The Advanced Gas Reactor Fuel Development and Qualification Program Overview

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Advanced Gas Reactor TRISO Fuels Program Review
July 18-19, 2017
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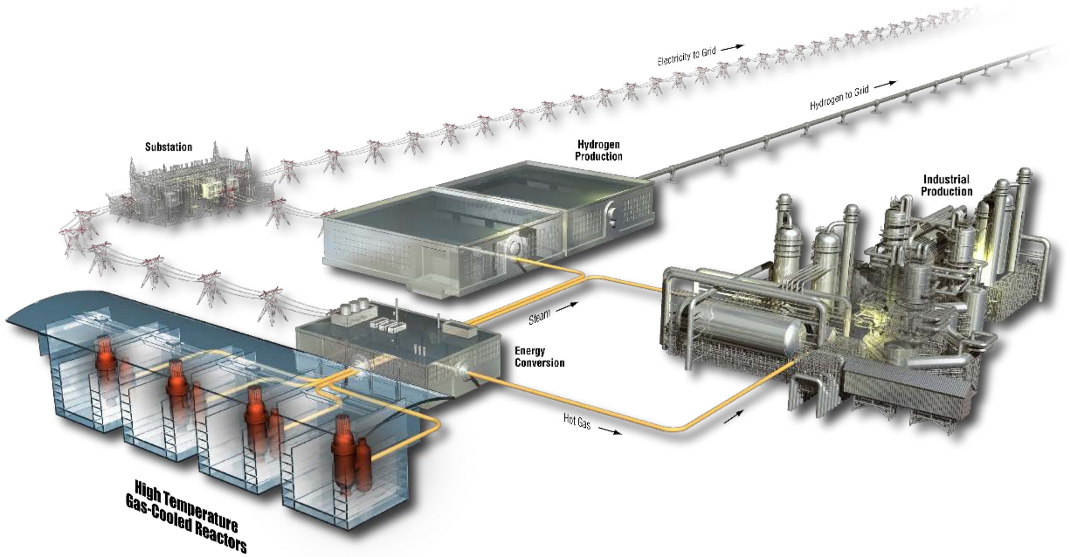

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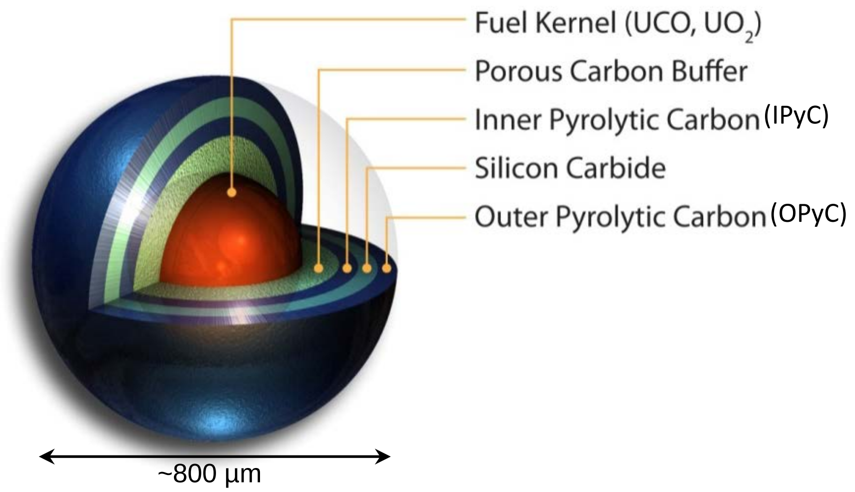
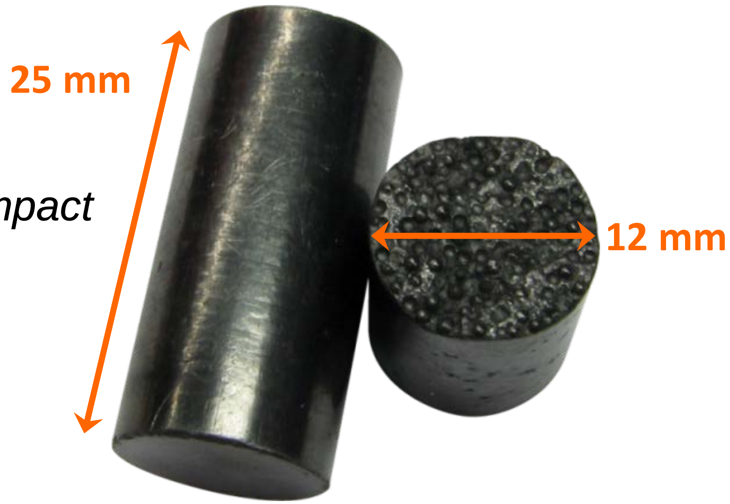
Tristructural isotropic (TRISO) Fuel



TRISO particle

AGR fuel compact



- TRISO fuel is at the heart of the safety case for modular high temperature gas-cooled reactors
- Key component of the “functional containment” licensing strategy
  - Radionuclides are retained within multiple barriers, with emphasis on retention at their source in the fuel

High-quality, low-defect fuel fabrication

Robust performance during irradiation and during high-temperature reactor transients

Low fission product release

AGR Program

Objectives and motivation

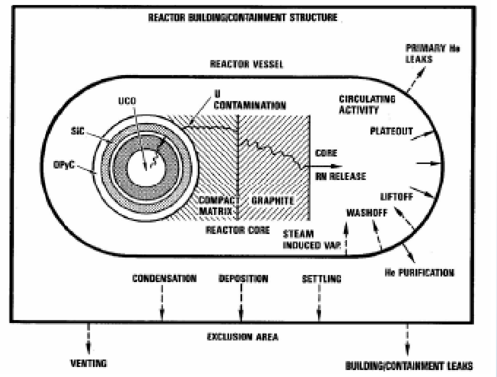
- Provide data for fuel qualification in support of reactor licensing
- Establish a domestic commercial vendor for TRISO fuel

→ **Reduce market entry risk**

Approach

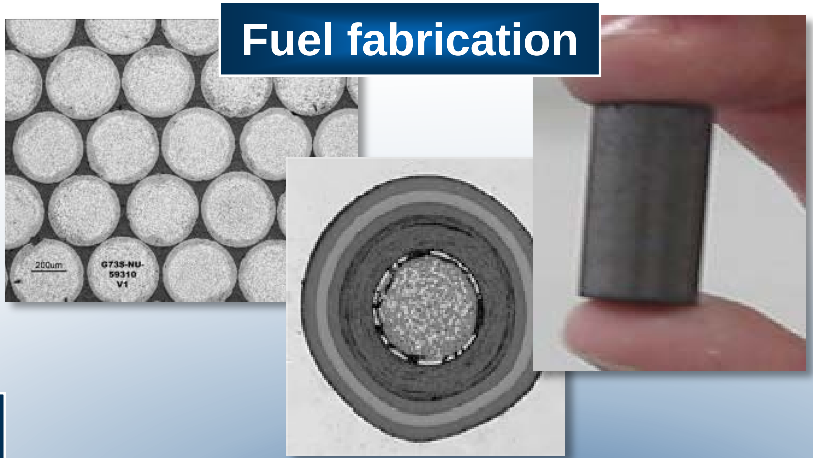
- Focus is on developing and testing **UCO** TRISO fuel
  - **Develop fuel fabrication and QC measurement methods**, first at lab scale and then at industrial scale
  - **Perform irradiation testing** over a range of conditions (burnup, temperature, fast neutron fluence)
  - **Perform post-irradiation examination and safety testing** to demonstrate and understand performance during irradiation and during accident conditions
  - **Develop fuel performance models** to better predict fuel behavior
  - **Perform fission product transport experiments** to improve understanding and refine models of fission product transport

Advanced Gas Reactor Fuel Development and Qualification Program Elements



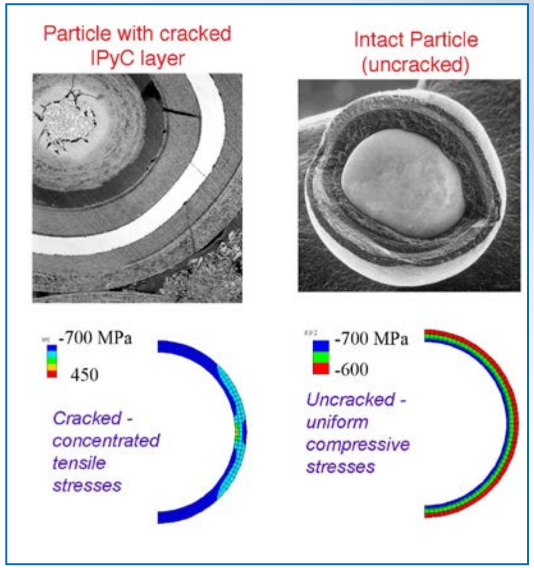
Fission product transport & source term

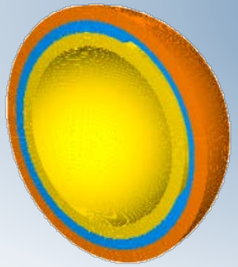
Fuel fabrication



Fuel irradiation

Program participants:
INL, ORNL, BWXT, GA

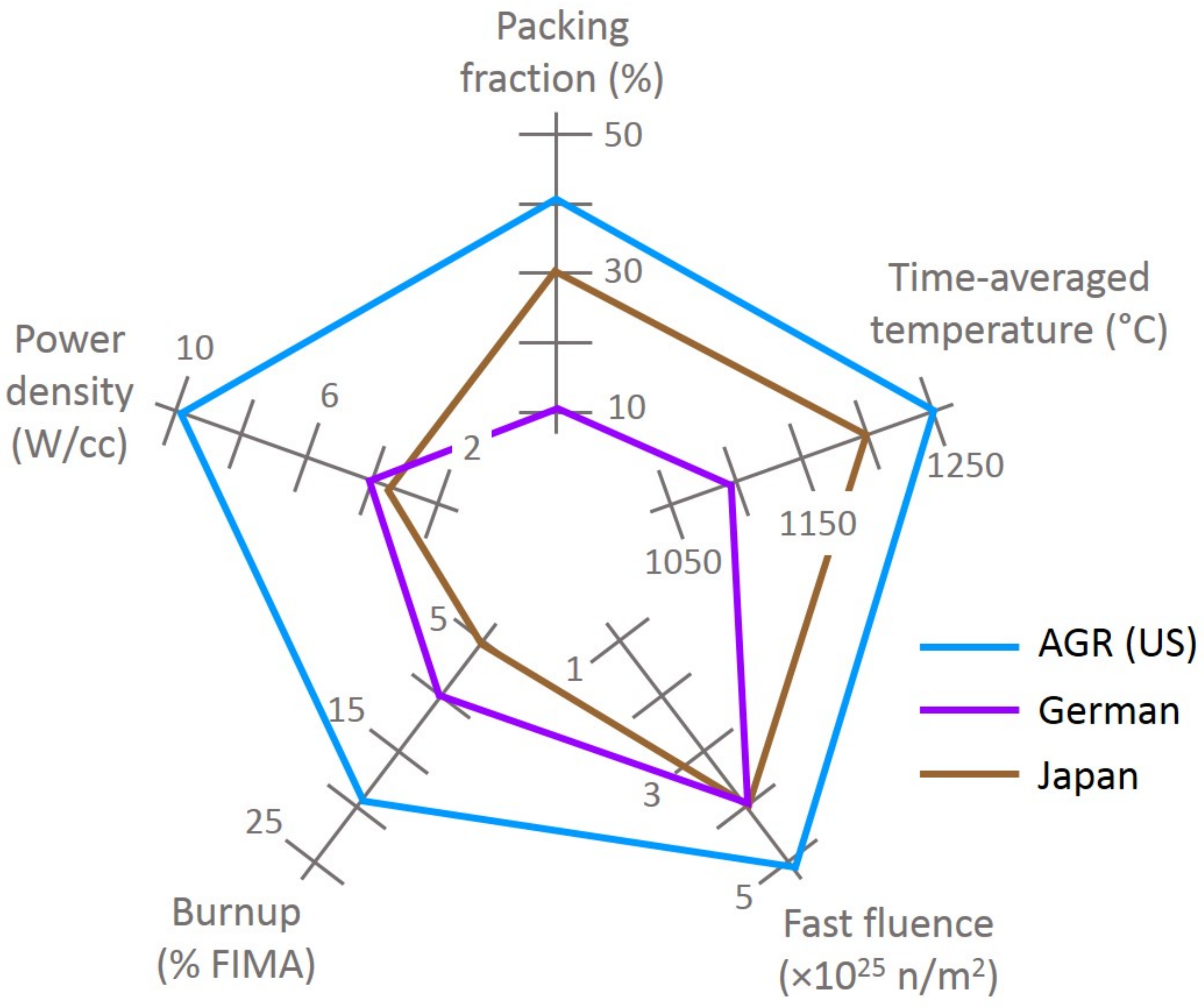




Fuel performance modeling

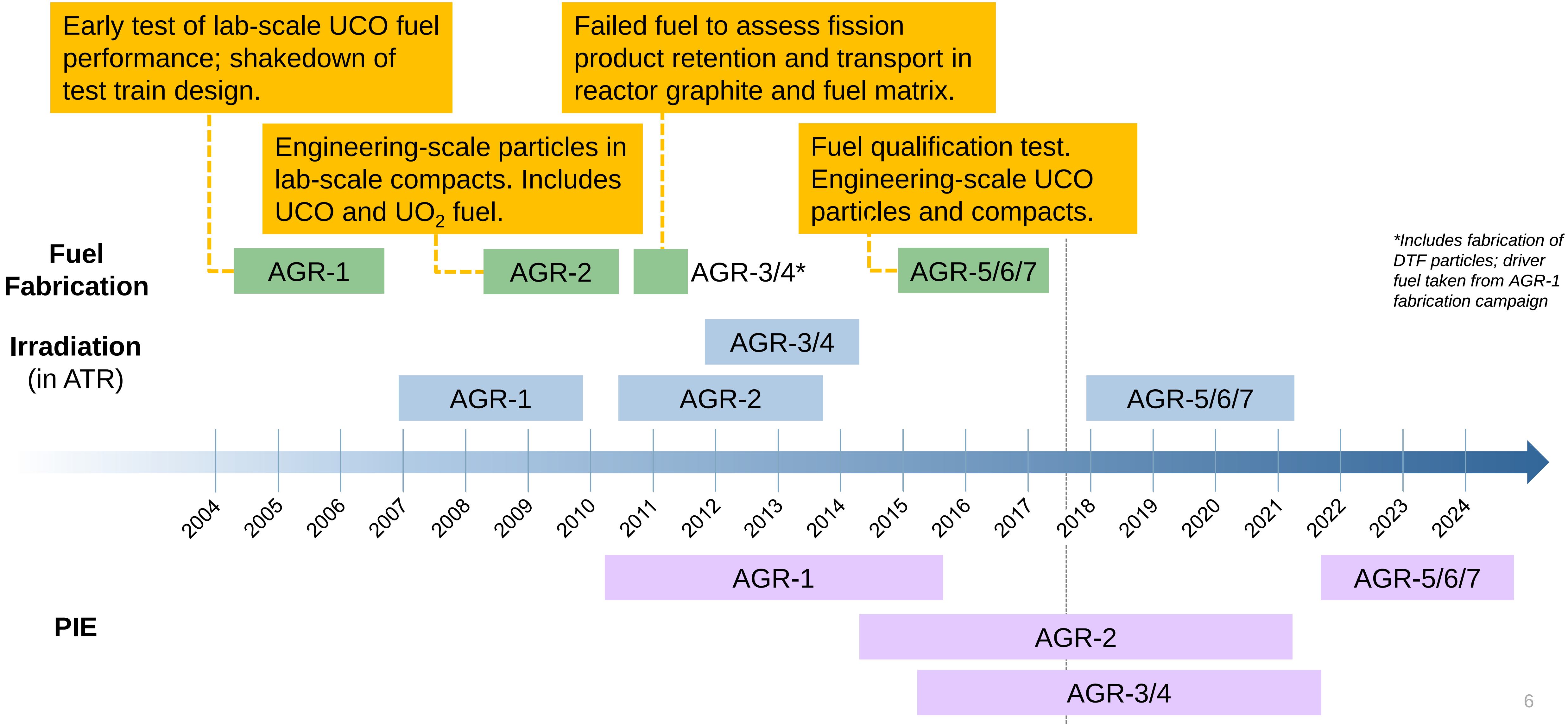
PIE and safety testing

Targeted Fuel Performance Envelope



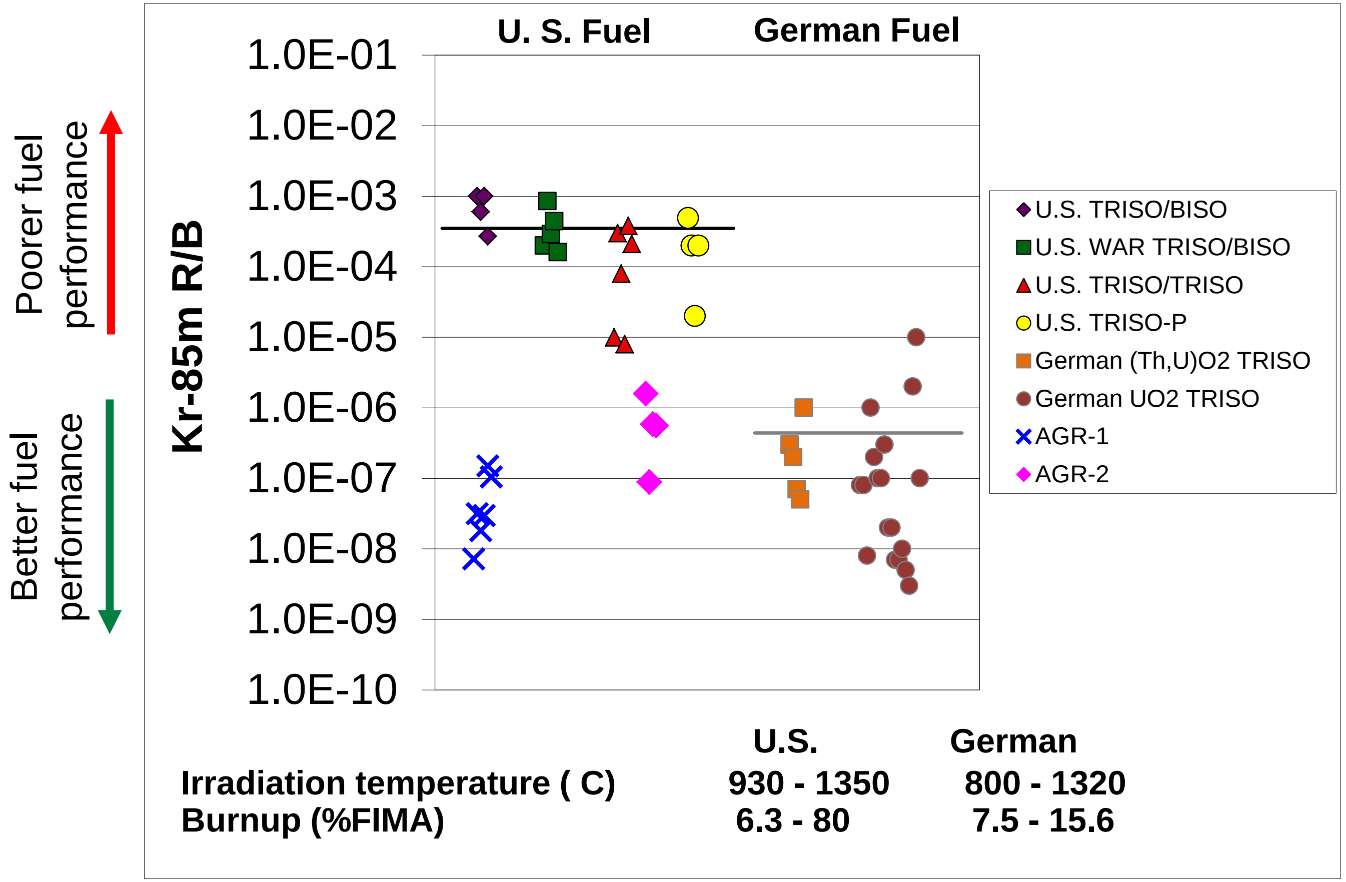
- Program goal is to qualify fuel to a performance envelope that is more aggressive than previous German and Japanese qualification efforts

AGR Program Timeline



AGR Fuel Irradiation Performance

German fuel has historically demonstrated ~1,000 times better performance than U.S. fuel.



Plot of Kr-85m release-to-birth ratio for various fuel types

AGR-1:
- Zero TRISO failures out of ~300,000 particles in the experiment
- Peak burnup ~20% FIMA

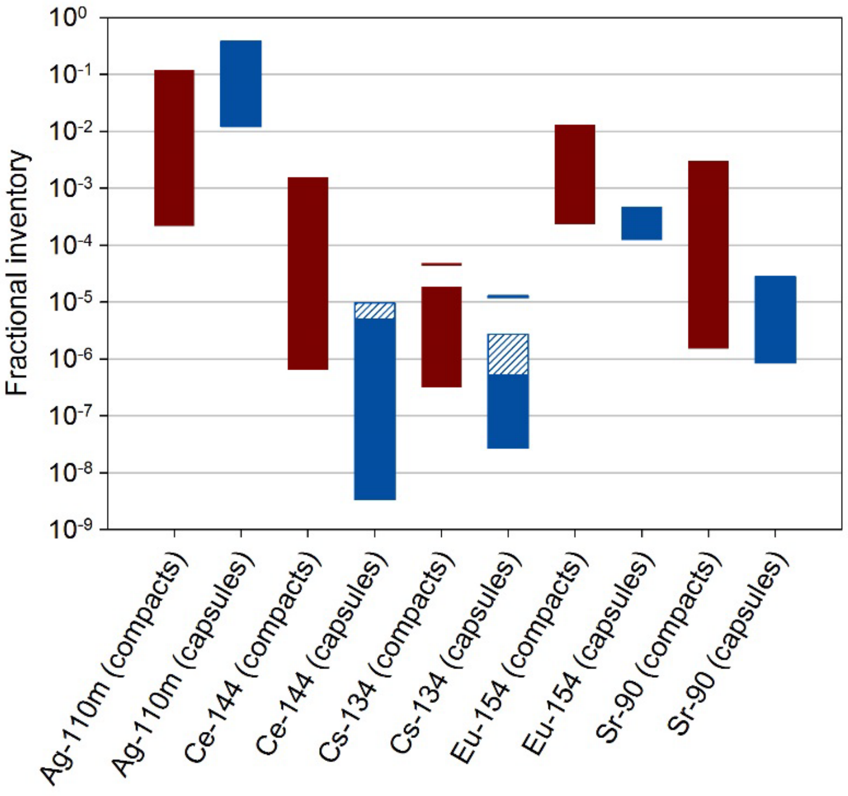
AGR-2
- 0 or 1 exposed kernel at beginning of irradiation in each capsule
- Possibility of small number of failures during irradiation

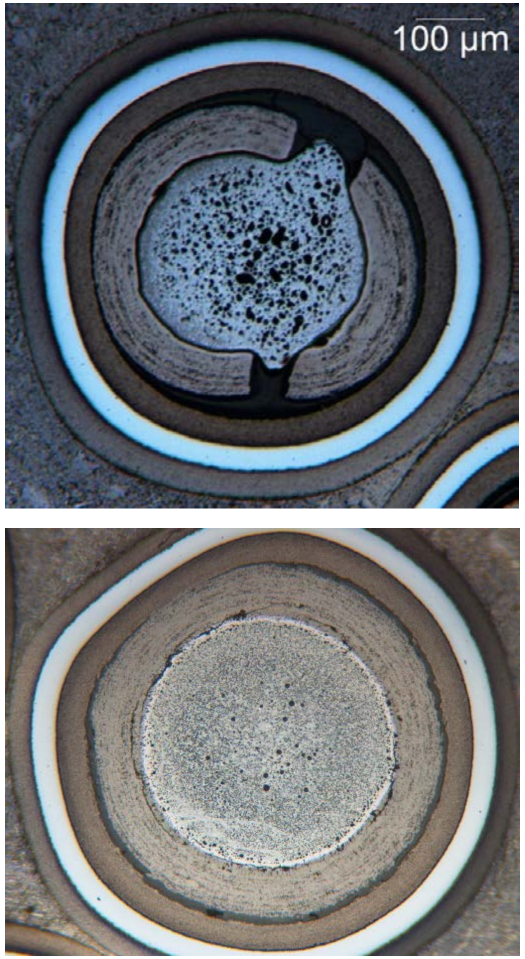
Today, in-reactor AGR TRISO fuel performance is as good as German fuel at twice the burnup

AGR-1 and AGR-2 Irradiation Performance

- **Low coating failure fractions** (AGR-1 TRISO failure fractions are below existing reactor design specs)
- **Low release of key fission products** (Kr, Cs, Sr)
- **Modest release of Eu; high release of Ag** (influenced by irradiation temperature)
- **Buffer fractures are common** but do not appear to be detrimental to outer coating integrity
- **UCO effective at controlling CO production** which limits gas pressure and kernel migration
- **Significant leaps in understanding causes of coating failures and fission product transport in coatings**

AGR-1 capsule-average fission product release

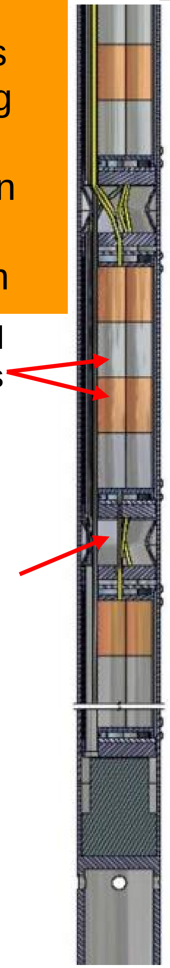




AGR-1 4-1-3 (19.3% avg burnup)

Studying failed particles greatly improves ability to characterize and understand fuel performance

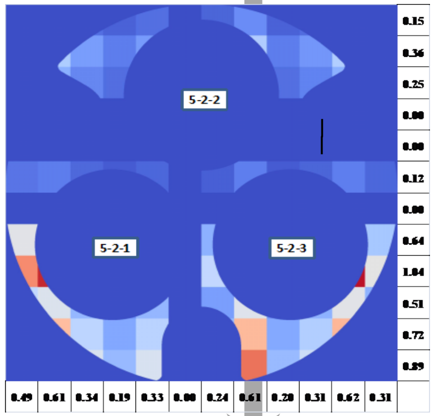
72 fuel compacts containing 300,000 particles in AGR-1 irradiation



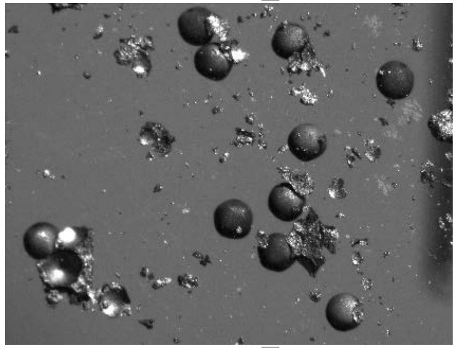
AGR-1 Test Train Vertical Section

Capsule disassembly

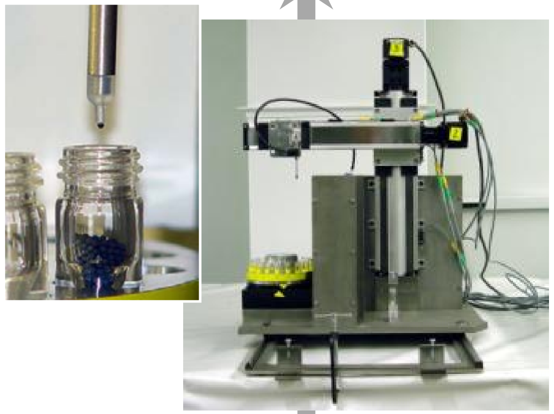
Gamma scan to identify cesium hot spots and compact location



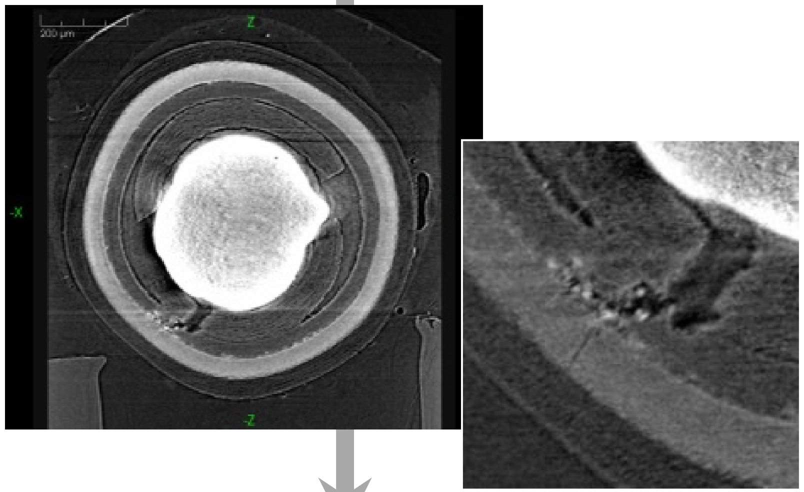
Deconsolidation to obtain ~4,000 particles from compact

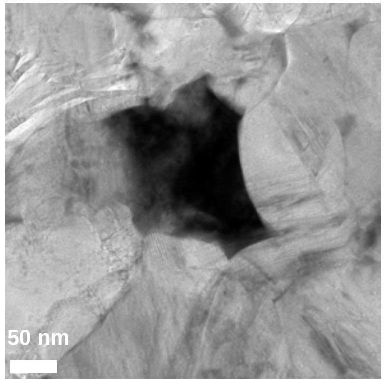


IMGA to find particles with low cesium retention



X-ray tomography to nondestructively locate defects/fractures

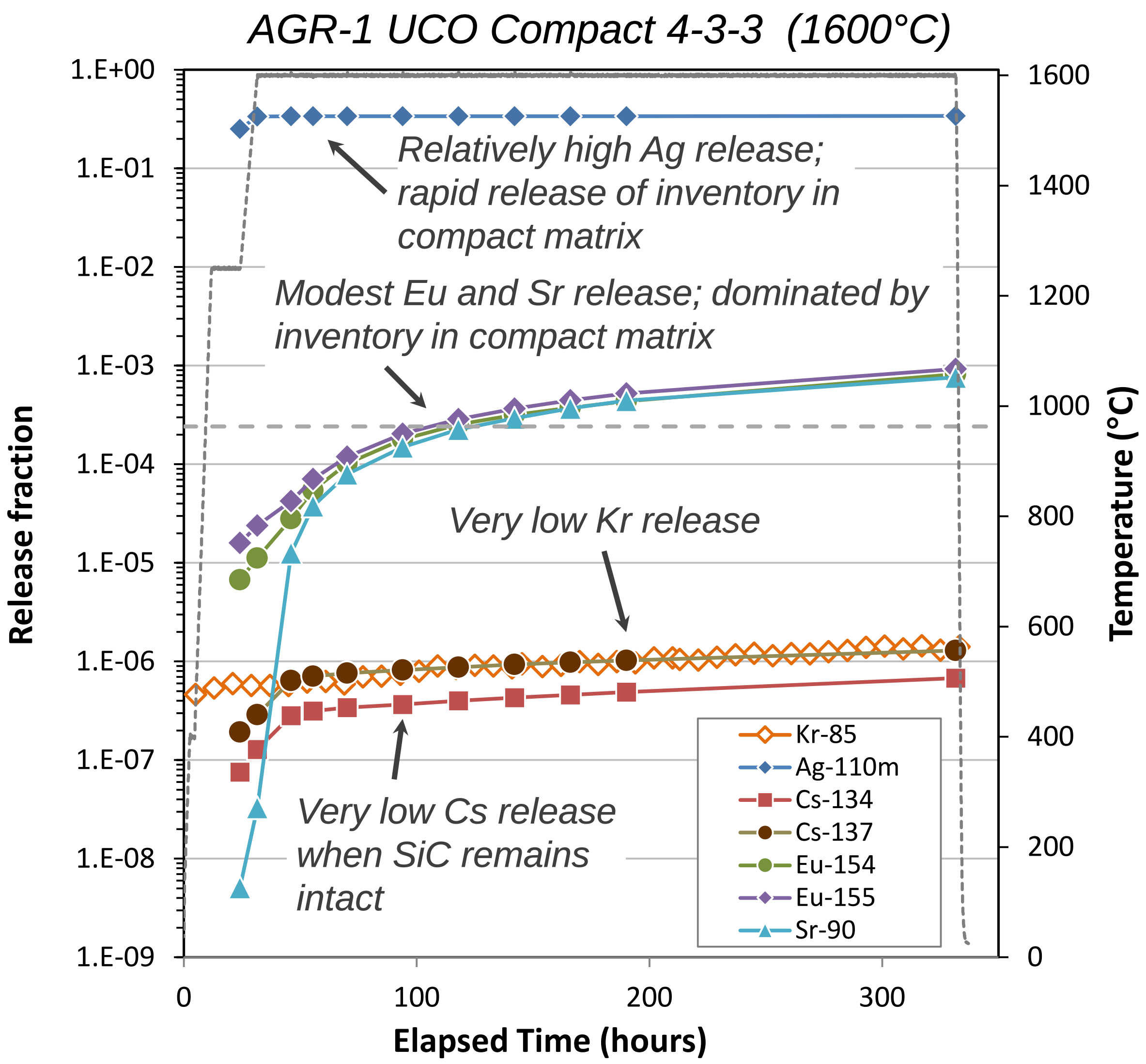




Advanced microscopy to study microstructure in detail

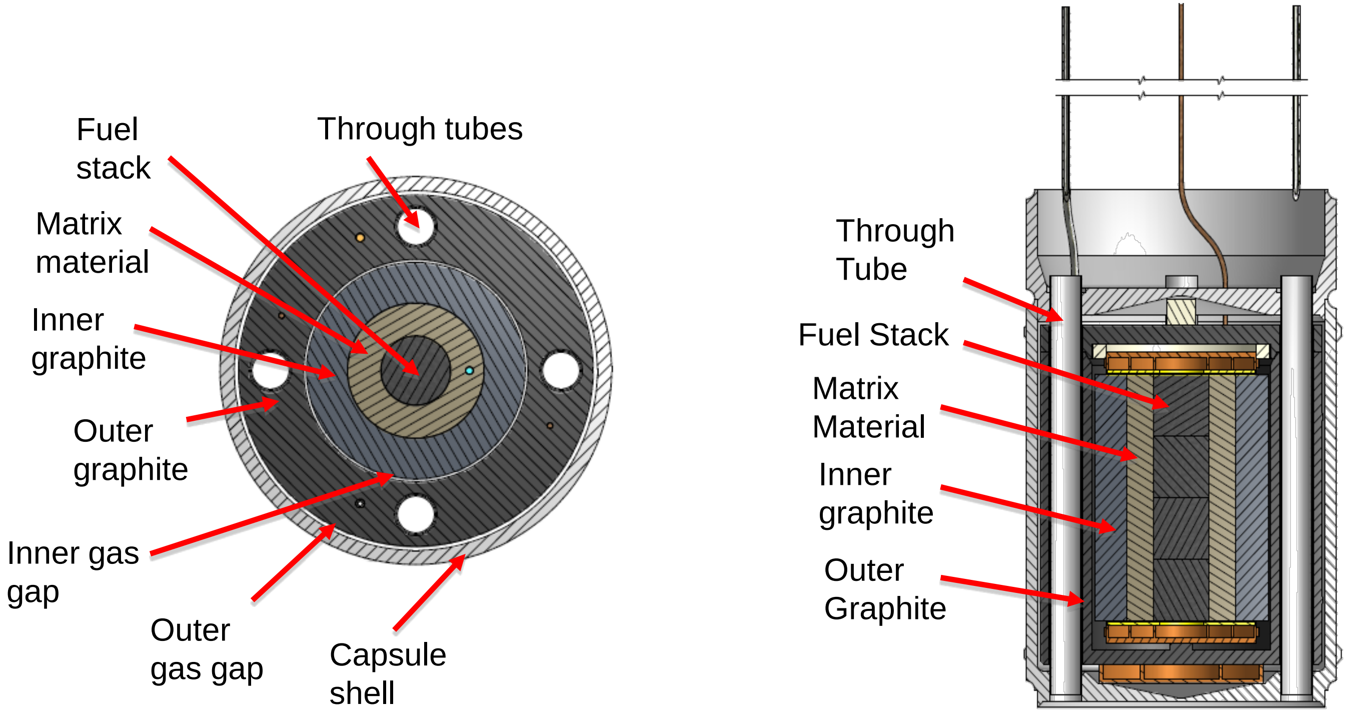
AGR-1 and AGR-2 Safety Test Performance

- **Excellent UCO performance up to 1800°C**
- **Low Cs release** (dependent on intact SiC)
- **Low Kr release**
- **Modest Sr and Eu release** (influenced by irradiation temperature)
- **High Ag release** (dominated by in-pile release from particles)
- **Low coating failure fractions** (UCO)
- **Accelerated SiC attack by Pd at higher temperatures**
- **UO_2 demonstrates much higher incidence of SiC failure due to CO attack**

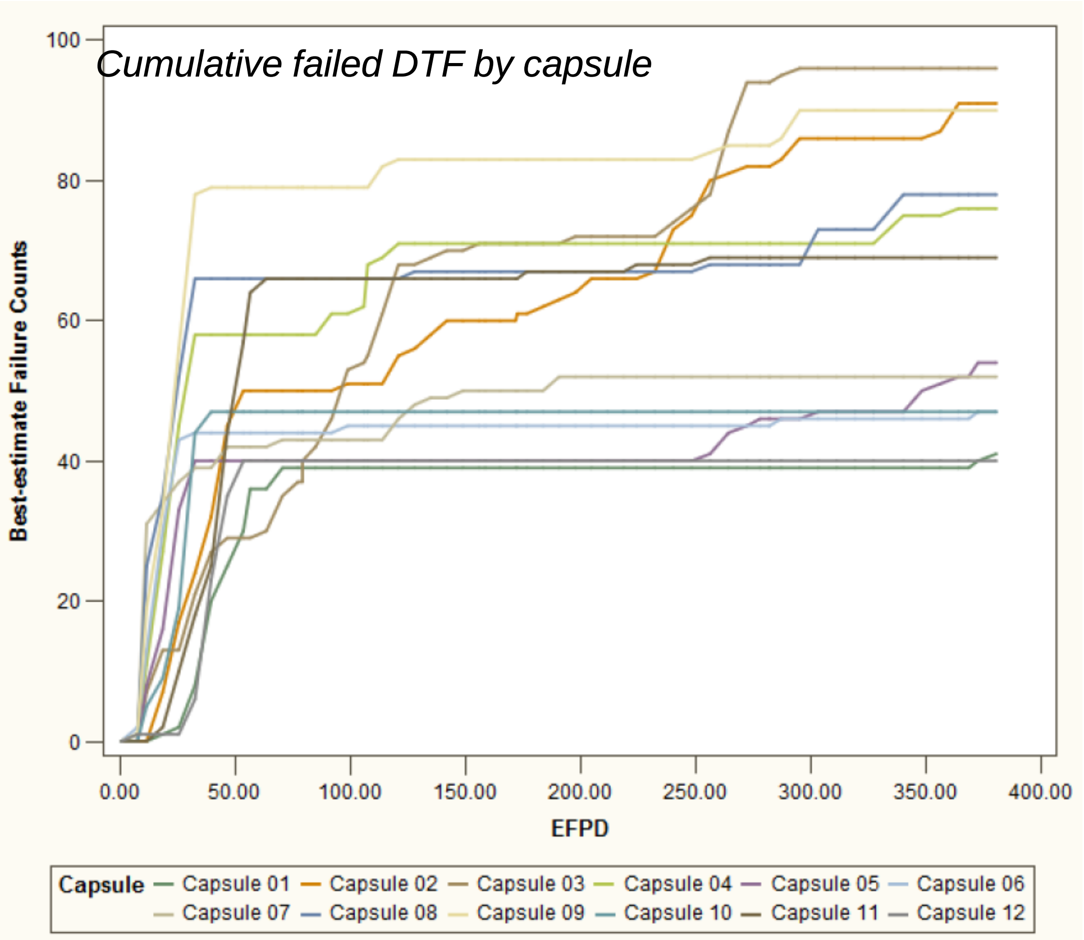


AGR-3/4 Irradiation

- AGR-3/4 irradiation completed April 2014
- Good performance of DTF particles, however:
  - Some difficulty identifying individual DTF failures during irradiation
  - Apparently not all DTF failed



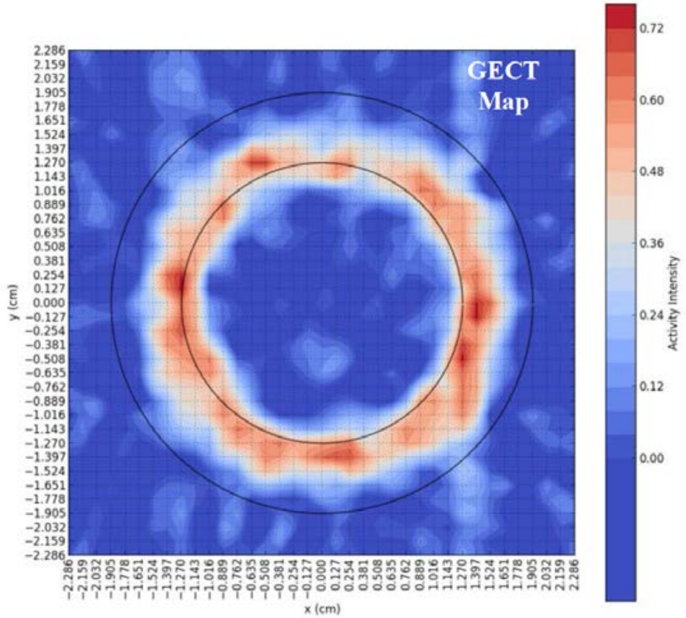
AGR-3/4 Capsule Cross Section



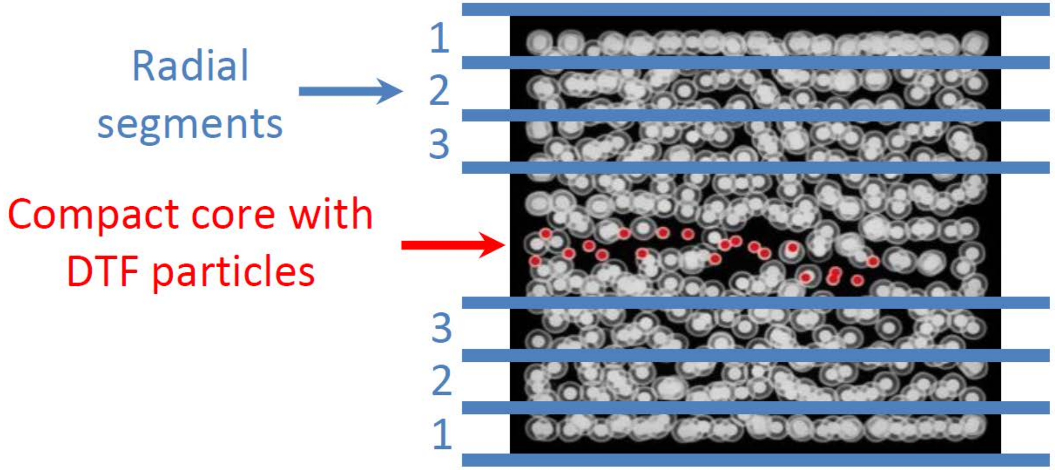
AGR-3/4 Post-irradiation Examination

- Extensive PIE is in progress
  - Focus is understanding fission product transport in fuel kernels, fuel matrix, and reactor core graphite
- Analyze fission product distribution in rings
- Analyze fission products in compact matrix
- Determine fission product release from fuel at high temperatures in inert and oxidizing atmospheres

Cs-134 gamma emission computed tomogram of an AGR-3/4 inner ring



Schematic of approach for performing radial deconsolidation on AGR-3/4 compact

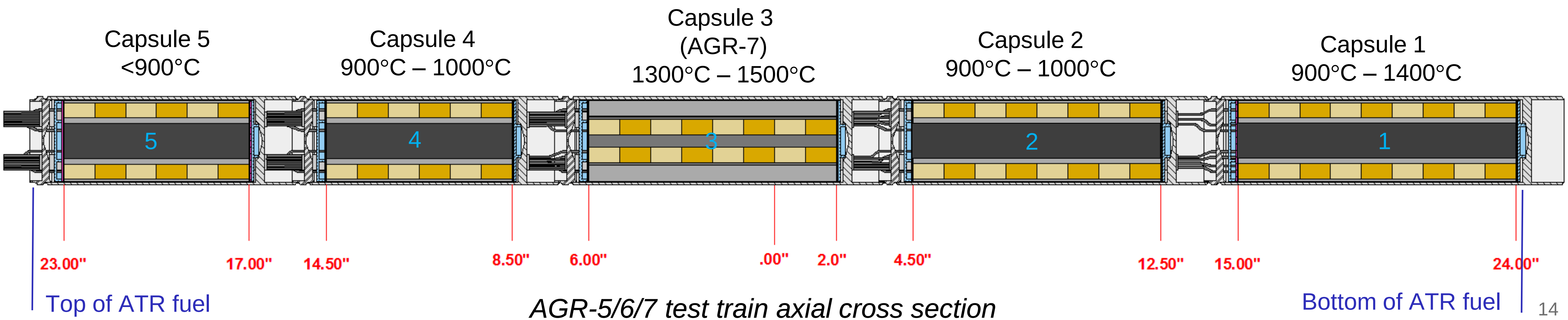


AGR-5/6/7 Irradiation

- Final fuel qualification irradiation; critical link in verifying fuel made at the commercial vendor meets performance requirements
  - Kernels, coated particles, and fuel compacts all made on pilot-scale fuel fabrication line at the commercial vendor
- AGR-5/6: Fuel qualification test
  - Irradiate sufficient number of particles to obtain fuel failure statistics
  - ~530,000 particles in four capsules
  - Temperature and burnup ranges attempt to represent HTGR core-wide distributions (~600 to 1400°C; ~7 to 18% FIMA)
- AGR-7: Fuel performance margin test
  - Explore the threshold for fuel performance
  - ~55,000 particles in a single capsule
  - Upper range of burnup values (~18% FIMA)
  - Time-average peak temperatures up to 1500°C

AGR-5/6/7 Irradiation Status

- AGR-5/6/7 fuel compacts have been fabricated and delivered to INL; QC measurements in progress
  - Some issues with specifications (OPyC thickness in TRISO, exposed kernel fractions in 40% PF compacts)
    - Highlights challenges with fabrication scale-up and maintaining operational rhythm at vendor
- Irradiation test train is mostly fabricated
- Irradiation is scheduled to start in the ATR Northeast Flux Trap in Nov-Dec 2017.



AGR-5/6/7 test train axial cross section

Conclusions

- AGR program is approximately 2/3 complete
- Key successes to date
  - Excellent overall UCO performance
  - Significant leaps in understanding fuel performance
- Major tasks to completion
  - Complete AGR-2 PIE and safety testing
  - Complete AGR-3/4 PIE
  - Complete AGR-5/6/7 irradiation, PIE, and safety testing
  - Perform key safety tests in oxidizing atmospheres
  - Support NRC interactions on licensing
  - Code comparisons to data
  - Program closeout and reporting
- Several companies are depending on AGR program completion to establish domestic vendor and qualify fuel and decrease market entry risk

INL

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