Status of the NGNP Fuel Development and Qualification Program

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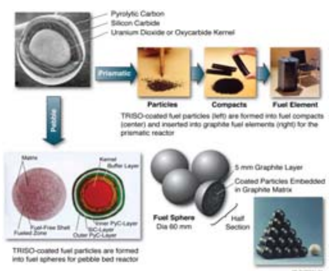
TRISO-Coated Particle Fuel is at the Heart of the High Temperature Gas Reactor Concept (provides technical basis for collocation)

Key aspects of TRISO Fuel:

- *German industrial experience demonstrated that TRISO-coated particle fuel can be fabricated to achieve high quality levels with very low defects*
- *This fuel is very robust with no failures anticipated during irradiation and under accident conditions.*
- *Fuel form retains fission products resulting in a high degree of safety*



NGNP Fuel Program Approach

- Qualify fuel that demonstrates the safety case for NGNP
  - Manufacture high quality LEU coated fuel particles in compacts
  - Complete the design and fabrication of reactor test trains for irradiation testing of coated particle fuel forms
  - Demonstrate fuel performance during normal and accident conditions, through irradiation, safety testing, and PIE
  - Improve the understanding of fuel behavior and fission product transport to improve predictive fuel performance and fission product transport models
- Lowest risk path to successful coated-particle manufacturing is to "replicate" the proven German coating technology to the extent possible in an uninterrupted manner on the AGR particle design (UCO), incorporating the lessons learned from prior U.S. fabrication and irradiation experience

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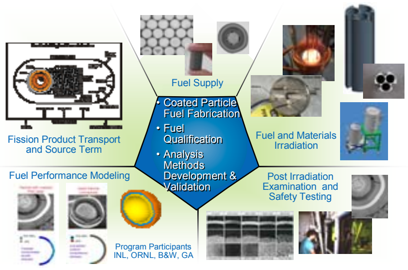
NGNP/AGR Fuel Program Elements



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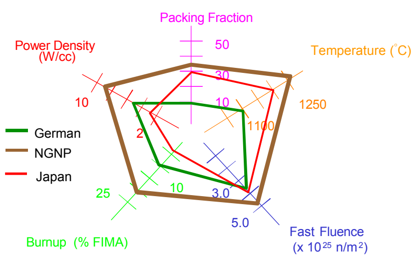
Performance Envelope for NGNP TRISO-coated Particle Fuel



Radar plot of five key parameters of fuel performance

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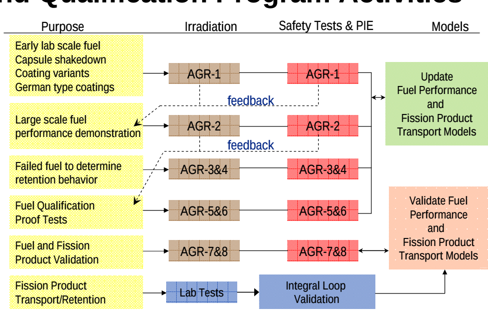
Overview of NGNP Fuel Development and Qualification Program Activities



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AGR Fuels Schedule

- Aggressive schedule of irradiations, safety tests and PIE
- Critical path for R&D
- Data used to support licensing and design verification

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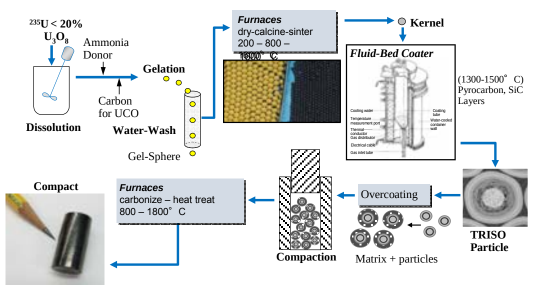
TRISO Particle Fabrication



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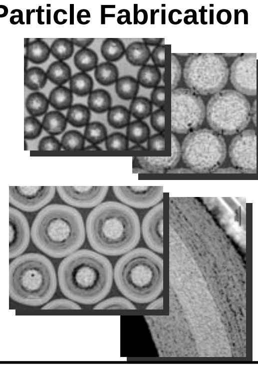
Particle Fabrication



Kernel Fabrication
- Key characteristics:
  - Diameter
  - Chemistry
  - Homogeneity
  - Sphericity

Coatings
- Key characteristics:
  - Coating thickness
  - Coating uniformity
  - Low defect fractions
  - Pyrocarbon anisotropy
  - Buffer density
  - SiC grain structure
  - Carbon dispersion in SiC

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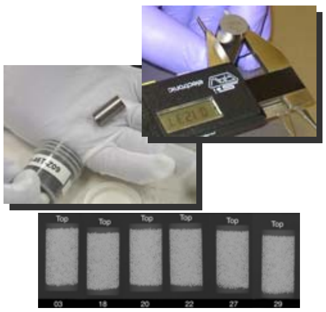
Compact Fabrication



Compacts

- Key Characteristics:
  - Matrix density
  - Particle packing fraction
  - Uniform particle distribution
  - Dimensional tolerances
  - Heavy metal contamination

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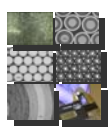
Fuel Fabrication Accomplishments

- Established capability to fabricate and characterize TRISO-coated particle fuel in the US after a 25 year hiatus
- Developed a significantly improved understanding of how to fabricate *high-performing TRISO fuel* (moving fuel fabrication from an "art" to a disciplined scientific/engineering endeavor) providing the *technical basis for co-location in industrial* complexes
- Currently fabricating *high-quality, low-defect (about 1 defect in* every 100,000 particles) TRISO-coated fuel particles at industrial scale (B&W). This has never been done in the US before
- Establishing a *domestic vendor* and associated fundamental understanding of key fuel fabrication parameters establishes credibility that the historical industrial experience from Germany in the 1980s is repeatable and has a sound technical basis



	AGR-1	AGR-2	AGR-5/6
Kernels	Engineering scale	Engineering Scale	Engineering Scale
Coatings	Lab Scale	Engineering scale	Engineering Scale
Compacting	Lab Scale	Lab Scale	Engineering Scale

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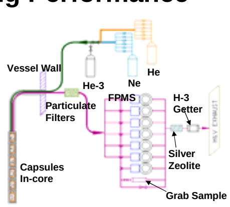
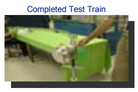
NGNP Fuel Irradiation Capsule AGR-1 Demonstrated Outstanding Performance

- Goal burnup ~ 18-19% FIMA
- T_{max} < 1250° C, T_{avg} ~ 1150° C
- Fast fluence < 5 × 10^{25} n/m^2
- Irradiation began in December 2006 and completed November 2009
- *Peak burnup of 19% FIMA with no failures out of 300,000 particles*



Individual capsule assembly with fuel compacts

Completed Test Train



Insertion into INL ATR

FPMS System

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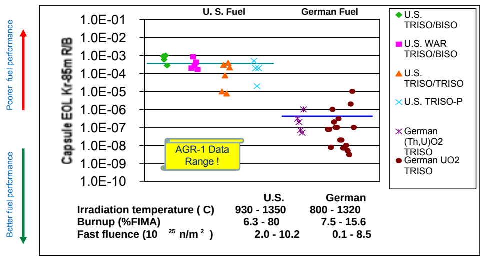
German Fuel has Historically Demonstrated 1000x Better Performance than U.S. Fuel. AGR-1 Data as Good as German Fuel at Twice the Burnup!



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AGR-2 will Test Industrial Scale UO2 and UCO

Capsule	Fuel Type	Vendor	Enrichment	Peak Burnup Goal	Peak Temperature
6	425 μm UCO	B&W	14%	12% FIMA	< 1250°C
5	425 μm UCO	B&W	14%	14% FIMA	< 1400°C
4	500 μm UO_2	PBMR	9.6%	11% FIMA	<1150°C
3	500 μm UO_2	B&W	9.6%	11% FIMA	<1150°C
2	425 μm UCO	B&W	14%	14% FIMA	< 1250°C
1	500 μm UO_2	CEA	19.6%	16% FIMA	<1150°C

Capsule fabrication underway. Irradiation expected to start in June 2010

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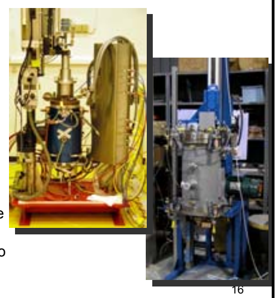
NGNP PIE and Safety Testing

- Assess the performance of NGNP particle fuel under normal and accident conditions
  - Fission product retention of particles
  - Coating/kernel microstructure and integrity
- Support fuel fabrication effort by providing feedback on the relationship between fuel processing, properties, and performance
- Provide data to support development and validation of fuel performance and fission product transport models
- Currently preparing facilities at INL and Oak Ridge National Laboratories for PIE activities
- AGR-1 PIE will begin in approximately April 2010

Fuel Annealing Furnaces: Getting Ready For Safety Testing Of Fuel

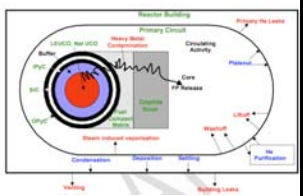
Key Features:

- Two systems for diversity: INL and ORNL
- Helium internal atmosphere
- High Temperature heating element (2000ºC max)
- Automatic cold plate transfer during annealing experiment
- Hot zone capacity for up to ~6 cm diameter sphere (INL furnace only)
- Anticipate isothermal and representative thermal response tests of fuel
- Statistically significant amounts of fuel to be tested



Fission Product Transport – Supporting a Mechanistic Source Term

- NGNP will use a mechanistic source term that takes credit for all fission product release barriers - kernels, coatings, graphite, primary coolant pressure boundary, reactor building - in order to meet radionuclide control requirements

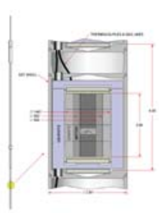


- Goal is to provide technical basis for source terms under normal and accident conditions to support reactor design and licensing
- Experimental data to be generated by 3 irradiation capsules, PIE, safety testing, out-of-pile loop testing, and in-pile loop testing
- Independent validation experiments are part of the plan

AGR 3-4 will Test “Designed to Fail” Fuel to Support Source Term Analysis

- Evaluate release from failed fuel
- Establish metallic fission product retention in fuel matrix and fuel element graphite
- Preliminary Design underway
- 12 separate capsules to span the temperature, burnup and fluence envelope of NGNP

Flux Trap Cut-Away



Axial Cutaway of one of the 12 capsules

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PARFUME Capabilities

Structural	Service Conditions	Physio-chemical	Layer Interactions	Failure
Intact particles	Any user specified temperature, burnup and fluence history	Booth equivalent sphere for fission gas release using Turnbull diffusivities	Amoeba effect	Monte Carlo based Sample
Cracked layers	Improved Thermal model for fuel element and particle	HSC thermodynamic based for CO production for any fuel composition	Fission product-SiC interactions (e.g. Pd)	Direct numerical integration
Debonded layers Faceted particles		Redlich Kwong EOS Fission product transport across each layer	Thermal Decomposition	

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Summary

- Completed most successful US irradiation of TRISO-coated particle fuel (AGR-1)
  - 300,000 particles – large statistically relevant population without a single particle failure
  - Relevant gas reactor conditions: time-average peak fuel temperature of <1250° C and a time-average volume-average temperature between 1050-1150° C; peak burnup of 19% FIMA and a peak fast fluence of 5×10^{21} n/cm^2
- Industrial scale fuel production continues to demonstrate repeatability of coated particle fuel production and final optimization of processes
- Plans are underway for AGR-1 post-irradiation examination, AGR-1 safety testing, and AGR-2 irradiation of $U0_2$ and UCO fuel produced from as industrial scale
- Preliminary design of the first source term capsule (AGR 3-4) is underway