Development and Operation of the Fuel Accident Condition Simulator (FACS) Furnace for High Temperature Performance Testing of Irradiated Fuel

Idaho National Laboratory

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Very High Temperature Gas Cooled Reactor (VHTR)

- Helium cooled, graphite moderated
- Coated particle fuel
- Outlet temperature 750-950°C
- Production of electricity and high temperature process heat for industrial applications

- Passive safety characteristics
- Very slow thermal transients during depressurized loss of force cooling
- Maximum core temperature \( \leq 1600°C \)
**Tristructural isotropic (TRISO) coated particle fuel**

- Coated particle fuel is at the heart of high temperature gas-cooled reactor performance.
- Fuel research, development, and qualification is focused on demonstrating fuel performance under normal and accident conditions.
  - Can be fabricated with very low defect fractions ($\leq 10^{-5}$).
  - This fuel is very robust with no failures anticipated during irradiation and under accident conditions.
  - Fission product retention within particles results in a high degree of safety.
TRISO fuel safety testing at INL

- Project initiated to develop safety testing capability at INL along the lines of the KÜFA furnace
- Requirements highlights:
  - Up to 2000°C in pure helium
  - Monitor fission gas releases (Kr-85) and collect fission products (Ag, Cs, Sr, Eu, I) with removable condensation plates
  - Accommodate samples up to 60 mm diameter
  - Designed for high level of automated remote operation
- System manufactured by TevTech LLC (Billerica, Massachusetts)
- Delivered to INL 2008
- Mock up testing from 2008 – 2010
- Installed in the Hot Fuel Examination Facility (HFEF) Main Cell in 2010
- 2011 – 2013 in-cell testing, troubleshooting, collection efficiency testing
Fuel Accident Condition Simulator

System components
- Main furnace assembly:
  - Main chamber
  - Cold finger assembly
  - Transfer assembly
  - Support frame and motors
- Control cabinet and user interface
- Cooling water heat exchanger
- Power supply
- Helium and argon gas supply system
- Fission gas monitoring system
FACS system schematic
Main chamber

- Graphite heating element (2000°C max temperature)
- ~770 Amps/28 V @ 1600°C
- Water-cooled steel shell
- Tantalum sample holder and hot zone components
- Sample temperature monitored with 2 Type C thermocouples
- Tantalum flow tube (84 mm inner diameter)
- Refractory metal (tungsten, molybdenum) and steel heat shields
- Adjacent condensation plate transfer chamber
Cold finger and condensation plate

- Aluminum cold finger construction
- Rotary actuator to capture condensation plate (CP)
- CP temperature monitored with 2 Type J thermocouples
- Water flow rate in cold finger is 28 L/min
- Stainless steel CP
- CP temperature is ~67 – 106°C with furnace at 1600°C
Transfer chamber assembly

- Manual loading/removal of condensation plates through access port
- Automated sequence for evacuation and He purge of transfer chamber once plate transfer initiated
Condensation plate transfers

- Entire sequence takes ~6 minutes on average
**Condensation plate analysis**

- Manual transfer from HFEF hot cells to Analytical Laboratory for analysis
- Gamma counting for **Cs-134, Cs-137, Ag-110m, Eu-154, and Eu-155** with HPGe spectrometers
- Acid dissolution and analysis for non-gamma emitting fission products
  - Chemical separation and gas flow proportional counting for **Sr-90**
  - Mass spectrometry for other isotopes (including **Pd** isotopes)
Fission gas monitoring system (FGMS)

- Dual lead shielded liquid nitrogen cold traps
- 2-HPGe, 10% relative efficiency, closed end coaxial detectors
- Adjustable tungsten shuttered collimators
- A variable lift cart for detector height positioning
- A complex valve manifold system to allow the user to run the monitors in a variety of configurations
- INL developed control software.

Additional details:
FGMS Schematic Diagram

Flow Options in Series
- Light Blue = Trap 2 then Trap 1
- Pink = Trap 1 then Trap 2

- Fission Gas Exhaust
- Gas Purifier
- Flow Meter
- To Cell Exhaust

- Charcoal Column
- Liquid Nitrogen Chamber
- Collimator
- Vacuum Jacket
- Shielding
- HPGe Detector
- To Data Acquisition Electronics and Computer Control

- Auxiliary Sample Trap (Not Normally Installed)
Current FACS Safety Testing Status

- Safety tests on irradiated TRISO fuel began in 2013
- Three fuel compacts from the AGR-1 irradiation experiment have been tested
- System performance has been very good; several lessons learned from first operational experience

<table>
<thead>
<tr>
<th>Compact</th>
<th>Fuel type</th>
<th>Burnup (% FIMA)</th>
<th>Fast Fluence (n/cm² x10²¹)</th>
<th>TAVA* (°C)</th>
<th>Safety test temperature (°C)</th>
<th>Test date</th>
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<td>AGR-1 6-4-1</td>
<td>Baseline</td>
<td>13.2</td>
<td>2.4</td>
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</table>

* Time-average volume-average temperature
Compact 4-3-3 Safety Test Summary Results

- Rapid release of ~34% of Ag-110m in first 30 hours but little release after reaching 1600°C. Silver is probably from inventory in matrix at end of irradiation.
- Very low Cs release (1E-6). Very good retention of Cs by intact TRISO coatings.
- Kr-85 release rate is low and constant throughout test. No failed TRISO.
- Eu and Sr release rate are approximately constant throughout test. Final Eu-154 release fraction is 8E-4.
Compact 4-3-2 Safety Test Summary Results

- Rapid release of ~6% of Ag-110m in first 30 hours. After ~100 h at 1600°C Ag-110m release again increase. May be result of Ag diffusion through SiC.

- Several rapid Kr-85 releases. Indicates failed SiC and failed TRISO.

- Cs release increases dramatically. Precedes with Kr release events. Indicates failed SiC and failed TRISO.

- Eu release rate is approximately constant for first 160 h of test, then increases. May be result of Eu diffusion through SiC.
Summary

- FACS furnace has been developed to perform safety testing of irradiated fuel in helium at temperatures up to 2000°C.
- System is installed and operational in the Hot Fuel Examination Facility main hot cell.
- Safety testing of AGR-1 TRISO fuel compacts is underway.
- System performance has been very good.
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- **Les Scott**: Lead FACS system engineer
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Idaho National Laboratory
Extra slides
Maintenance and sample loading configurations

- Flow tube replacement
- Sample loading
- Heating element maintenance
- Lower flange maintenance

Pneumatic clamps

- Heat shield removal and maintenance
Condensation plate transfers
Condensation Plate Activity (Compact 6-4-1)