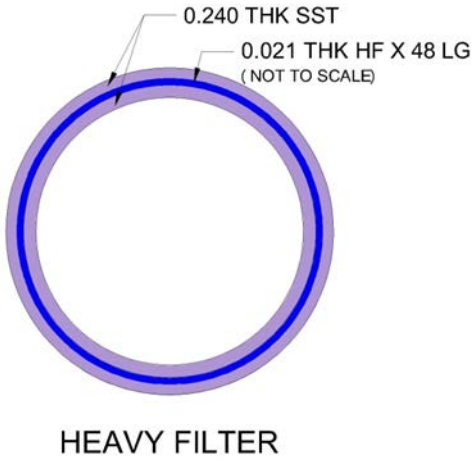


Capsule 3
cross-section

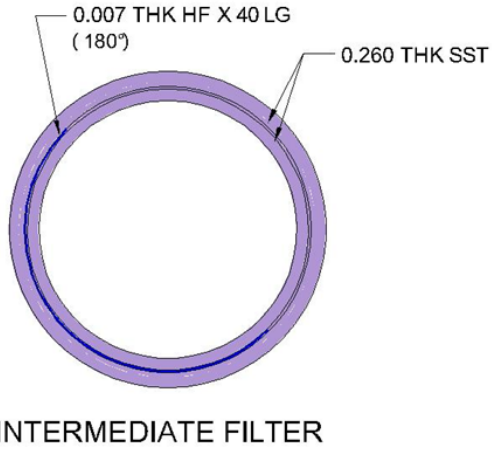


Capsules 2, 4, 5
cross-sections

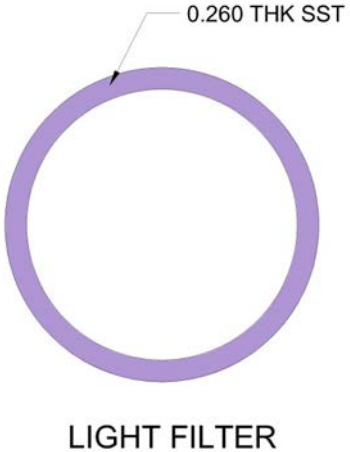
AGR-5/6/7 Neutron Filters



HEAVY FILTER



INTERMEDIATE FILTER



LIGHT FILTER

Filters aid in tailoring the fast/thermal spectrum over a much wider operating band

FY-17 Work Scope Plans

Date (approximate)	Scope
February 2017	Complete machining of all metal components, complete machining of graphite holders except for final hole size for fuel channels, complete brazing of all capsule heads
March 2017	Receive all fuel from B&W
April 2017	Complete machining on graphite fuel holders
June 2017	Begin assembling capsules and welding heads on
July 2017	Complete test train core section
Aug/Sept 2017	Complete test train assembly
November 2017	Commence irradiation in ATR cycle 162B (Delay due to ATR schedule slippage)

FY-17 Milestone Status

- Achieve ‘Ready to Insert’ Status for the AGR-5/6/7 Test Train (M2)
  - Due September 25, 2017
  - Experiment Safety Analysis is reviewed and approved
  - Data Package reviewed and approved
  - Control system software modification installation scheduled 7/10
  - Test train assembly approximately 50% complete with no issues. Assembly is expected to complete ahead of milestone due date.

- Complete Conversion of Fission Product Monitoring System (FPMS) to Digital Operation (M3)
  - Due September 15, 2017
  - Working – currently on track with no issues

Questions

Michael Davenport, ART Irradiation Technical Lead
michael.davenport@inl.gov
208-526-6214

Idaho National Laboratory