INL/MIS-21-63335-Revision-0

AGR Program Path Forward

July 2021

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Changing the World's Energy Future

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AGR Program Path Forward

Advanced Reactor Technologies

AGR Program Timeline

Early test of lab-scale UCO fuel performance; shakedown of test train design.

Engineering-scale particles in lab-scale compacts. Includes UCO and UO_2 fuel.

"Designed-to-fail" (DTF) fuel to assess fission product retention and transport in reactor graphite and fuel matrix.

Fuel qualification test. Engineering-scale UCO particles and compacts.

Program participants:
INL
ORNL
BWXT

Fuel Fabrication

AGR-1 | AGR-2 | AGR-3/4* | AGR-5/6/7

Irradiation (in ATR)

AGR-3/4
AGR-1
AGR-2
AGR-5/6/7

2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

PIE

AGR-1
AGR-5/6/7
AGR-2
AGR-3/4

**Includes fabrication of DTF particles; driver fuel taken from AGR-1 fabrication campaign*

Major Tasks to Completion

- AGR-3/4 PIE and data analysis
- AGR-5/6/7 PIE and data analysis
  - Priority is to understand Capsule 1 behavior
- Oxidation testing
- Reporting

A Decade of Changes in Coated Particle Fuel Development

~2010

- AGR fuel form:
  - 425 µm LEU UCO TRISO particle
  - Cylindrical compact
- Intended for prismatic mHTGR

2021

- Large variety of reactor designs
  - ~1 MWe to ~300 MWe
  - Prismatic, pebble bed
  - Coolant: Helium, Flibe
- Many fuel design variations
  - Kernel composition
  - Kernel size
  - Coating architecture
  - Matrix material
  - Fuel form (compact, pebble)

Impact of modified fuel designs and different operating conditions will have to be evaluated as part of fuel qualification

Coated-Particle-Fueled Reactor Concepts and Fuel Designs

Developer	Description	Fuel design
X-energy	Xe-100 (200 MWt PB HTGR)	UCO TRISO fuel pebbles
	Xe-Mobile (1 – 5 MWe microreactor)	UCO TRISO
Framatome	SC-HTGR (625 MWt)	UCO TRISO fuel compacts
UltraSafe Nuclear	MMR (15 MWt microreactor)	TRISO particles in SiC matrix (“FCM”)
BWXT	Microreactor (50 MWth)	UCO TRISO compacts
	BANR[6]	UN TRISO in SiC matrix
Kairos Power	KP-FHR (140 MWe salt-cooled SMR)	UCO TRISO fuel pebbles
	HERMES (50 MWt test reactor)	UCO TRISO fuel pebbles
Urenco	U-Battery 10 MWt microreactor	UO_2 TRISO fuel compacts
Westinghouse	eVinci 7-12 MWt microreactor	TRISO or other
StarCore Power	20 MWe HTGR	TRISO
HolosGen	22 MWt scalable microreactor	TRISO in fuel compacts
Radiant Nuclear	>1 MWe microreactor	TRISO
ORNL	Transformational Challenge Reactor	UN TRISO in SiC matrix
NASA	NTP, NEP	Various

Useful references:

- Advances in Small Modular Reactor Technology Developments. A Supplement to: IAEA Advanced Reactors Information System (ARIS), 2020 Edition, IAEA (https://aris.iaea.org/Publications/SMR_Book_2020.pdf)
- https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx

TRISO Fuel Variations

Kernel	Kernel diameter	Coating architecture	Matrix material	Form	Coolant
UCO UO_2 UN	425 µm 500 µm 800 µm Other/ unknown	“Standard” TRISO “Modified” TRISO	Graphite and carbonized resin SiC	Standard cylindrical compacts Standard 60 mm pebbles Modified compacts (different size and packing fraction) Modified pebbles (different diameter; variable density) Custom geometry via AMM	Helium Flibe

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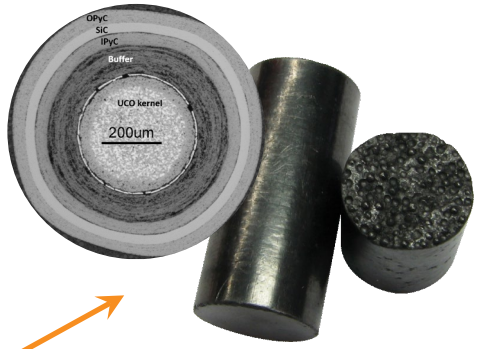

AGR-5/6/7 reference fuel

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Figure source: X-energy

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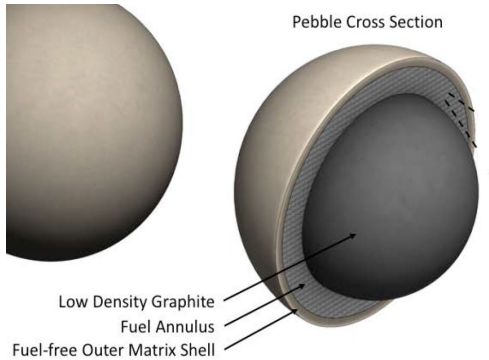

Figure source: Kairos Power

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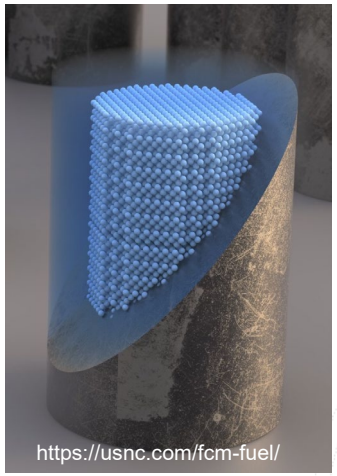

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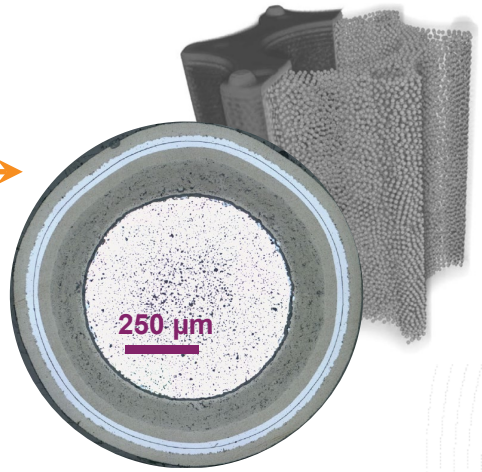
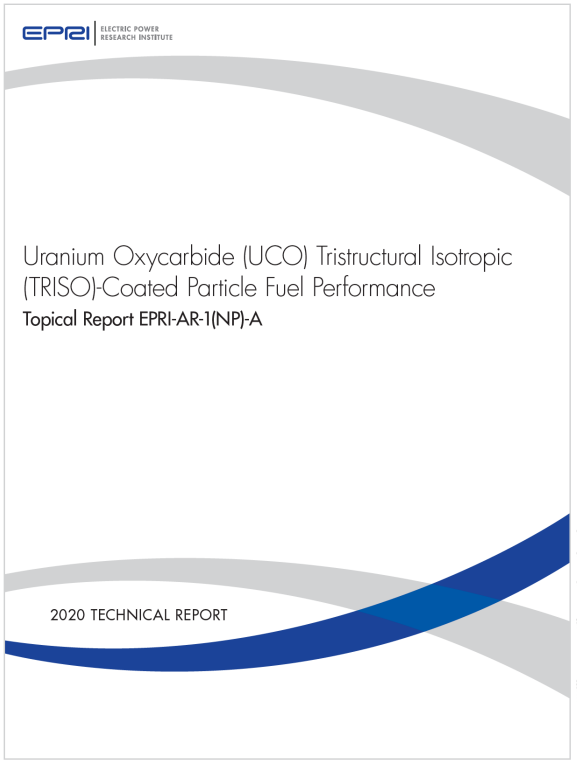


Terrani et al., J. Nucl. Mater. 547 (2021) 152781

Topical Reports

- "Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO)-Coated Particle Fuel Performance," Topical Report EPRI-AR-1(NP))-A, 3002019978 (NRC safety evaluation issued Aug 2020)
  - Topical report preparation process was enhanced by engagement with reactor developers and fuel fabricators
  - Prominent objective was to focus on particle performance to emphasize "technology neutral" aspects of current results
- Topical report candidates:
  - Fission product transport in fuel and core materials based primarily on AGR-3/4 data and analysis
  - Empirical evaluation of fission product release from all AGR experiments
  - AGR-5/6/7 fuel performance, including margin testing to ~1450° C time-average temperature



AGR Program Lessons Learned Evaluation

Topical areas:

- Fuel fabrication
- Irradiation
  - AGR-2 and AGR-5/6/7 suffered numerous issues
  - TCs
  - Capsule design
- PIE
- Fuel performance key findings: impacts on future fuel qualification efforts
- Fuel qualification and NRC interactions

Concluding Remarks

- The AGR program is considered a success story by DOE
  - Funding longevity with good results and a defined completion target date
- Core activities remaining are defined
  - AGR-3/4 and AGR-5/6/7 PIE and data analysis
  - Oxidation test program
  - Reporting
- Current DOE direction is that qualification of other TRISO fuel forms will be led by individual vendors

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