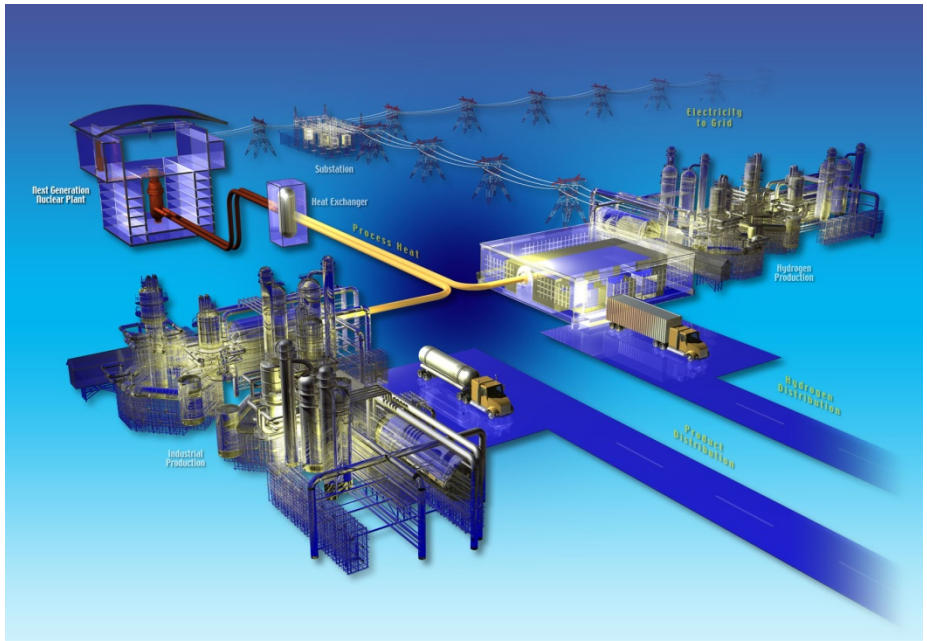
The Next Generation Nuclear Plant Fuels Development Program

Paul Demkowicz

June 30, 2010

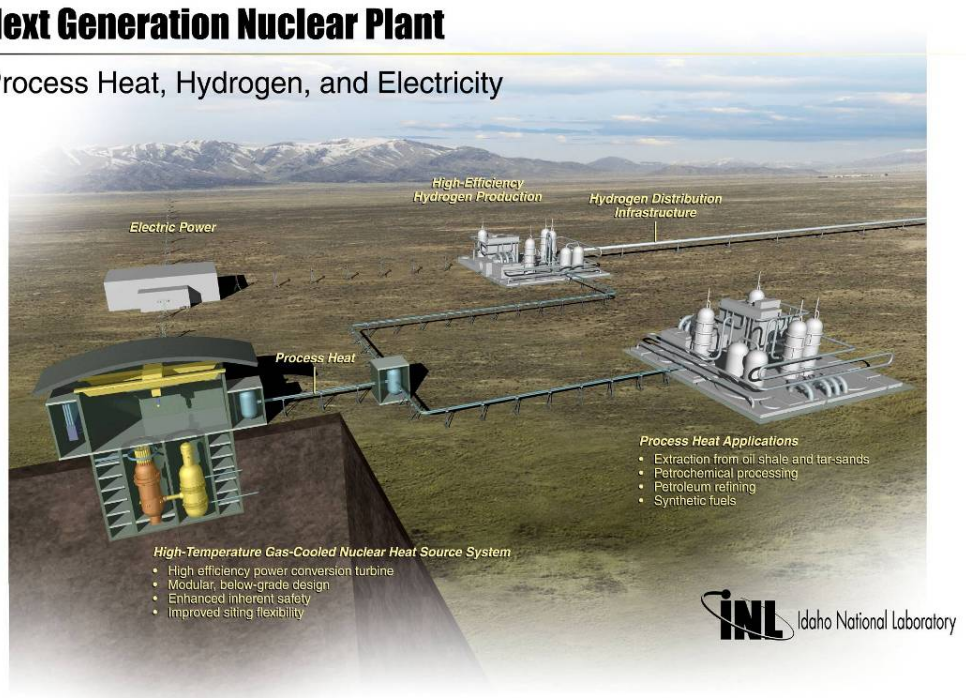


www.inl.gov

Idaho National Laboratory

NGNP background

- NGNP
  - Very High Temperature Gas-Cooled Reactor (VHTR)
  - He coolant
  - Outlet temperature 850-950ºC.
  - Production of electricity and process heat for industrial applications
  - HTGRs have numerous advantages, but a commercial scale demonstration is needed

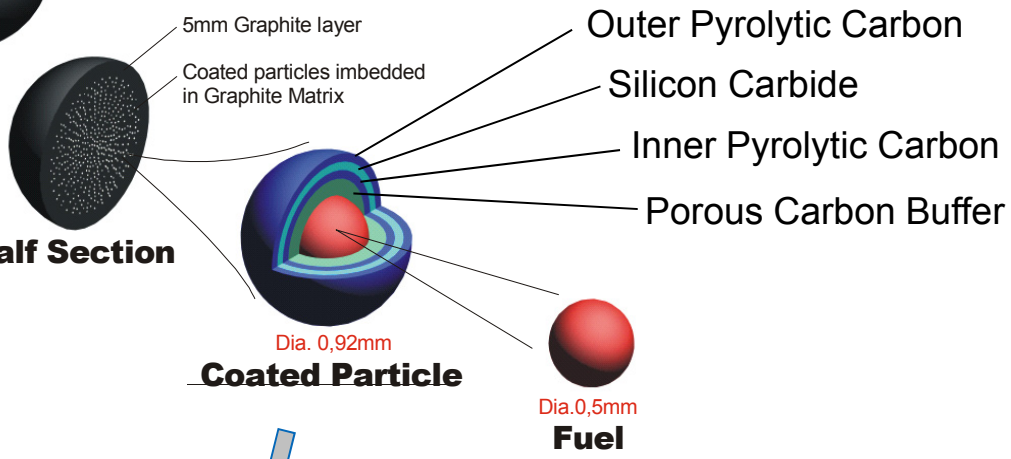


- NGNP Fuels Program:
  - Provide a fuel qualification data set in support of NGNP licensing
  - Fabricate and test performance of TRISO-coated particle fuel under normal operating and accident conditions

NGNP Next Generation Nuclear Plant

Coated particle fuel

Dia. 60mm
Fuel Sphere



Pebble bed fuel elements

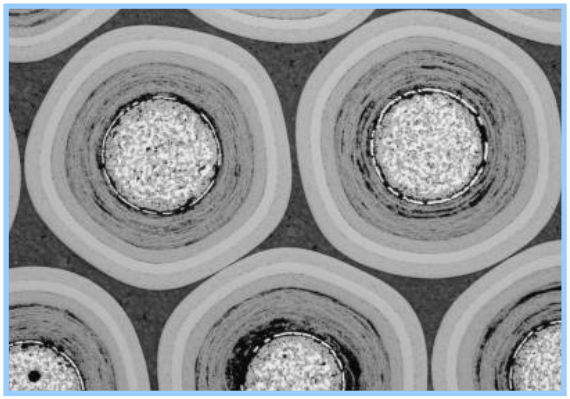
Prismatic fuel elements

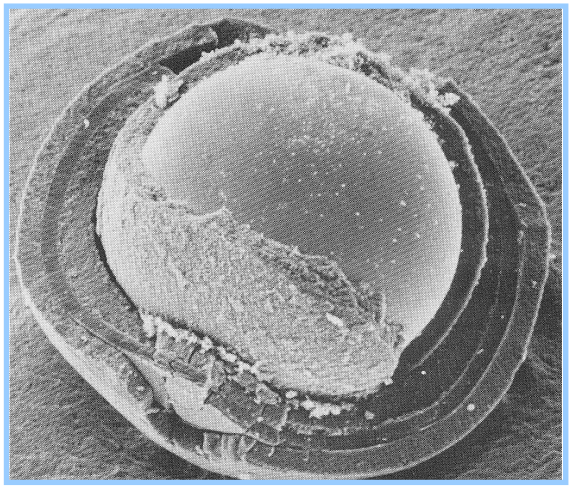
Particles | Compacts | Fuel Element

NGNP Next Generation Nuclear Plant

TRISO fuel performance

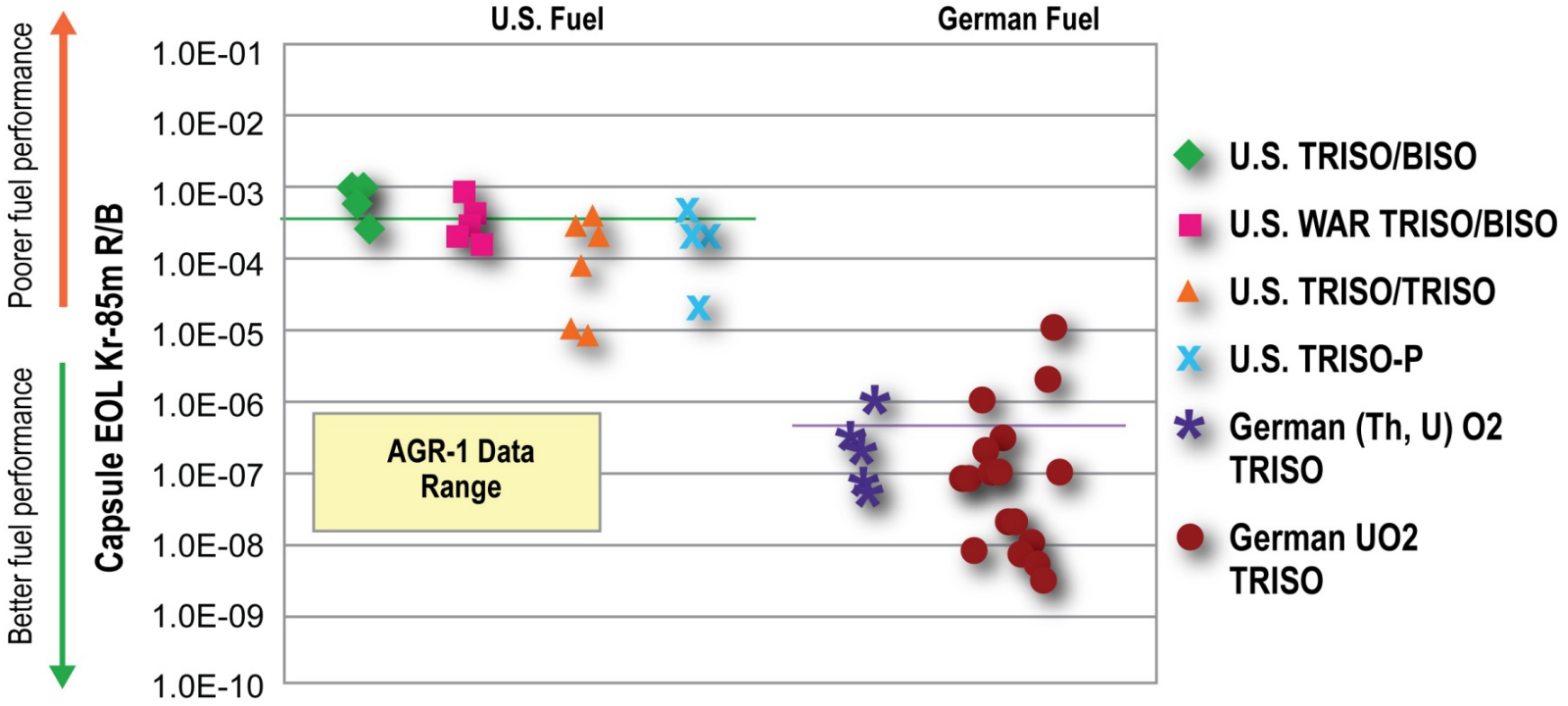
- Coated particle fuel is at the heart of high temperature gas-cooled reactor performance
- Fuel research, development and qualification is focused on demonstrating fuel performance under normal and accident conditions
  - ⇨**Can be fabricated with very low defect fractions (≤10^{-5})**
  - ⇨**The fuel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





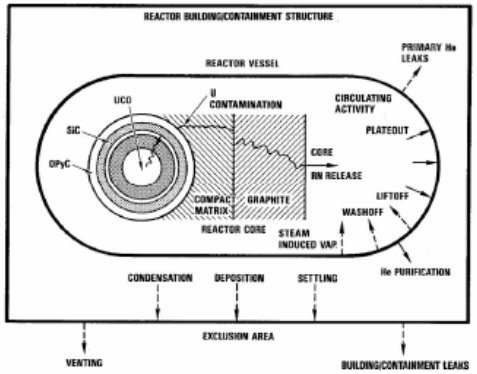
The AGR challenge

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

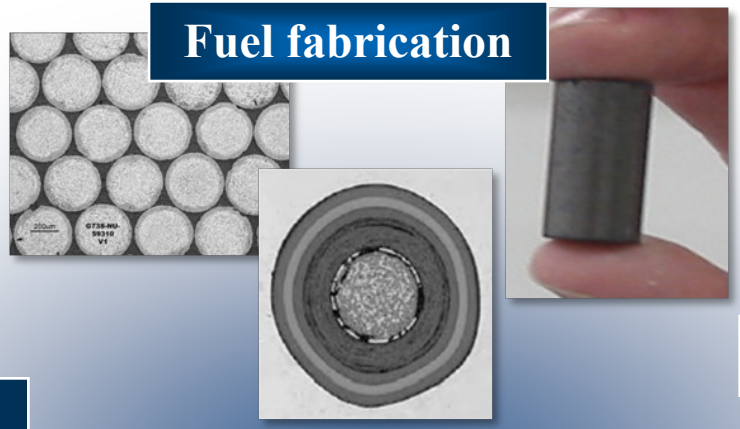


	U.S.	German
Irradiation temperature (C)	930 – 1350	800 – 1320
Burnup (% FIMA)	6.3 – 80	7.5 – 15.6
Fast fluence (10^{25} n/m^2)	2.0 – 10.2	0.1 – 8.5

NGNP Fuel program elements



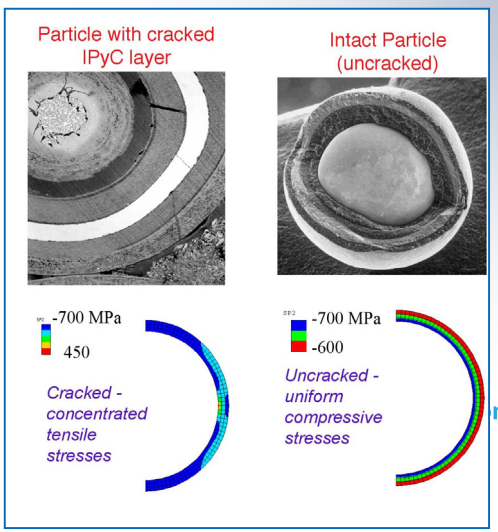
Fission product transport & source term

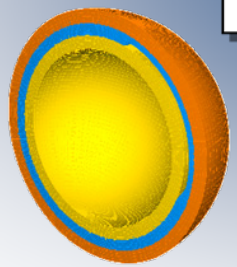


Fuel fabrication

Fuel irradiation

Program participants:
INL, ORNL, B&W, GA

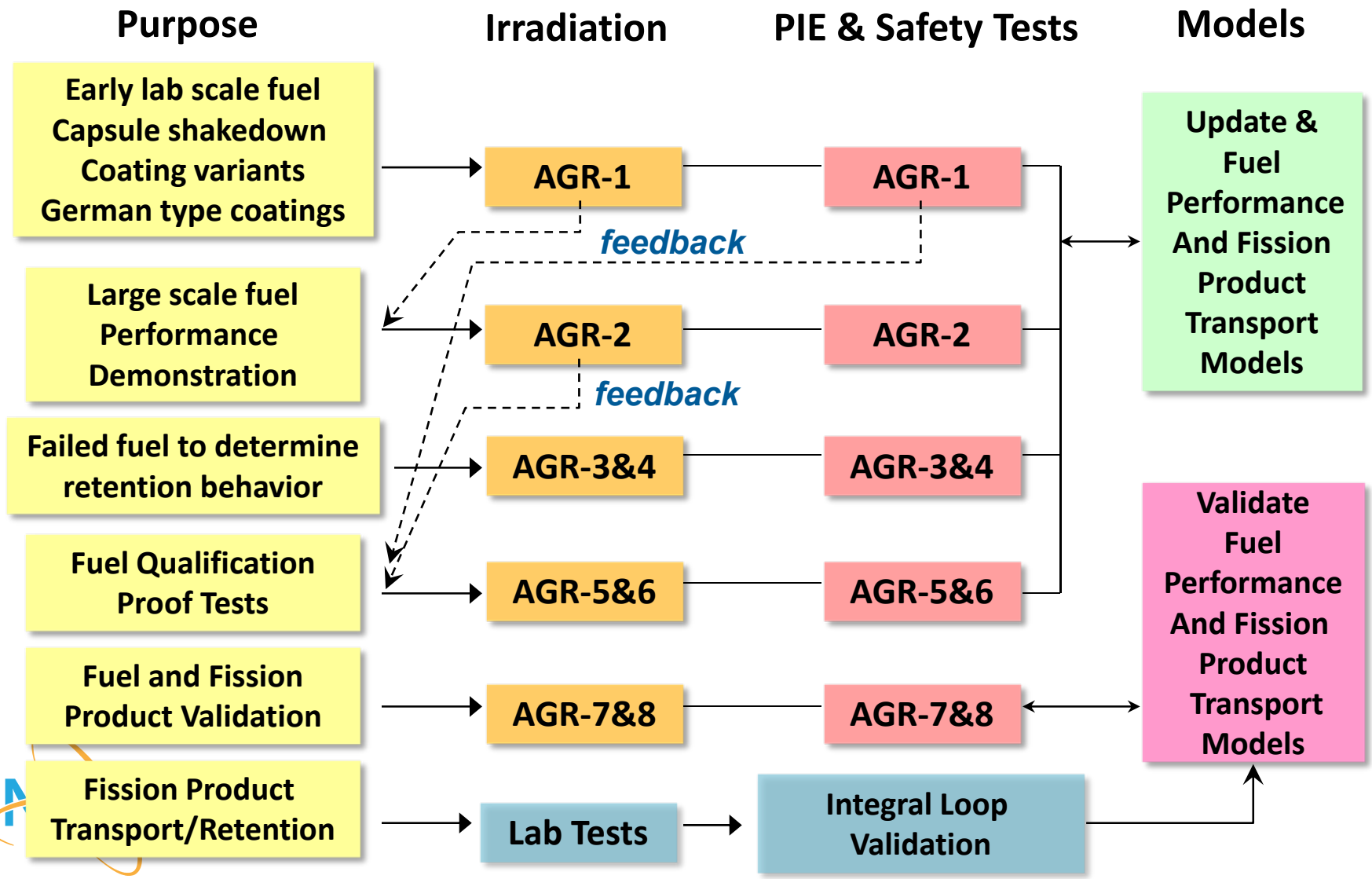




Fuel performance modeling

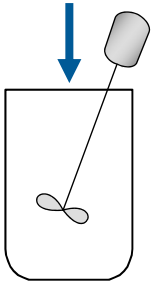
PIE and safety testing

NGNP fuel irradiation tests



TRISO particle fabrication

$^{235}U < 20\%$
U_3O_8

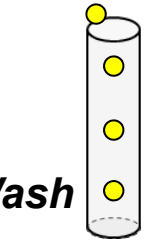


Dissolution

Ammonia Donor

Carbon for UCO

Gelation

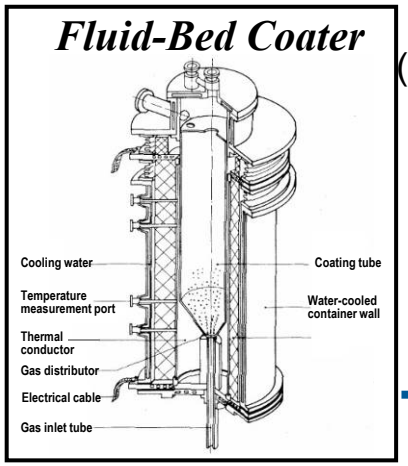


Water-Wash

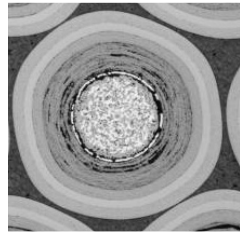
Gel-Sphere

Furnaces
dry-calcine-sinter
200 – 800 – 1600°C

Kernel

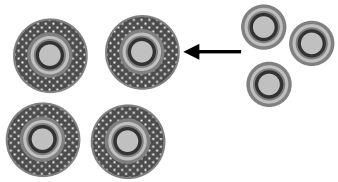


(1300-1500°C) Pyrocarbon, SiC layers

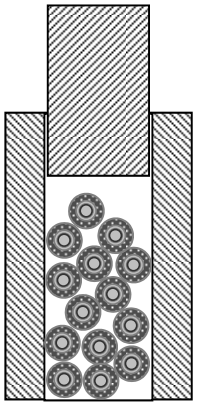


TRISO Particle

Overcoating



Matrix + particles



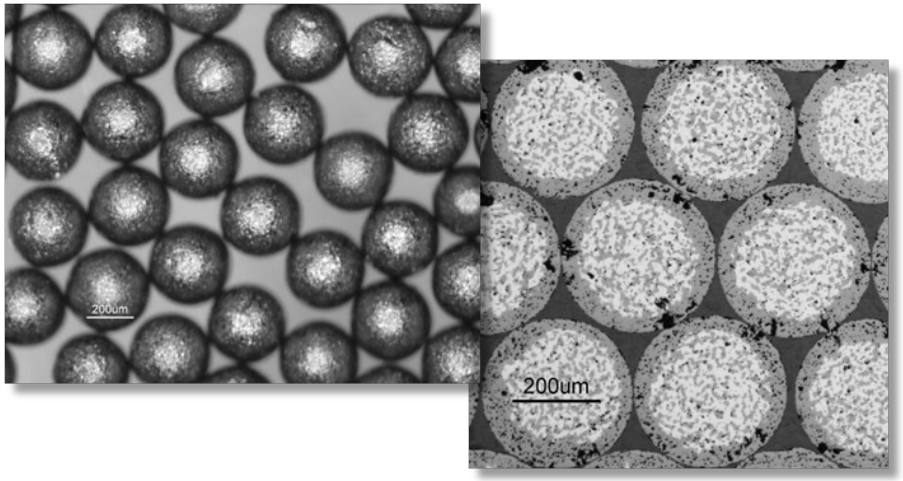
Compaction

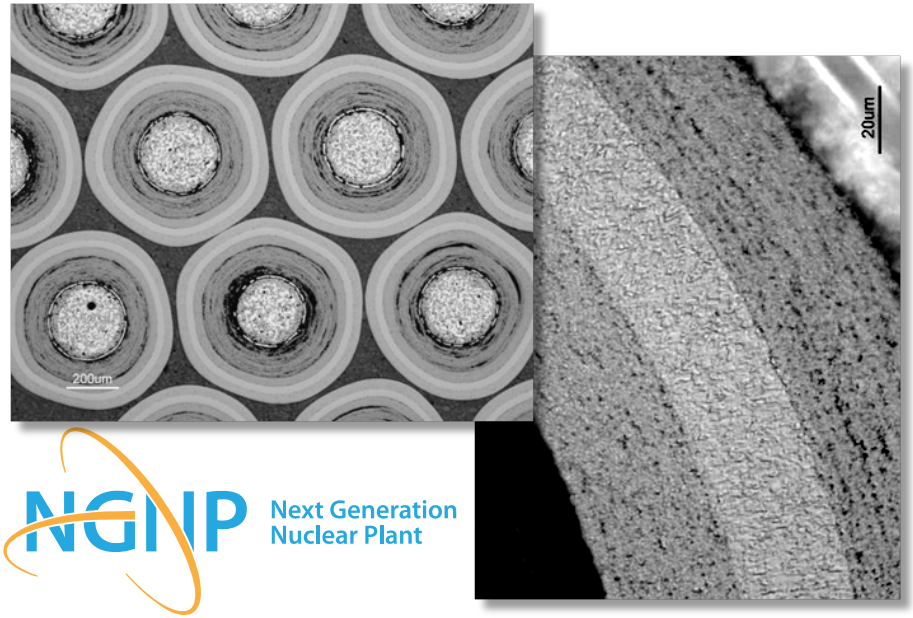
Furnaces
carbonize – heat treat
800 – 1800°C

Compact

NGNP Next Generation Nuclear Plant

Particle fabrication





Kernel fabrication

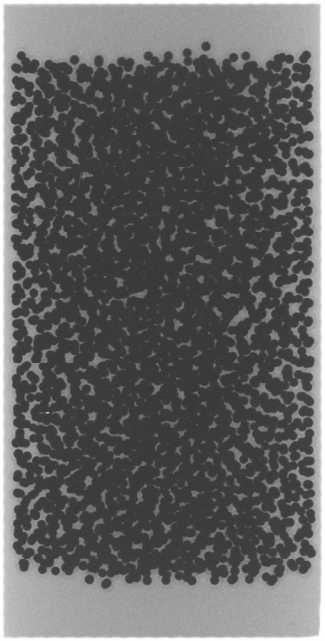
- Key characteristics:
  - Diameter
  - Chemistry
  - Homogeneity
  - Sphericity

Coatings

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

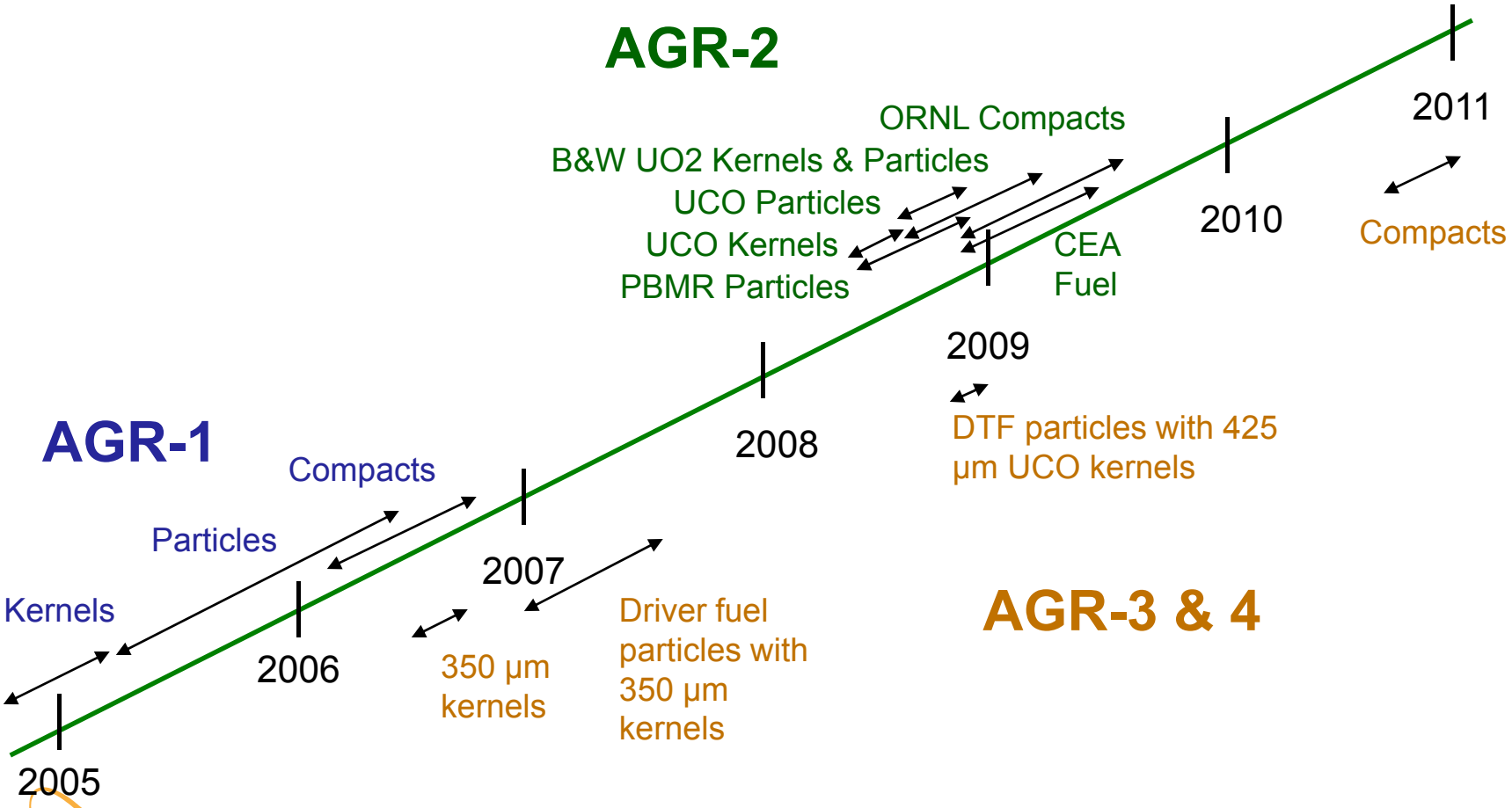
NGNP Next Generation Nuclear Plant

Compact fabrication



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

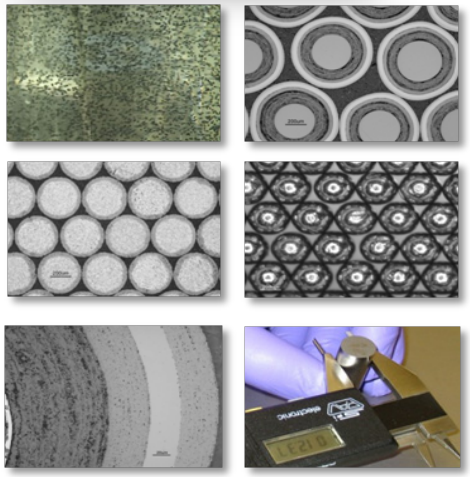
Fuel fabrication timeline



NGNP Next Generation Nuclear Plant

Fabrication accomplishments

- Established capability to fabricate and characterize TRISO -coated particle fuel in the U.S. after a 10-15 year hiatus
- Developed a significantly improved understanding of how to fabricate high-performing TRISO fuel 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 U.S. 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

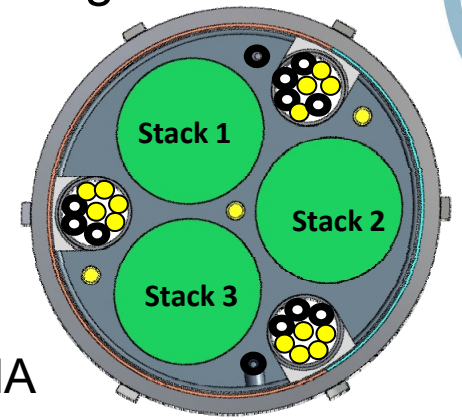


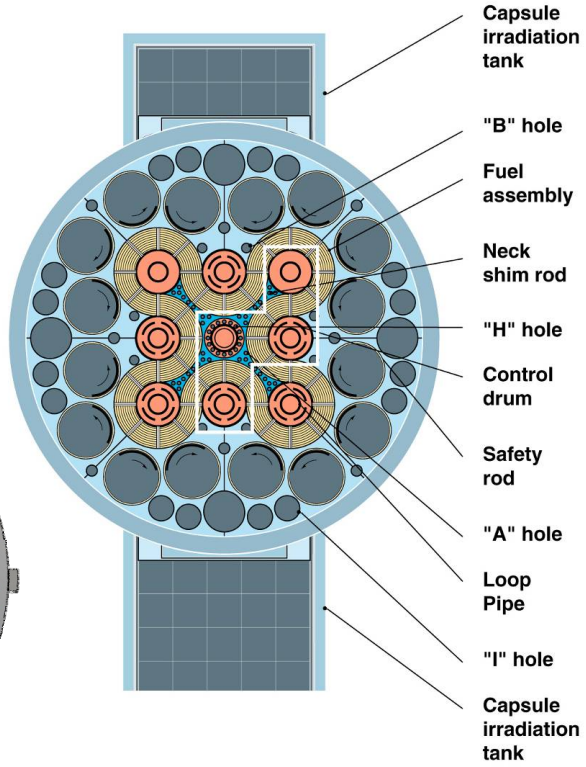
	AGR-1	AGR-2	AGR-5/6
Kernels	Engineering scale	Engineering Scale	Engineering Scale
Coatings	Lab Scale	Engineering scale	Engineering Scale
Compacting	Lab Scale	Lab Scale	Engineering Scale

NGNP Next Generation Nuclear Plant

AGR-1 irradiation

- Irradiation in ATR large B-hole
- Test train consists of six separate capsules with independent temperature control and fission product monitoring
- Fuel compacts:
  - 3 fuel stacks
  - 4 compacts/stack
  - 12 fuel compacts/capsule
- Irradiation goals:
  - 14% FIMA < Burnup < 18% FIMA
  - T_{max} < 1250°C, T_{avg} ~ 1150°C
  - Fast fluence < 5 x 10^{25} n/m^2

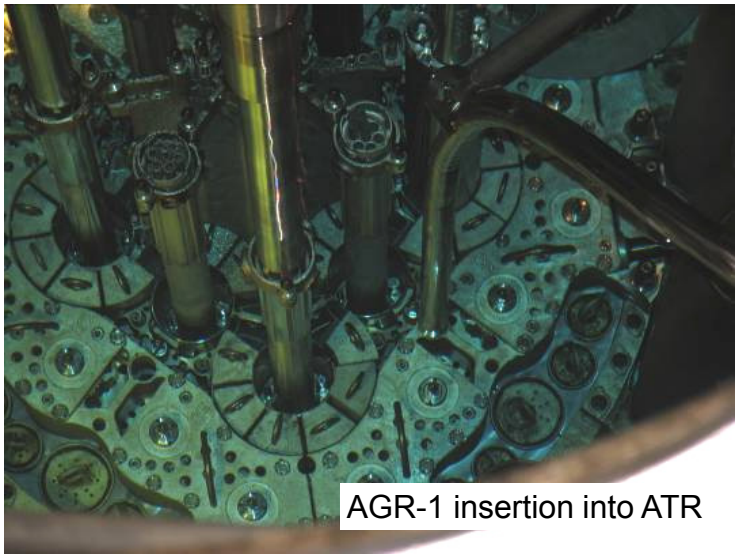




AGR-1 Irradiation

- Began Dec 2006
- Completed Nov 2009
- 622 effective full power days of irradiation
- Peak burnup > 19% FIMA with zero failures out of 300,000 total particles
- Very low fission gas release-to-birth ratios during the irradiation (generally much less than 10^{-7})

AGR-1 fission product monitoring system



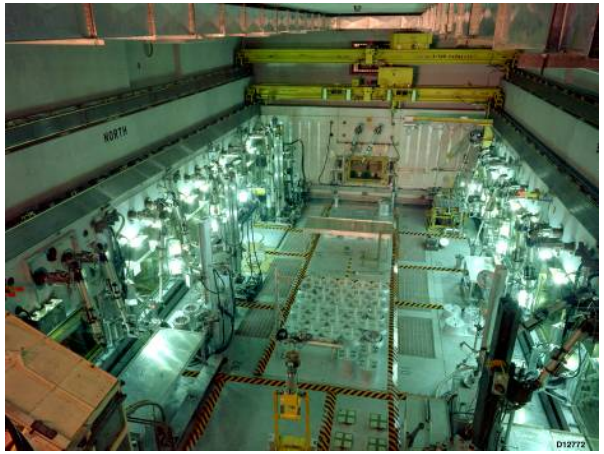
AGR-1 insertion into ATR

AGR-1 burnup and temperatures

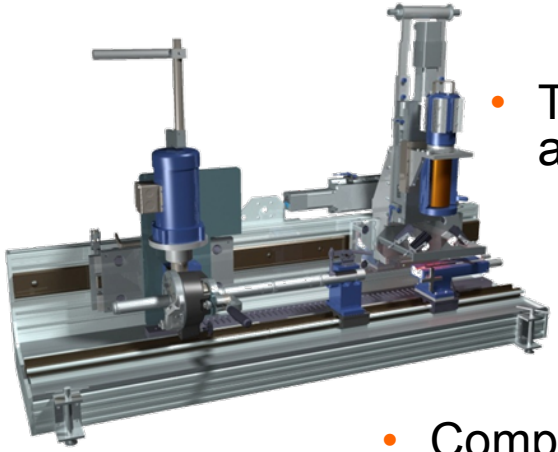
Capsule	Burnup (%FIMA)	Time average temperatures (°C)		
		Peak	Volume average	Minimum
1	13.4 - 17.2	1162	1038	840
2	16.0 – 19.1	1238	1101	885
3	17.1 – 19.6	1211	1076	858
4	16.5 – 19.5	1254	1121	902
5	14.3 – 18.4	1231	1097	883
6	11.5 – 15.0	1183	1076	886

AGR-1 post-irradiation examination

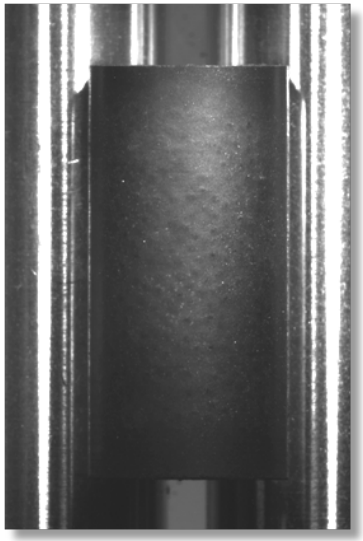
- Assess the performance of NGNP particle fuel under normal and accident conditions
  - Fission product retention of particles
  - Coating/kernel microstructure and integrity
- Support fuel fabrication effort by providing feedback on the relationship between fuel processing, properties, and performance
- Provide data to support development and validation of fuel performance and fission product transport models
- Facilities at INL and ORNL upgraded to support AGR fuel PIE
- AGR-1 PIE began in March 2010



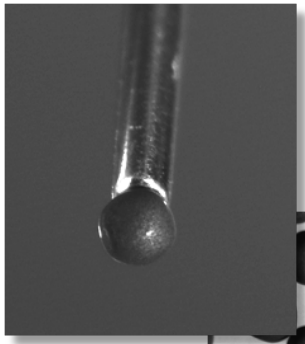
PIE activities overview



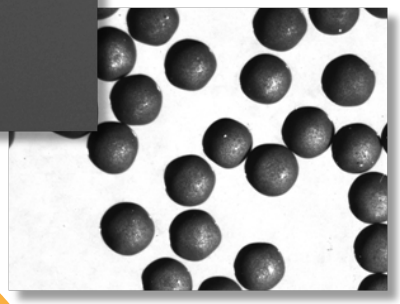
- Test train inspection and disassembly



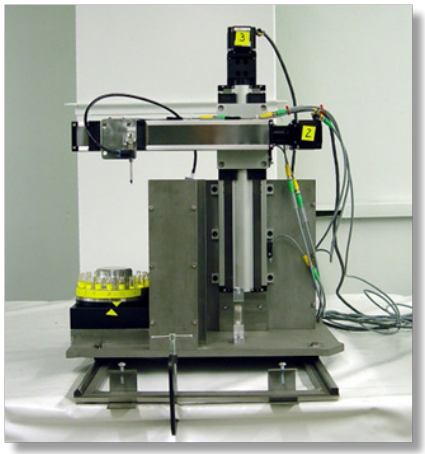
- Fuel inspection and dimensional measurements
- Compact and particle micro-analysis to evaluate coating integrity



- Compact deconsolidation and particle inspections



- Leach-burn-leach testing for failure fraction analysis

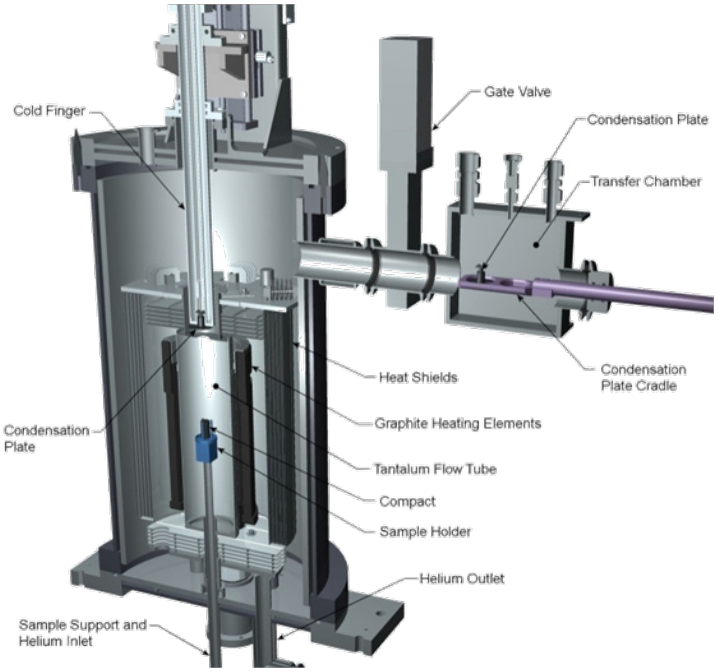


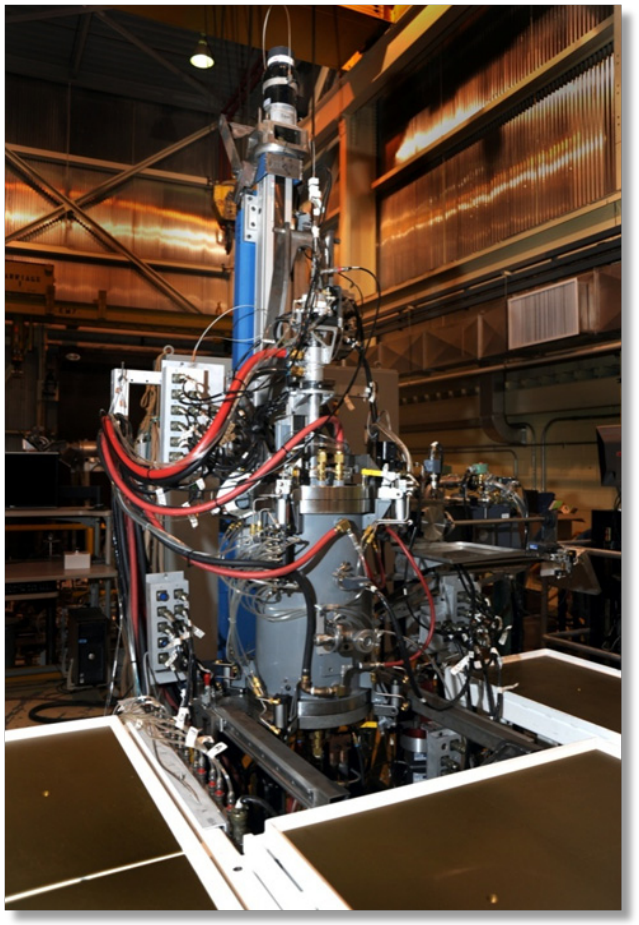
- Particle gamma spectrometry
- Accident testing to determine fission product release at 1400 – 1800°C

NGNP Next Generation Nuclear Plant

Safety testing

- High temperature (1400-1800ºC) testing of compacts in flowing helium
- Measure releases of fission gases (**Kr, Xe**) and fission metals (**Ag, Cs, I, Sr, Eu**)
- Verify fuel performance under simulated accident conditions
- Additional testing in air/moisture mixtures will be needed to simulate air/moisture ingress accidents





Fuel Accident Condition Simulator (FACS) Furnace

NGNP Next Generation Nuclear Plant

AGR program summary and accomplishments

- Fuel development and qualification needed to support NGNP program
- 8 fuel irradiation experiments are planned to examine fuel performance and fission product transport, qualify a reference fuel, and support code development
- Completed most successful U.S. irradiation of TRISO-coated particle fuel (AGR-1). 300,000 particles tested to peak burnup of 19.6% FIMA and peak temperatures less than 1250°C under prototypical HTGR conditions with no failures
- Upgraded INL and ORNL facilities and initiated AGR-1 PIE
- Completed fabrication of AGR-2 fuel produced by industrial teams (B&W, PBMR and CEA/CERCA)
- Fabrication and assembly of AGR-2 irradiation capsule is complete; irradiation to begin in June 2010
- Design of AGR-3/4 is underway