FY 2024 CINR Topic Area 5-Fuels

July 10, 2023

U.S. DEPARTMENT OF ENERGY

Advanced Fuels Campaign

FY 2024 CINR Topic Area 5 – Fuels

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Introduction

Advancements in fuel systems, fabrication processes, cladding concepts, and evaluation techniques are important to ensure that a robust supply chain of well-characterized and optimized fuels is available to support the emerging advanced reactor fleet. NE is seeking proposals for R&D to enhance the performance or resilience of innovative fuels for light-water reactor (LWR) or other advanced reactor applications.

Topics of interest include, but are not limited to, accident tolerant fuels, silicon carbide fuel cladding, TRISO-particle fuels, metallic fuels, and salt fuels. All aspects of fuel design, testing, and evaluation will be considered.

Sub-Topic: Accident Tolerant Fuels - 1

NE is cooperating with U.S. LWR fuel suppliers to develop ATF concepts with significant support from the U.S national laboratories and universities. Near-term concepts include coated zirconium cladding and doped UO2 pellets. Longer term concepts include iron-chromium/aluminum cladding, silicon carbide composite cladding, and high uranium density fuels.

Proposals are sought in areas that can contribute to enhancing LWR safety and performance including, but not limited to, potential applications of ATF fuel concepts to Small Modular Reactors (SMRs).

Federal POC – Frank Goldner, Lab POC – Dan Wachs

Sub-Topic: Accident Tolerant Fuels - 2

Accident Tolerant Fuels

- **Near-Term Concepts**
  - Coated Cladding
  - Doped UO2
- **Long-Term Concepts**
  - Iron-Chrome-Aluminum Cladding
  - Silicon Carbide Cladding
  - High Uranium Density Fuel
- **Uranium Enrichment**

	High-Assay, Low-Enriched Uranium	
Current LWR Fuel	ATF Fuel at High Burnup	Advanced Reactor Fuel
0% < E <= 5%	5% < E <= 10%	10% < E < 20%

Sub-Topic: Silicon Carbide & TRISO - 1

Silicon Carbide fuel cladding is being studied as part of the ATF Program in order to provide robust safety performance for high temperature thermal hydraulic transient conditions. Proposals are sought for activities that enable the goal of licensing silicon carbide cladding for operating nuclear reactors. Potential focus areas could include, but are not limited to, nondestructive evaluation methods, quality assurance characterization techniques, and advances in silicon carbide fuel cladding fabrication methods.

TRISO-particle fuel has demonstrated robust safety performance for high temperature applications. Numerous U.S. companies are pursuing the use of TRISO fuel in their advanced high temperature reactor concepts. Proposals are sought for activities that enable the goal of licensing and operating nuclear reactors that utilize TRISO fuel. Potential focus areas could include, but are not limited to, a comprehensive understanding of fuel and fuel matrix properties under irradiated conditions; addressing unique challenges associated with the use of TRISO fuel in non-typical environments; and activities to evaluate or develop novel TRISO

Federal POCs – Madeline Feltus for SiC, & Matthew Hahn for TRISO; Lab POC – Dan Wachs

Sub-Topic: Silicon Carbide & TRISO - 2

Silicon Carbide (SiC) Fuel Cladding Potential Research Focus Areas:

- Irradiated and unirradiated SiC Cladding materials properties evaluation methods
- Development of novel Non-Destructive Evaluation (NDE) methods
- Advances in SiC fuel cladding fabrication methods
- New fabrication characterization and post-irradiation evaluation (PIE) methods.

Industrial Partners: General Atomics, Ceramic Tubular Products/Novatech, Framatome, etc.

Laboratory Partners: Idaho and Oak Ridge National Laboratories

Reference: **Takaaki Koyanagi, Yutai Katoh, "SiC/SiC Development Strategy and 5-Year Execution Plan," Oak Ridge National Laboratory March 2023, ORNL/SPR-2023/2890**

Suggestions:

- Use NQA-1 quality assurance approach and NDMAS AGR TRISO data system information
- Do not duplicate previous NEUP projects, abstracts and reports: NEUP - Home (inl.gov)

Federal POC – Madeline Feltus, Lab POC – Dan Wachs

Sub-Topic: Silicon Carbide & TRISO - 3

TRISO-Particle Fuel Potential Research Focus Areas:

- Irradiated TRISO fuel and matrix properties
- Development of novel TRISO fuel designs, e.g., UN kernels, refractory metal coatings, non-graphitic matrix materials, getters
- Use of TRISO fuel in non-helium environments
- New fabrication characterization and post-irradiation evaluation (PIE} methods

Industrial partners: X-energy, BWXT, Kairos, Ultrasafe Nuclear, etc.

Laboratory partners: Idaho and Oak Ridge National Laboratories

References:

- AGR TRISO Program Licensing Topical Report: https://www.nrc.gov/docs/ML1915/ML19155A173.pdf
- IAEA TRISO FUEL HTGR Report: https://www.iaea.org/publications/10451/advances-in-high-temperature-gas-cooled-reactor-fuel-technology

Suggestions:

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Federal POC – Madeline Feltus, Lab POCs– Dan Wachs, Paul Demkowicz, AGR Program Manager - Matthew Hahn

Sub-Topic: Metallic Fuels for Advanced Reactors - 1

Metallic fuels for advanced reactors can operate in open or closed fuel cycles. The design of open cycle metallic fuels focuses on optimizing fuel life and energy output and facilitating storage and disposal. For example, chemically reactive or liquid bonds are to be avoided in this group due to complications with storage and disposal. Closed cycle metallic fuel designs seek to maximize fuel burnup to support an efficient and economic fuel cycle, facilitate reprocessing, and minimize geologic repository burden. Fuel/clad bonding is acceptable in this group as long as it does not hinder reprocessing operations. Both open and closed metal fuel cycle applications place a high priority on manufacturability, economics, safety, and resource utilization.

Proposals are sought that will develop and evaluate new or already proposed metallic fuel innovations. Ideally, results will support modeling of metallic fuel performance

Federal POC – Ken Keller, Lab POC – Dan Wachs

Why Metal Fuels?

- Established – EBR II legacy of good performance. Licensable foundation.
- Useful – Metal currently provides a capable, high density option to current advanced (once-through) reactor concepts. Some of these concepts could evolve into more advanced fuel cycles.
- Flexible – Metallic fuel make up can be varied greatly (U/Pu, fission products, actinide content, etc,
- Potential – Evolutionary improvements being explored can increase metal fuel capability e.g. temperature. Readily lends itself to closed fuel cycles which are a future must for efficient resource utilization.
- Non-metal? – the program is open to non-metal advanced fuels. Those concepts should pass comprehensive scrutiny to be considered for exploration and development.

Sub-Topic: Molten Salt Fuel Production - 1

Unlike conventional reactors in which the fuel and coolant are separate phases, some MSR concepts use a molten salt solution as both the fuel and the coolant. There has been considerable effort in characterizing and modeling the thermophysical and thermochemical properties of molten salt as well as the atomic level structure and chemistry of potential salt fuels as a function of composition. Additional progress is needed to develop scalable process chemistries and technologies to produce molten salt fuels that meet the MSR developer specifications for impurities such as oxygen and water. Process chemistries and technologies should be able to produce fuel salt from a variety of non-irradiated enriched uranium sources including high purity UF6 and U metal as well as uranium oxides, carbides, silicides, or nitrides. In addition to high purity enriched uranium sources, there are mixed sources where enriched uranium is incorporated in an inert metal, ceramic, or graphite matrix.

Proposals are sought for development of robust scalable processes and/or equipment for preparing molten fluoride or molten chloride startup or make-up fuel salt to meet one or more MSR vendor specifications using one or more types of the more plentiful non-irradiated enriched uranium source materials.

Federal POC – James Willet, Lab POC – Dan Wachs

Sub-Topic: Molten Salt Fuel Production - 2

- Depending on the MSR design
  - Fuel salt will be molten chloride or molten fluoride
  - Different matrix salt compositions
- Fuel salt production will require
  - Blending and purification of matrix salt
  - Conversion of fissile source material to appropriate halide in appropriate redox state
    - UF_6 -- $UF_6 \rightarrow UF_4$; $UF_6 \rightarrow UCl_3$
    - UO_2 -- $UO_2 \rightarrow UF_4$; $UO_2 \rightarrow UCl_3$
- Fissile source conversion can be designed to produce pure halide or to produce fissile halide in a molten salt solution.
- Proper packaging of all salts will be essential
  - Protected from air and moisture during production,storage and transport
  - Packaged for clean transfer to the MSR