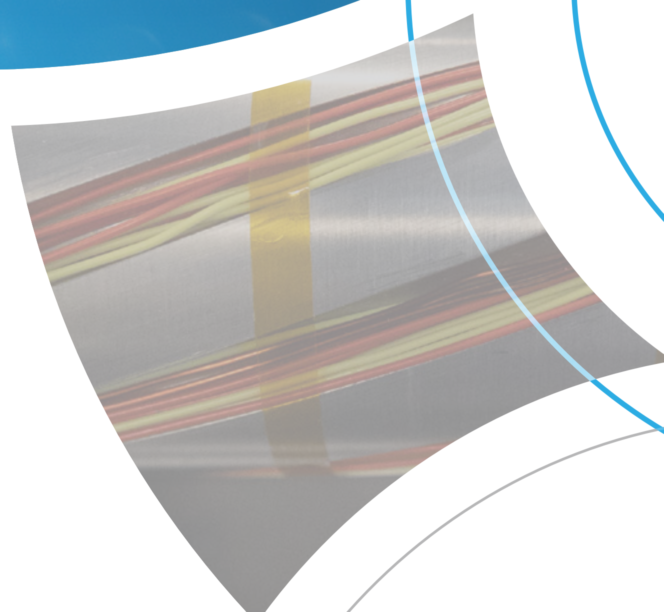
ADVANCED FUELS CAMPAIGN

STRATEGIC VISION

INL/MIS-26-91374
REVISION 1



Advanced Fuels Campaign

APRIL **2026**

Advanced Fuels Campaign: Strategic Vision

April 2026

https://www.nuclearfuel.inl.gov

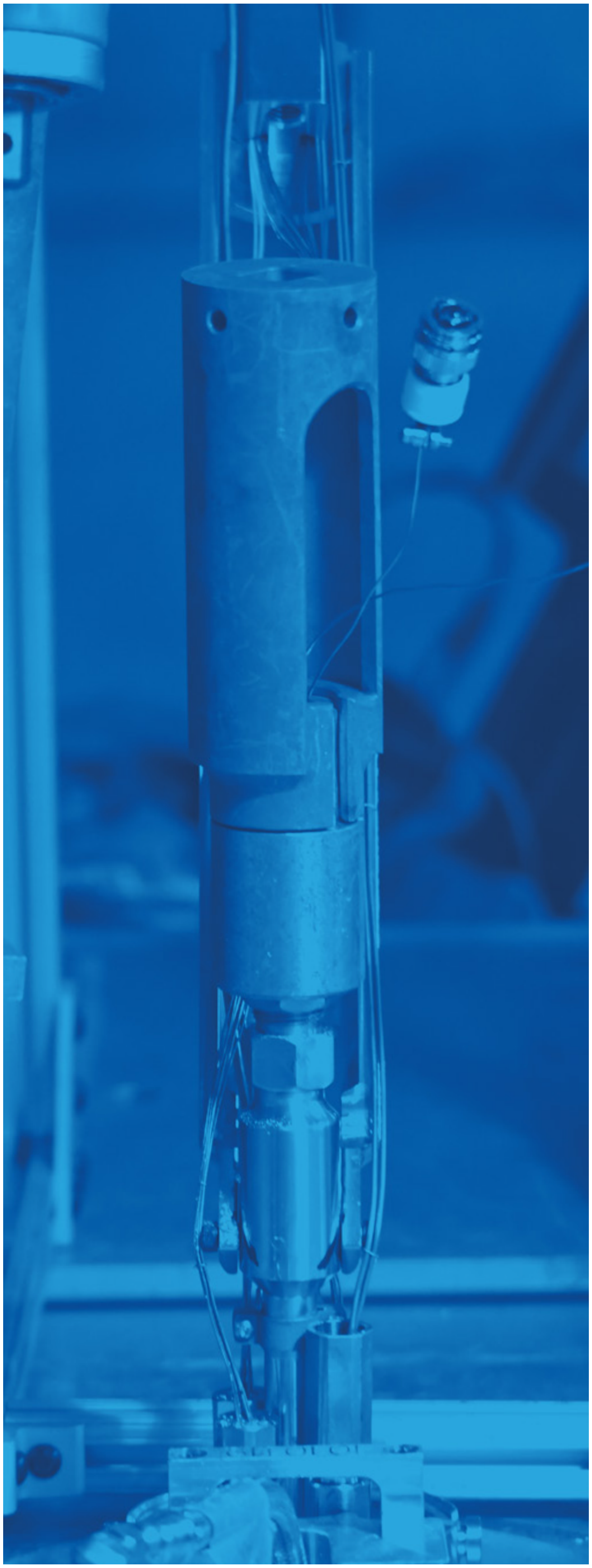
PREPARED FOR THE

U.S. Department of Energy

Office of Nuclear Energy

Under DOE Idaho Operations Office

Contract DE-AC07-05ID14517



CONTENTS

ACRONYMS

AFC
Advanced Fuels Campaign

AFDQ
accelerated fuel development and qualification

AGR
advanced gas-cooled reactor

AI
artificial intelligence

AMIX
Air-Moisture Ingress Experiment

ARDP
Advanced Reactor Demonstration Project

ASI
Advanced Sensors and Instrumentation

ATF
accident tolerant fuels

ATR
Advanced Test Reactor

CRAFT
Collaborative Research for Advanced Fuel Technologies

DOE
Department of Energy

eATF
enhanced accident tolerant fuel

EBR
Experimental Breeder Reactor

EPRI
Electric Power Research Institute

FFTF
Fast Flux Test Facility

FIDES
Framework for Irradiation Experiments

FOAK
first-of-a-kind

GCR
gas-cooled reactor

GIF
Generation IV International Forum

GW
gigawatt

GWD
gigawatt-days

HALEU
high-assay low-enriched uranium

HBU
high burnup

HFIR
High Flux Isotope Reactor

HTGR
high-temperature gas reactor

HTR
high-temperature reactor

IAEA
International Atomic Energy Agency

IFR
Integral Fast Reactor

INL
Idaho National Laboratory

JHR
Joules-Horowitz Reactor

LEU
low-enriched uranium

LOCA
loss of coolant accident

LWR
light water reactor

LWRS
Light Water Reactor Sustainability

MIT
Massachusetts Institute of Technology

MITR
MIT Reactor

ML
machine learning

MRWFD
Materials Recovery and Waste Form Development

MSR
molten salt reactor

MTU
metric ton of uranium

NE
Nuclear Energy

NEA
Nuclear Energy Agency

NEAMS
Nuclear Energy Advanced Modeling and Simulation

NEUP
Nuclear Energy University Program

NGF
Next Generation Fuels

NRC
Nuclear Regulatory Commission

NSUF
Nuclear Science User Facilities

OECD
Organisation for Economic Co-operation and Development

ORNL
Oak Ridge National Laboratory

PICS:NE
Program Information Collection System for Nuclear Energy

PIE
post irradiation examination

R&D
research and development

RD&D
research, development and demonstration

RIA
reactivity-initiated accident

SAI
Systems Analysis and Integration

SFR
sodium-cooled fast reactor

SMR
small modular reactor

t@T
time at temperature

TREAT
Transient Reactor Test Facility

TRISO
Tri-structural Isotropic

TRL
technical readiness level

U.S.
United States

UCO
uranium oxycarbide

UFC
Uranium Fuel Supply

U-Zr
uranium-zirconium

U-Pu-Zr
uranium-plutonium-zirconium

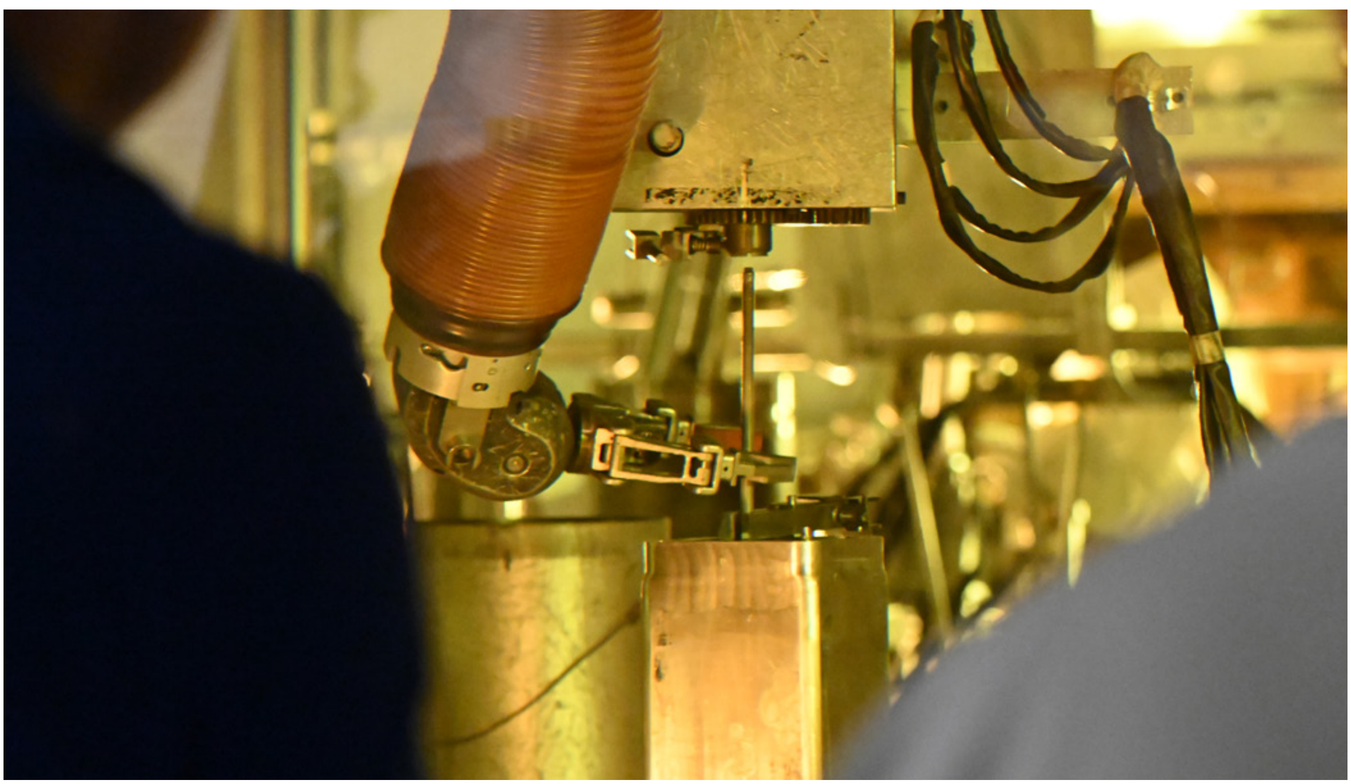
INTRODUCTION

The Advanced Fuels Campaign (AFC) is responsible for leading research, development and demonstration (RD&D) activities related to nuclear fuels and materials development.

The AFC has a **strategic vision** for a thriving U.S. nuclear energy sector that leverages nuclear fuel technology to optimize the integrated fuel cycle and **a mission** to advance nuclear fuel technology through advanced RD&D to meet U.S. energy capacity, security, and economic needs.

AFC is the primary national reservoir for crosscutting advanced nuclear fuel technology expertise. The program provides stewardship of the nation's extensive nuclear fuels and materials knowledge developed through decades of federal investment. AFC applies this expertise to drive modern RD&D programs that are focused on meeting national nuclear fuel related challenges across the full nuclear energy technology landscape, with a vision to meet the needs of today and to prepare for the needs of the future.

The United States (U.S.) Department of Energy (DOE), Office of Nuclear Energy (NE), and its predecessor organizations, sponsored applied technology programs aimed at advancing nuclear fuel technology for over 60 years. This long-term RD&D delivered the nuclear fuel technologies that form the foundation for the advanced nuclear reactor systems that are both commercial deployed and proposed for demonstration and subsequent commercial deployment in the U.S. and abroad. Today, this includes light water reactor (LWR) fuels with features that enhance performance (both economically and under accident conditions) and a suite of technology enabling next generation fuels (NGF). NGFs include metallic alloy fuels for sodium fast reactors (SFR), Tri-structural Isotropic (TRISO) coated particle fuels for high temperature gas reactors (HTGR), and salt fuels for molten salt reactors (MSR). Anchored by legacy RD&D, AFC has identified reference fuel designs for each reactor system and is rapidly progressing them toward qualification, subsequent licensing, and broad commercial deployment while simultaneously seeking innovative fuel technologies that will make nuclear energy increasingly competitive.



AFC is dedicated to propelling and maintaining the U.S. at the **forefront of nuclear fuel technology** through a comprehensive strategic vision. The vision is structured around five key goals.

Lead nuclear fuel technology RD&D.

Expand energy production from the existing fleet.

Initiate and complete qualification basis for advanced reactor fuels.

Champion innovation in advanced nuclear fuel technology.

Cultivate high-impact teams driven by efficiency, collaboration, and exceptional results.

By focusing on these goals, AFC aims to define and implement cutting-edge nuclear fuel technologies, support industry advancements, achieve critical fuel qualifications, foster innovative research, and ensure effective program management and stakeholder engagement. This strategic approach will maintain the U.S. position as a global leader in nuclear energy and fuel technology, while also preparing for the future of cost effective and reliable access to energy.

Currently, AFC fuel technology RD&D resources are prioritized toward near-term fuel qualification, which will enable immediate deployment in collaboration with industrial partners. There are two broad programmatic focus areas, and the objectives of each area are depicted in Figure 1.

1. **Enhanced Accident Tolerant Fuel (eATF)** technology development to increase the generating capacity of the current LWR fleet through improved fuel performance.
2. **NGF** technology to develop, deploy, and optimize advanced nuclear reactor fuel technologies in the near term and to optimize the fuel cycle of the future.

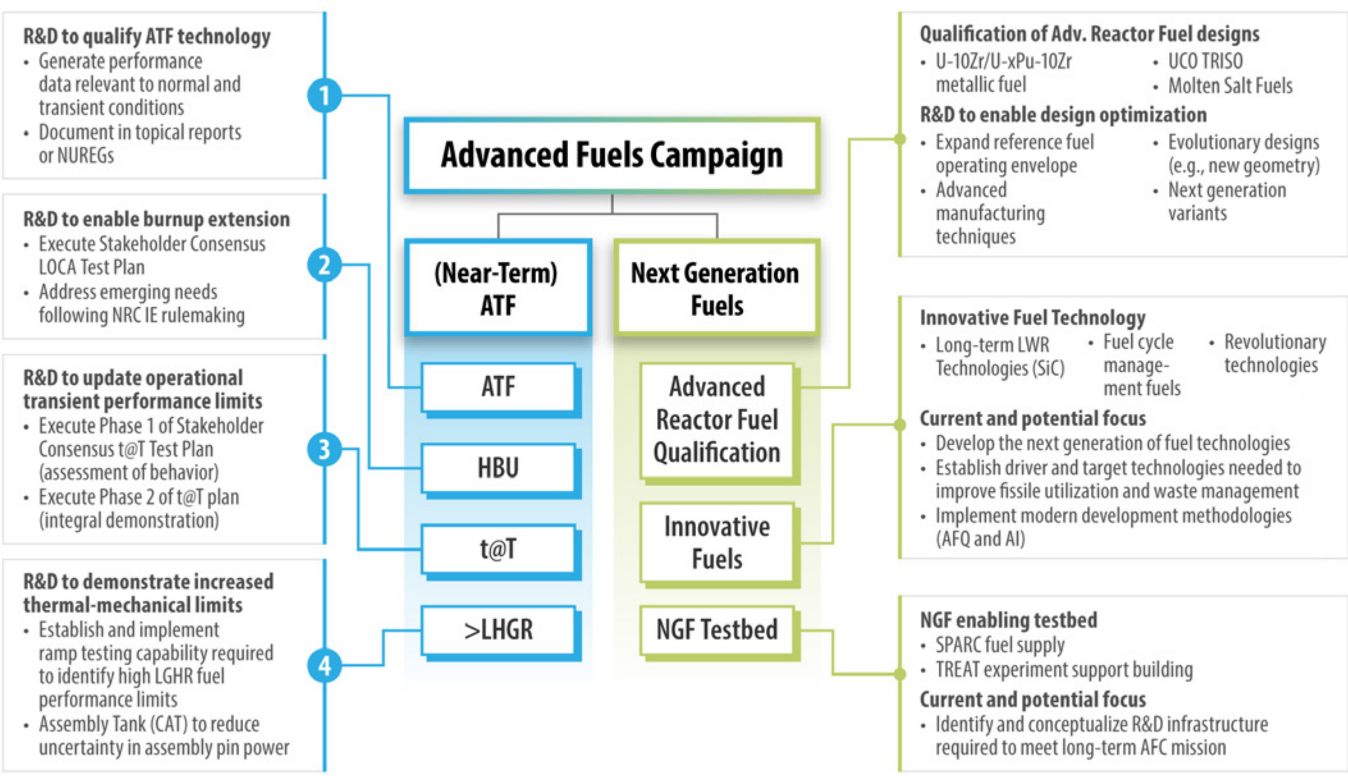


Figure 1. Structure of AFC including ATF and NGF programs.

Enhanced Accident Tolerant Fuels (eATF)

The Accident Tolerant Fuels (ATF) program was launched in 2012 in response to the damage done to the Fukushima Daichi nuclear site in Japan following the Great Tohoku Earthquake and subsequent Tsunami in March 2011. At its inception, a three-phase program was envisioned to 1) identify and screen viable concepts, 2) develop and qualify new technologies, and 3) commercially deploy technologies. During the first two phases, the program has achieved, and even exceeded, many of its defined goals. Most notably delivering lead test assemblies to commercial plants in 2018 (*four years ahead of the proposed schedule*). To further accelerate adoption of ATF technology, Congress updated the program in 2019 to include use of low-enriched fuel (LEU)+ (increased enrichment to 5-10%) and increased burnup to maximize the value of using ATF technologies. As the program enters Phase 3, the eATF program shifted focus toward conducting RD&D activities that accelerate the technology deployment.

This transition coincides with the new Executive Orders calling for significant increases in nuclear generating capacity. The technologies being developed by the eATF program are key to achieving 5 gigawatts (GW) of new capacity by the end of the decade[a] and 300 GW of new generating capacity by 2050[b]. The eATF program has enabled cooperative research programs with each of the three major U.S. nuclear fuel suppliers, Westinghouse, General Electric/Global Nuclear Fuels, and Framatome, leading to development of fuel designs and analytical methods that support US utilities in achieving this objective. These fuel designs simultaneously provide enhanced performance under postulated accident conditions and offer expanded operating margins. As outlined in utility proposals issued in 2026, these new margins can be captured to improve plant performance, economics and, thus, enable significant generating capacity increases for both the existing fleet and new plants constructed in the future.

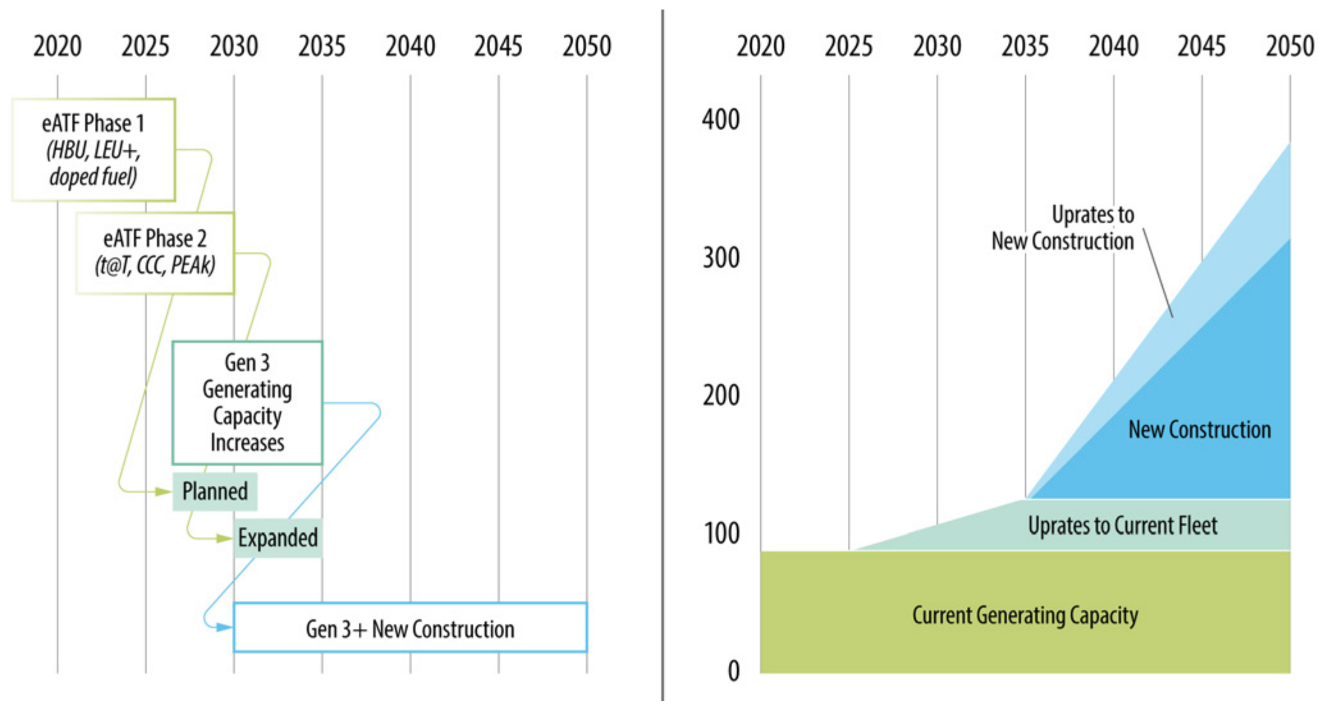


Figure 2. RD&D for eATF nuclear fuel technology will drive several stages of nuclear generating capacity expansion.

a Executive Order 14302, "Reinvigorating the Nuclear Industrial Base," https://www.federalregister.gov/documents/2025/05/29/2025-09801/reinvigorating-the-nuclear-industrial-base

b Executive Order 14300 "Ordering the Reform of the Nuclear Regulatory Commission," https://www.federalregister.gov/documents/2025/05/29/2025-09798/ordering-the-reform-of-the-nuclear-regulatory-commission

This pathway follows trends observed over the last 40 years, where ongoing research investment has resulted in remarkable increases in burnup limits[c], realization of near-zero defects during operation, significant power uprates, enhanced operational flexibility, and resilience under upset conditions. All of which ultimately translate to delivering more abundant, affordable, and safe energy. Continuous investment in the fuel cycle supporting the fleet is critical to ensuring that energy is both available to users and that it remains an affordable resource in the face of dramatic demand increases.

Next Generation Fuels (NGF)

The NGF program is required to enable the demonstration of advanced reactors, push existing nuclear reactor technologies in revolutionary directions, and implement integrated fuel cycle objectives. Ongoing public/private partnerships to demonstrate advanced reactor technology are reliant on completing decades-long DOE-led fuel development and qualification programs, which must be finished in the next 5 years to meet high-level demonstration project timelines. Notably, the nearest term reactor demonstration projects such as TerraPower's Natrium, X-energy's Xe-100, Kairos' Hermes, OKLO's Aurora, Natura's MSR-1, and Southern Company's MCRE depend on using legacy data and recent research and development (R&D) activities to complete the qualification of the metallic alloy, TRISO, and molten salts fuel forms before the U.S. Nuclear Regulatory Commission (NRC) can deliver the design certification and operating licenses.

Following these seminal demonstration projects, it is expected that the next generation of advanced reactors will follow a similar trend to LWRs. During the first period of deployment, the technical focus is placed on *demonstration* of the reactor technology. That focus will quickly shift to *optimization* of its operation and fuel cycle to pursue economic viability. The nuclear fuels community (industrial and research combined) will be responsible for delivering both the foundational fuel systems needed for initial operations during the design and demonstration phase but must simultaneously anticipate and execute the R&D necessary to accelerate the reactor performance optimization phase that

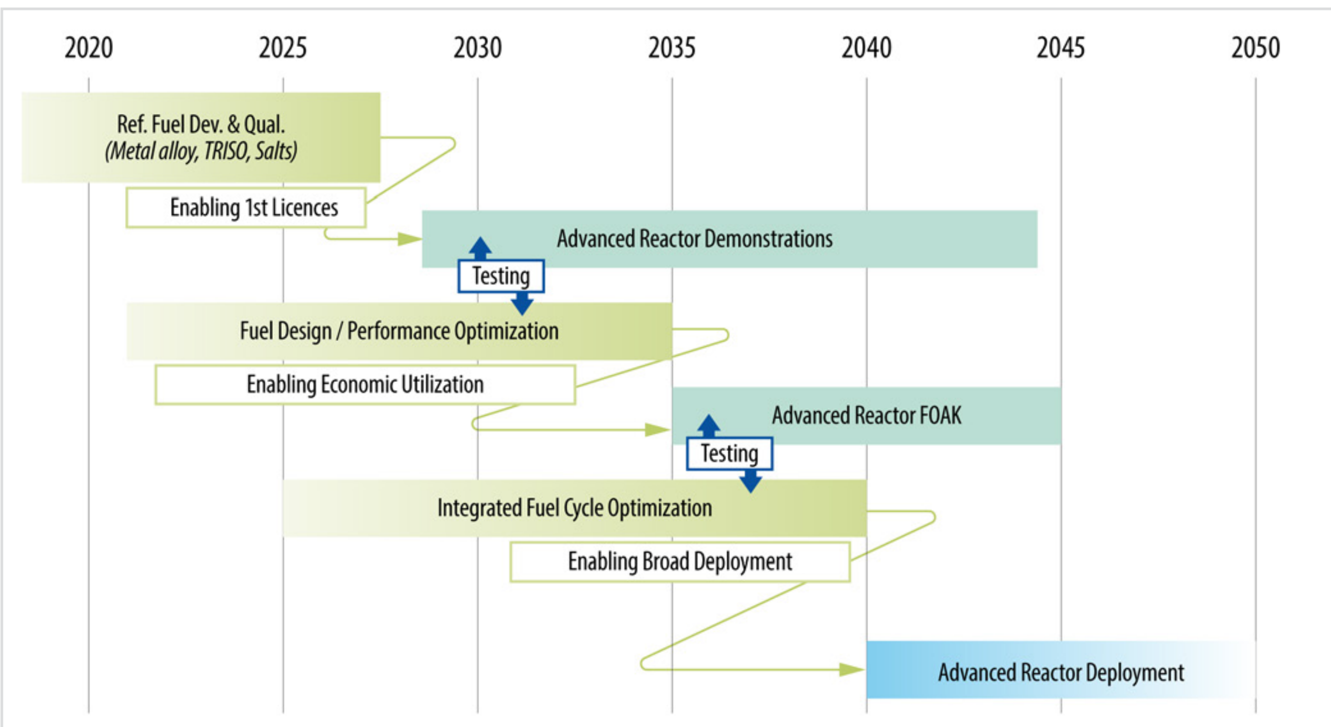


Figure 3. NGF RD&D will enable the demonstration, optimization, and economic deployment of advanced reactor technology.

c The average fuel assembly utilization has increased from approximately 20–30 GWD/MTU to over 50 GWD/MTU since the mid-1980s. https://www.eia.gov/nuclear/spent_fuel/ussnftab3.php.

Temperature Heat sink Overpower Response Mixed-Oxide Transient OverPower (THOR-MOXTOP) experiment.

impacts economic viability of the first-of-a-kind (FOAK) demonstrations. These optimizations must then be integrated into a broader fuel cycle and supply chain system that ultimately underpins the success of a fleet of advanced reactors. The long-term viability of advanced fuel technologies will require continued RD&D to fit within an integrated nuclear material utilization lifecycle that accounts for fissile sourcing, enrichment, fabrication, power generation, storage, recovery, and disposition.

To remain competitive, innovative technologies must be continuously developed that can further enhance the existing reactor systems, pivot toward emerging needs and opportunities, or revolutionize nuclear energy technology. As these new reactor and fuel/fuel cycle technologies mature together, the opportunity for innovation injection will be uniquely available. Emergence of new fuel technologies during this critical time frame is essential to establishing the highest 'ceiling' for the overall nuclear enterprise. Strategic investments in R&D that identifies and matures promising concepts is a critical element of the DOE program portfolio that must accompany its deployment driven efforts.

Development Methodologies to Accelerate Innovation

AFC RD&D programs study all aspects of the fuel utilization lifecycle spanning fuel system design, fabrication, in-service performance, and off-normal performance. This work requires development, utilization, and stewardship of a wide range of unique experimental and modeling capabilities that are specifically tailored to critical materials and the applications of interest. Thus, the opportunity to accelerate innovation in nuclear fuel technology relies heavily on implementing methodologies, some new and some traditional, that shorten the development and deployment lifecycle (commonly referred to as accelerated fuel development and qualification [AFDQ] methods). Establishing these tools is a foundational element that underpins the program and is a central theme of the AFC mission and strategy laid out in this document.

INTEGRATION OF AFC WITHIN DOE-NE

DOE-NE plays a critical role in development and deployment of civilian nuclear technology as outlined in its Strategic Vision[a]. DOE-NE is an applied energy R&D organization that enables innovation, supports unique research infrastructure, and solves crosscutting nuclear energy challenges.

DOE-NE invests in R&D that the private sector or other non-government stakeholders are unable to perform due to the radioactive nature of the materials, cost, scale, and time frame required. DOE-NE funding creates opportunities for world-class researchers in industry, academia, and the national laboratories to collaborate and solve scientific and engineering challenges. By leveraging private-public partnerships and the U.S. national laboratory system, DOE-NE is making nuclear energy more cost effective, accelerating advanced reactor deployment, making nuclear fuel cycles more cost effective, encouraging a resilient supply chain, and promoting a robust and expanding nuclear workforce.

Consistent with these priorities, recent federal policy direction reinforces the urgency of accelerating innovation across the reactor and fuel cycle enterprise. On May 23, 2025, four Executive Orders were issued to expand advanced nuclear deployment and strengthen the supporting infrastructure.

- *Deploying Advanced Nuclear Reactor Technologies for National Security, Executive Order 14299[b].*
- *Ordering the Reform of the Nuclear Regulatory Commission, Executive Order 14300[c].*
- *Reforming Nuclear Reactor Testing at the Department of Energy. Executive Order 14301[d].*
- *Reinvigorating the Nuclear Industrial Base, Executive Order 14302[e].*

Together, these directives emphasize rapid deployment of advanced reactors, modernization and streamlining of licensing processes, expanded testing and demonstration capacity at DOE facilities, restoration of domestic fuel cycle capabilities—including high-assay low-enriched uranium (HALEU) availability—and development of a world-class nuclear workforce.

In pursuit of these goals, DOE-NE has laid out **four top priorities that serve as primary organizing principles[a,f].** These priorities include:

Reestablishing a domestic enrichment program,

Fostering new reactor builds,

Expanding international export of U.S. nuclear products, and

Establishing a complete nuclear fuel cycle.

a Department of Energy. Office of Nuclear Energy: Strategic Vision, 2021, https://www.energy.gov/sites/default/files/2021/01/f82/DOE-NE%20Strategic%20Vision%20-Web%20-%2001.08.2021.pdf.
b Executive Order 14299, Deploying Advanced Nuclear Reactor Technologies for National Security, The White House, May 23, 2025
c Executive Order 14300, Ordering the Reform of the Nuclear Regulatory Commission, The White House, May 23, 2025.
d Executive Order 14301, Reforming Nuclear Reactor Testing at the Department of Energy, The White House, May 23, 2025.
e Executive Order 14302, Reinvigorating the Nuclear Industrial Base, The White House, May 23, 2025.
f Hon. Theodore Garrish, Senate Energy & Natural Resources Full Committee Hearing to Examine the Department of Energy's Implementation of President Trump's May 2025 Nuclear Energy Executive Orders, March 19, 2026

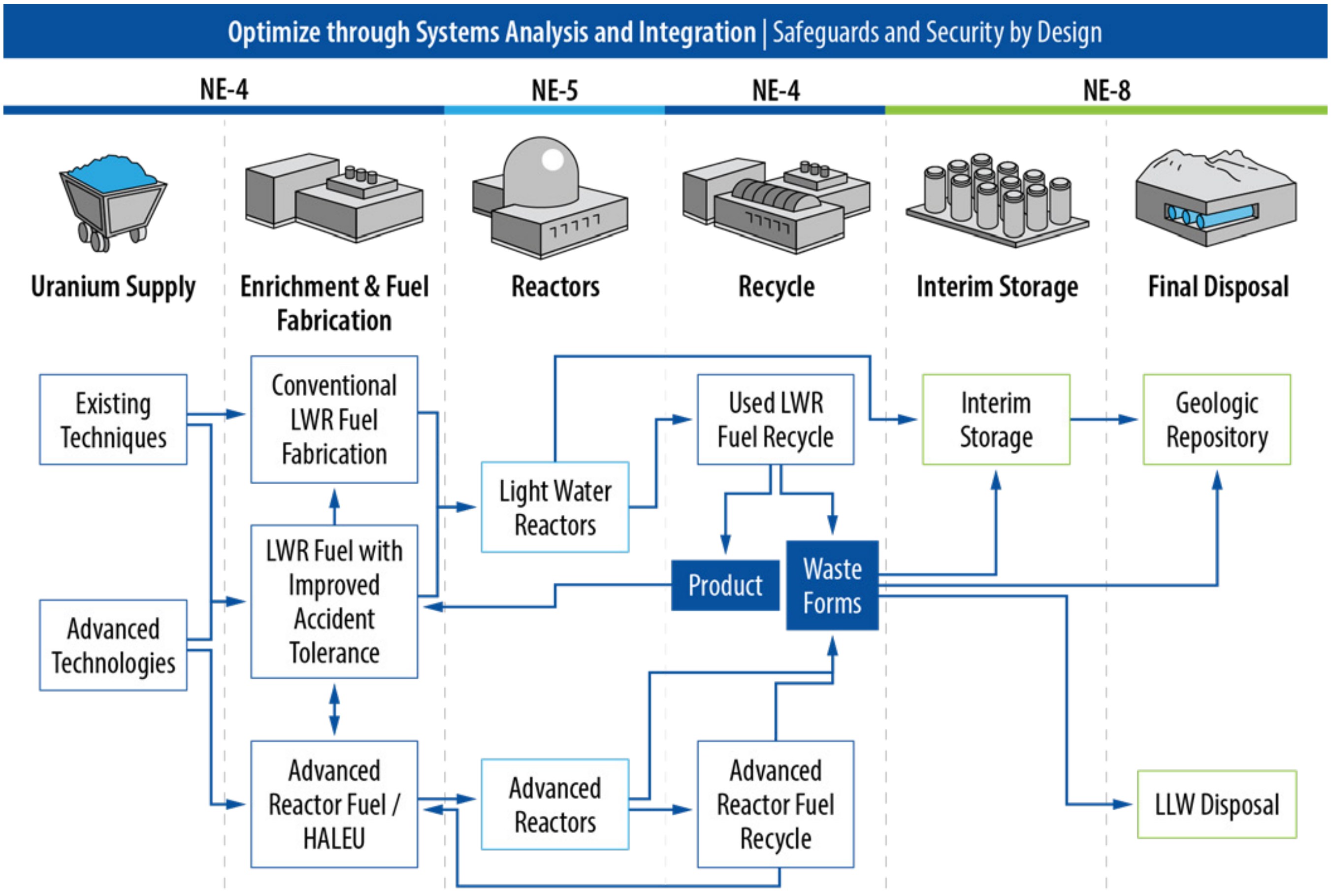


Figure 4. Elements of the DOE-NE Nuclear Reactor and Fuel Cycle R&D portfolio[g].

Execution of these policy objectives depends fundamentally on the availability of qualified, high-performance fuel systems supported by defensible data and accelerated development and licensing methodologies. AFC, through its work within the enhanced accident tolerant and next generation fuels programs provides essential technical capability that underpins each of DOE-NE's priorities. AFC activities are therefore directly aligned with, and necessary for, successful implementation of both DOE-NE's Strategic Vision and the broader federal directive to deploy secure, reliable, and economically competitive nuclear energy systems.

Advanced nuclear fuel technology is foundational to DOE-NE's four strategic priorities and the objectives established in the May 23, 2025 Executive Orders. Reactor technology (both current and advanced) is typically the focal point for energy conversion (from fission to electricity/process heat) and requires significant RD&D to successfully realize innovations that enable development, deployment, and efficient operation of this essential resource. However, parallel RD&D focused on the associated fuel cycle is also necessary to ensure these critical assets function in a broadly optimized fashion that addresses secure, reliable, abundant, and economic energy supply. Both needs are reflected in the organizational structure of the DOE-NE offices[h] and their associated missions, shown in Figure 4. Most relevant here among these

g Office of Nuclear Energy. n.d. "Leadership," Accessed March 15, 2024, https://www.energy.gov/ne/leadership.
h Office of Nuclear Energy. "Nuclear Energy Advisory Committee Meeting." Presentation at Hilton Washington DC National Mall, The Wharf, Washington, DC, August 2, 2022, https://www.energy.gov/ne/articles/neac-meeting-august-2-2022.

offices are the DOE-NE Office for Reactor Fleet and Advanced Reactor Deployment (NE-5) and Office of Nuclear Fuel Cycle and Supply Chain (NE-4).

The three branches of the NE-4 office focus on supporting the fuel cycles that drive the various reactor technologies. The NE-41 office supports development of the fuel cycle front end by delivering fissile materials including both fresh uranium supply needed to ensure a secure source of LEU for the existing fleet and an expanded supply of HALEU to enable advanced reactor deployment (e.g., spanning across mining, milling, conversion, and enrichment). This also includes allocation of high value materials (both enriched uranium and plutonium) recovered from legacy DOE-owned fuels that are suitable for repurposing in new nuclear fuel products. The NE-42 office supports RD&D on advanced nuclear fuel technology through AFC that ensures efficient utilization of fissile resources (both fresh and recovered). This includes supporting the LWR community through the development of eATFs, which improve economics and safety of the current and future fleet of LWRs, as well as the development and qualification of advanced fuels, which make both federally and privately sponsored advanced reactor demonstration projects possible. The NE-43 office is responsible for R&D focused on the management of used fuel through the development and assessment of separations technology required to recover fissile resources for reuse and develops waste forms to enable safe disposition of the remaining materials (e.g., fission products and off-gases). The interdependence between these R&D programs and the resulting technology is so critical that crosscutting initiatives implementing integrated system analysis for overall evaluation and non-proliferation principles are fully embedded within the office.

GOALS AND OBJECTIVES

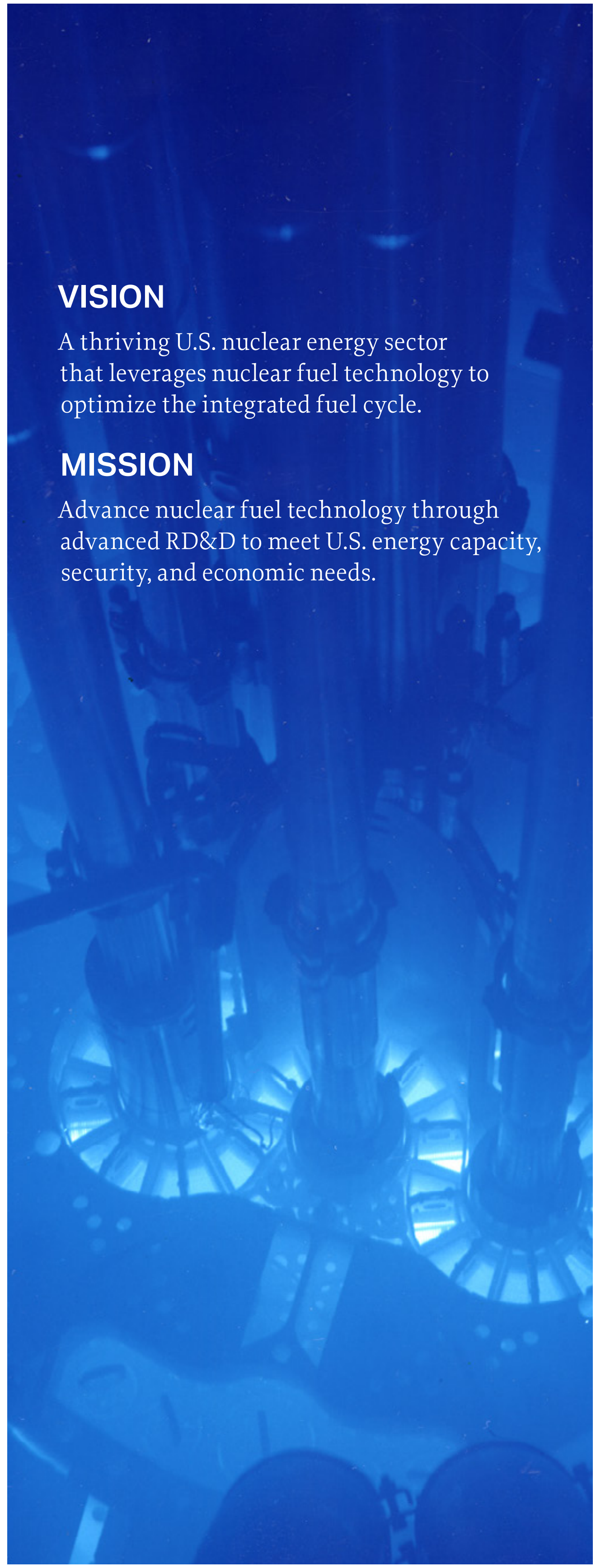
AFC is dedicated to propelling the U.S. to the forefront of nuclear fuel technology through a comprehensive strategic vision.

The vision is structured around five key goals:

- **Driving U.S. leadership in nuclear fuel technology**
- **Expanding nuclear energy production from the existing fleet**
- **Completing the qualification basis for advanced reactor fuel technology**
- **Driving innovation in advanced nuclear fuel technology**
- **Enabling a high-performing organization**

By focusing on these goals, AFC aims to define and implement cutting-edge nuclear fuel technologies, support industry advancements, achieve critical fuel qualifications, foster innovative research, and ensure effective program management and stakeholder engagement. This strategic approach will solidify the U.S. position as a global leader in nuclear energy and fuel technology, while also preparing for the future of secure, reliable, abundant, and economic supply of nuclear energy.

To achieve the AFC vision of a *thriving U.S. nuclear energy sector that leverages nuclear fuel technology to optimize the integrated fuel cycle* and the mission to *advance nuclear fuel technology through advanced R&D to meet U.S. energy, environmental, and economic needs*, Table 1 outlines the goals, objectives, and performance indicators essential for success.



VISION

A thriving U.S. nuclear energy sector that leverages nuclear fuel technology to optimize the integrated fuel cycle.

MISSION

Advance nuclear fuel technology through advanced RD&D to meet U.S. energy capacity, security, and economic needs.

Table 1. Goals, objectives, and performance indicators.

Goals	Objectives	Performance Indicators	
1. Lead nuclear fuel technology R&D	1. Define nuclear fuel technologies for the integrated *fuel cycle of the future* 2. Demonstrate domestic and international technical leadership in nuclear fuel R&D 3. Steward and maintain world-class research test beds 4. Develop a highly trained nuclear fuels workforce	• By 2026, collaborate with partner DOE programs to draft a HALEU utilization timeline integrating fissile availability, fuel fabrication, fuel qualification, irradiation, and disposition for first movers. • By 2027, collaborate with partner DOE programs to draft fissile recycle technology options.	• Establish and retain leadership positions in key Nuclear Energy Agency (NEA) international joint programs and working parties. • Annually update bilateral cooperation agreements for technical cooperation with key international partners. • By 2027, establish a world-leading LWR Fuels Test Bed.
2. Expand energy production from the existing fleet	1. Support industry in achieving ATF technology qualification 2. Develop the fuel performance basis to enable LWR power uprates 3. Develop the fuel performance basis to enable LWR burnup extension 4. Utilize the LWR Fuels Test Bed to deliver steady state and transient irradiation performance data	• By 2026, update stakeholder consensus research plans for ATF properties, cladding time-at-temperature, high-burnup (HBU) fuel behavior, and "post Halden" recommendations. • By 2027, complete the execution of planned research activities required to enable commercial deployment of large-grain UO2 fuel pellets. • By 2028, complete execution of planned research activities required to enable regulatory approval for extended burnup (≥75 GWD/MTU).	• By 2028, complete execution of planned research activities required to enable regulatory approval for extended operating cycles (24 months) through the utilization of LEU+. • By 2030, complete execution of planned research activities required to inform operators/regulators on improved time-at-temperature limits to enable power uprates. • By 2030, complete execution of planned research activities required to enable regulatory approval for the implementation of coated cladding with benefits.
3. Initiate and complete qualification basis for advanced reactor fuels	1. Complete the qualification basis of the Advanced Gas-Cooled Reactor (AGR) Program TRISO fuel design 2. Complete qualification basis for the metal fuel design (uranium-zirconium [U-Zr], uranium-plutonium-zirconium [U-Pu-Zr]) 3. Develop framework for molten salt fuel development and qualification	• By 2026, develop a molten salt fuels qualification roadmap lessons learned from other advanced reactor fuel types. • By 2029, complete TRISO topical reports for HTGR test series and submit to NRC. • By 2027, complete binary metal (U-Zr) topical reports and submit to NRC.	• By 2029, complete ternary metal (U-Pu-Zr) topical reports and submit to NRC. • By 2030, complete execution of planned off-normal and accident studies on AGR TRISO and SFR metal fuel technology.

Table 1, continued. Goals, objectives, and performance indicators.

Goals	Objectives	Performance Indicators	
4. Champion innovation in advanced nuclear fuel technology	1. Demonstrate methodologies to accelerate innovation in nuclear fuel technology 2. Conduct research that advances technical readiness level (TRL) for innovative fuel technologies 3. Conduct research that improves the utilization of existing fuel technologies 4. Conduct research that improves the fissile utilization and integration of the nuclear fuel cycle	• By 2026, establish a national nuclear fuels data repository and implement the first machine learning (ML)/ artificial intelligence (AI) features, direct data-to-storage interfaces, and digital twin capability. • By 2026, establish R&D portfolio and development plans for next generation advanced reactor fuel forms that will optimize LWR/small modular reactor (SMR), SFR, high-temperature reactor (HTR), and MSR demonstration plant performance.	• By 2027, complete NEA report for Task Force on Accelerated Qualification of Nuclear Fuel (TF-AQUA-NF). • By 2029, assess impact of recycled fuel on advanced fuel system performance including both once-through and closed-cycle fuel designs. • By 2029, deliver lead test components to Advanced Reactor Demonstration Projects (ARDP) that will improve plant and fuel cycle performance.
5. Cultivate high-impact teams driven by efficiency, collaboration, and exceptional results	1. Support and invest in AFC program staff 2. Effectively manage program, projects, and R&D investments 3. Enhance communications with stakeholders 4. Modernize AFC institutional memory and digital infrastructure	• Collaborate annually with Nuclear Energy University Program (NEUP) and Nuclear Science User Facilities (NSUF) programs to maintain a robust portfolio of university partnerships and faculty/student pipelines for nuclear fuel technology. • Generate an annual update to the AFC program execution plan that outlines program management structure and cost/schedule targets for 5-year technical objectives.	• Engage in structured outreach to various stakeholder communities ranging across industrial partners, regulators, private innovators, and the public. • By 2027, implement a secure, quality-governed AFC institutional knowledge system that enables traceable linkage between experimental data, modeling results, and qualification documentation for priority fuel systems.

GOAL 1:
Drive U.S. Leadership in Nuclear Fuel Technology

AFC plays a central leadership role in identifying, shaping, and advancing the nuclear fuel technologies that will define the future of the U.S. and global nuclear energy landscape.

As part of the U.S. DOE's broader mission, AFC not only contributes to technology development but leads the systematic identification, prioritization, and down-selection of high-impact fuel cycle innovations that are most likely to enhance energy security, economic competitiveness, and nonproliferation objectives. This leadership in technology identification is critical to ensuring that U.S. nuclear energy systems remain globally competitive and are widely adopted.

This role is executed through a combination of strategic analysis, targeted research, and strong engagement in international collaborative programs. AFC actively shapes the global technical agenda by placing experts in key leadership and advisory positions within multinational nuclear organizations and initiatives. In parallel, AFC actively contributes to the evaluation of long-term nuclear fuel cycle options, ensuring that emerging industrial strategies consider state-of-the-art fuel technology.

To enable this mission, AFC develops and maintains world-class research test beds that allow for rapid maturation and validation of promising technologies. Equally important, AFC invests in attracting, developing, and retaining top-tier scientific and engineering talent capable of anticipating future technology needs and guiding innovation pathways. Through this integrated approach, AFC ensures that the U.S. not only participates in, but leads, the identification and deployment of next-generation nuclear fuel technologies worldwide.

OBJECTIVE 1: *Define Nuclear Fuel Technologies for the Integrated Fuel Cycle of the Future*

The nuclear fuel cycle encompasses a series of processes involved in the production, use, recycle, and disposal of nuclear fuel. It begins with the extraction and processing of uranium ore into enriched UF6, followed by the fabrication of nuclear fuel assemblies that are used in reactors to generate electricity or other useful products. After the fuel has been irradiated in a reactor, it is currently stored onsite in anticipation of ultimate disposition. This could include either direct geologic storage (i.e., open fuel cycle) or processing to recover fissile materials for reuse, as well as reduce toxicity and volume, prior to geologic storage (i.e., closed fuel cycle). Optimizing the nuclear fuel technology for compatibility with each element of the nuclear fuel cycle is essential for enhancing the economics, efficiency, safety, and viability of nuclear energy.

In recent years, the DOE has undertaken extensive analysis of modern fuel cycle options to identify the most promising pathways for future nuclear energy systems. This includes refined evaluations on both closed fuel cycles, and open fuel cycles. These analyses considered factors like economic viability, resource utilization, waste generation, and non-proliferation concerns. However, the landscape continues to change as the market calls for a quadrupling of the nuclear energy supply by 2050, new reactor technologies approach commercialization (leading to a diverse fuel cycle ecosystem), and the global fissile supply chains respond to evolving geopolitics. By rigorously reassessing options within this context, AFC and its DOE partner programs aim to guide the enabling R&D

needed to inform future fuel cycle decision makers to maximize the benefits of nuclear energy while addressing its unique constraints.

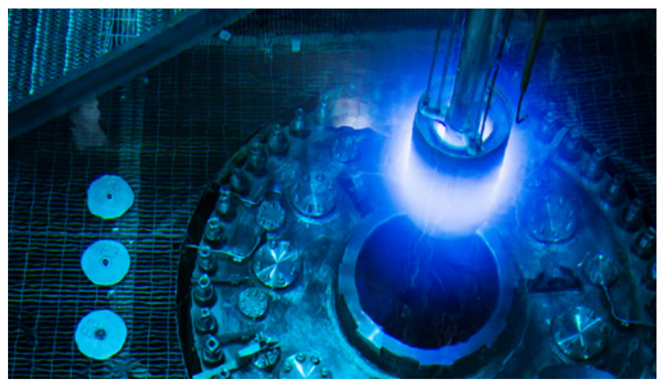
In particular, emerging fuel cycle challenges are associated with the supply of both LEU+ and HALEU, the selection and optimization of fuel technologies for advanced reactors, and the management of legacy LWR waste. Global uranium supply chains—from mining and conversion to enrichment—are increasingly influenced by geopolitical factors, posing potential risks to domestic energy security. Fuel technology choices can, in turn, affect the resilience of this complex network. HALEU is essential for many advanced reactor designs due to its higher enrichment levels; however, its supply chain requires significant development to meet projected demand. This gap may be partially mitigated through the recycling of recovered fissile materials. Advanced reactors, which offer the potential for improved safety and efficiency, also require new fuel types and technologies, creating opportunities to advance fabrication methods, enhance fuel performance, and streamline regulatory processes. Additionally, the management of legacy LWR waste remains a significant challenge, necessitating advanced strategies for storage, potential recycling, and disposal to support both near-term energy security and long-term system viability.

Informing decision-makers and expanding options will require coordinated efforts between AFC and other DOE programs to conduct R&D that delivers potential solutions.

OBJECTIVE 2: *Develop and Maintain World-Class Research Test Beds*

Developing and maintaining state-of-the-art testing research facilities is fundamental to advancing innovation in nuclear fuel technology and resolving emerging issues with technologies already in regular use. These facilities support comprehensive experimental testing including in-pile and out-of-pile experiments, which are crucial for understanding the behavior of advanced nuclear fuels under various conditions. They are also needed to identify and develop *disruptive* new technologies with the potential to broadly impact nuclear energy applications. By investing in cutting-edge equipment and infrastructure, AFC can ensure that U.S. research capabilities remain at the forefront of global nuclear innovation.

The DOE complex maintains several key state-of-the-art irradiation testing facilities, including the Advanced Test Reactor (ATR) at Idaho National Laboratory (INL) and the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL), as well as affiliate facilities like the MIT Reactor (MITR) at the Massachusetts Institute of Technology (MIT). Each of these test reactors play a unique role in the nuclear fuel technology R&D ecosystem. ATR is equipped with a diverse range of test positions that support a variety of experiment types, most notably the large volume positions that allow for engineering-scale, integral testing in loop-type devices. This capability is complemented by additional test positions at ATR, HFIR, and MITR that facilitate experiments on separate effects at scale targeting specific physical phenomena. While DOE provides funding to operate these unique assets, the AFC program is responsible for maintaining the irradiation testing infrastructure that makes technology-specific research possible.



Refueling at the High Flux Isotope Reactor at Oak Ridge National Laboratory.

Steady-state testing must be complemented by transient testing capabilities to assess the fuel's dynamic response to changes in its operating conditions. A network of research facilities is required to simulate all relevant environments, ranging from operational power shifts to severe accidents. At the center of this capability is the Transient Reactor Test Facility (TREAT) at INL, which is designed to perform a wide range of nuclear driven transient tests that simulate complex changes in reactor power and/or coolant conditions. These capabilities are complemented by ramp testing capabilities in the ATR that simulate moderate power shifts, typical of near-normal conditions, and hot cell furnaces at INL and ORNL that can simulate slower transients lasting for hours to days. These tests provide valuable data on fuel behavior during accident conditions, helping researchers develop fuels with demonstrated safety criteria.

However, the existing capabilities are not considered sufficient to meet the needs of the future. For example, over the last two decades, test facilities supporting LWR fuel technology research have significantly deteriorated. Closure of the Swedish R2 reactor, French OSIRIS reactor (coupled with massive delays in the start of the French Joules-Horowitz Reactor [JHR]), and the sudden closure of the Halden Reactor in Norway in 2018 marked the end of a significant era in nuclear fuel research. These shutdowns created critical gaps in the global nuclear research infrastructure and potentially established Russia as the default leader in advanced nuclear fuel testing capability. Since then, the AFC program has focused on expanding domestic LWR research capabilities by establishing new test loops in ATR, loss of coolant accident (LOCA) and Reactivity-Initiated Accident (RIA) testing capability at TREAT, LWR fuel refabrication capability, and expanded the range of in-situ instrumentation available for experiments

Research capabilities supporting advanced reactor fuel technologies are equally challenged and require active investment to maintain and develop the relevant nuclear reactor systems (e.g., LWR, SFR, gas-cooled reactor [GCR], and MSR). Without this focused attention, these capabilities will atrophy and not be available to meet anticipated R&D needs. For example, while ATR was successfully used to conduct the irradiation testing required to develop and qualify TRISO-coated particle technology, the research infrastructure was removed after completing the DOE-led demonstration program in 2018. Shortly thereafter, significant new testing needs emerged to support diverse industrial applications for coated particle fuel designs requiring additional study. Failure to manage these systems with a long-term mindset, delayed and increased the cost of subsequent technology development and deployment efforts. Similarly, although ATR and HFIR can be used for some SFR fuel research needs, the lack of a fast spectrum test facility significantly hampers critical technology development

Researchers at INL's TREAT reactor evaluate the performance of fuels and structural materials, aiding the development and commercialization of new technologies.

objectives in several areas. Salt fuel development is even more significantly constrained by a lack of even the most basic irradiation testing capabilities. AFC will continue to advocate for reestablishing critical irradiation testing capability and for a fast spectrum test reactor to be constructed in the U.S.

Irradiation testing must be complemented by modern post-irradiation examination (PIE) capabilities. State-of-the-art hot cell facilities at both INL and ORNL are indispensable elements of this mission. These heavily shielded facilities allow safe handling and analysis of highly irradiated fuel samples, providing critical information on fuel performance, microstructural changes, and fission product behavior. The hot cells at INL and ORNL are equipped with classical engineering scale examination equipment and advanced analytical tools, such as electron microscopes and material property analysis tools, enabling detailed characterization of irradiated materials. This capability is essential for developing fuel performance models and guiding the selection of next-generation fuel technologies.

Advanced fabrication technology is also a key component of the national research infrastructure. Cutting-edge fabrication techniques must be adapted for nuclear applications and applied to allow researchers to produce nuclear fuels with unique material compositions, specialized geometric features, precise microstructures, and tailored properties. By leveraging these advanced fabrication technologies, AFC develops fuels that offer improved performance, safety, and longevity. Additionally, ongoing research into innovative fabrication methods will help the U.S. stay at the forefront of fuel manufacturing and support the commercialization of advanced reactor designs.

Sectioned view of additively manufactured heat exchanger to test heat transfer properties of advanced nuclear fuel lattice design.

AFC will develop and annually update a Nuclear Fuels Test Bed status report. This report will identify the capabilities needed to support current and long-term R&D objectives to support the key nuclear reactor systems (e.g., LWR, SFR, GCR, and MSR). It will provide a comprehensive overview of the available test bed infrastructure, highlight key achievements, and outline future plans. By regularly reviewing and updating this report, AFC can ensure that the national research strategy remains aligned with the evolving needs of the nuclear energy sector.

OBJECTIVE 3: *Develop Highly Trained Nuclear Fuel Scientists and Engineers for the Future Workforce*

The AFC program relies on its unique technical experts to drive innovation and maintain leadership in nuclear fuel R&D. AFC is committed to ensuring that its technical experts remain at the cutting edge of technology and research through continuous professional development and recruitment of new talent.

The identification and recruitment of new talent is pivotal to sustaining AFC's innovative culture. The DOE-sponsored NEUP serves as a critical pipeline for sourcing high-caliber candidates. AFC will actively participate in NEUP's initiatives by providing topical areas of interests, contributing to proposals, and collaborating with university faculty to support students access to unique AFC facilities and staff. Going beyond NEUP, AFC also hosts a variety of internships, supports joint advanced degrees projects, and hosts postdoctoral staff to provide valuable, hands-on experience in nuclear fuel research areas. These initiatives will allow students to pursue their academic goals while working closely with the AFC team on real-world projects.

OBJECTIVE 4: *Demonstrate International Technical Leadership that Facilitates the Adoption of U.S. Technology Worldwide*

The development and deployment of nuclear energy technology is a global endeavor. This effort requires committed, long-term relationships between multiple countries. In this unique landscape, success relies on functional government/commercial partnerships to effectively navigate a highly competitive marketplace. Thus, the engagement of federally supported R&D organizations tasked with continuously enhancing the economics, safety, efficiency, and viability of nuclear fuel technology greatly enhances the position of U.S. nuclear technology companies worldwide. International cooperation with like-minded partners is also essential for addressing common technology development challenges, developing and sharing best practices, and advancing innovative solutions that are consistent with U.S. nuclear energy values, including, for example, safety and non-proliferation. AFC supports both these aims by demonstrating international technical leadership through active participation in international collaborative research programs sponsored by both national and multinational nuclear energy organizations.

Knowledge sharing and outreach are essential components of the national strategy. AFC organizes international workshops, collaborative research projects, and participates in international workshops to identify strategic opportunities, disseminate research findings, and influence international technical priorities. These events also serve as platforms for exchanging ideas, fostering partnerships, and addressing common challenges in nuclear fuel development and deployment. By facilitating open communication and collaboration, AFC can accelerate both the development and deployment of advanced U.S. nuclear fuel technologies worldwide.

AFC will also maintain leadership positions and make meaningful contributions to key multinational nuclear agencies including the Organisation for Economic Co-operation and Development (OECD) NEA, Generation IV International Forum (GIF), and International Atomic Energy Agency (IAEA). The highest emphasis will be placed on the NEA's international joint programs and working parties. This involvement will allow AFC to contribute to the development of international policies, standards, and guidelines that promote the appropriate use of nuclear energy. By taking on leadership roles, AFC can ensure that U.S. perspectives and innovations are well-represented in global decision-making processes.

Joint activities conducted under U.S. bilateral agreements for technical cooperation with key international partners, most notably France, the United Kingdom, Japan, and South Korea, will be annually updated to reflect the latest advancements and priorities in nuclear fuel technology R&D. These agreements will facilitate joint research projects, accelerate technology maturation, and capacity-building initiatives. By strengthening international partnerships, AFC can leverage the expertise and resources of allies to achieve common goals and address shared challenges.

One key outcome of international collaboration will be executing high-profile technical demonstrations of advanced nuclear fuel technologies. Joint programs, like the NEA Framework for Irradiation Experiments (FIDES), enable these demonstrations to take place in both U.S. reactors and international facilities to showcase the performance and reliability of U.S. nuclear technology innovations. By providing tangible evidence of the safety and efficiency of U.S. technologies, we can build confidence among international stakeholders and encourage their adoption.

GOAL 2:

Expand Nuclear Energy Produced by the Existing Fleet

AFC plays a vital role in fostering collaboration between industry, national laboratories, and regulatory bodies.

By facilitating open communication and information exchange, AFC helps align research priorities and ensure that industry needs are effectively addressed. The Electric Power Research Institute's (EPRI's) Collaborative Research for Advanced Fuel Technologies (CRAFT) initiative plays a significant role in integrating these efforts, providing a platform for coordinating eATF development activities. Regular workshops, technical meetings, and collaborative research projects, including those under the CRAFT initiative, offer platforms for stakeholders to discuss progress, share findings, and identify potential challenges. This collaborative approach not only accelerates the development of eATF technologies but also ensures that they meet the stringent safety and performance standards required for regulatory approval.

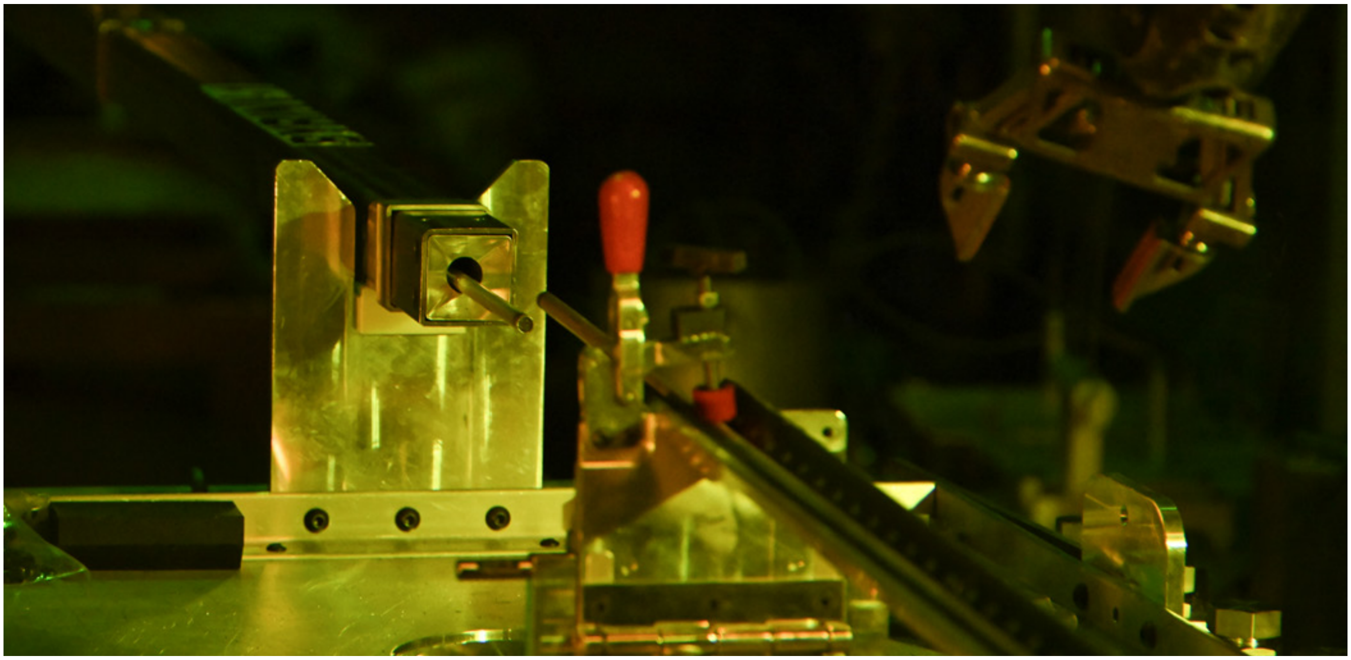
Close-up of an ATR cloverleaf assembly, highlighting its segmented geometry and illuminated internal structure.

OBJECTIVE 1: *Support Industry in Achieving Near-Term ATF Technology Qualification*

Since 2012, AFC has supported the industrial fuel suppliers in achieving the development and qualification of ATF technologies. These advanced fuel designs are engineered to enhance the safety and economic performance of the existing fleet of commercial LWRs. To achieve this goal, AFC collaborates closely with the broad stakeholder community, including the fuel suppliers, utilities, and NRC, while providing essential resources, technical expertise, and access to state-of-the-art research facilities. This comprehensive support was envisioned to accelerate the development, testing, and regulatory approval of commercial ATF technologies, ultimately ensuring their successful deployment in the field.

Following an extensive concept proposal and screening phase, the ATF program is now completing the qualification of two technologies, doped fuel pellets and coated claddings, by the end of the decade. (Longer-term technologies will continue to mature as part of the advanced LWR fuel effort under NGF). Significant progress has been made in both areas. Fuel suppliers have, in collaboration with U.S. utilities, performed lead test rod irradiations in commercial plants. Several of these are currently under examination at the U.S. national laboratories to assess performance and provide fuel suppliers with the data necessary for topical reports. Further deployment relies heavily on the completion of these exams and subsequent safety testing. These activities are primarily funded by DOE and executed under cooperative research agreements between the fuel suppliers and national laboratories to protect relevant intellectual property developed by the commercial fuel suppliers.

After fuel suppliers submit, and the NRC approves, topical reports on ATF behavior, the first commercial procurements of batch reload quantities will be possible. However, these will be implemented with only some of the performance and economic benefits realized. Although some immediate benefits are expected, optimizing the fuel utilization will require improvements in understanding the ATF material properties, fuel behavior under steady-state and off-normal conditions, and modeling and simulation tools. Ongoing research, including in-pile and out-of-pile testing, alongside early adoption will be necessary to more broadly expand deployment.



Section of the first Byron rod being cut open.

OBJECTIVE 2: *Develop the Fuel Performance Basis to Enable LWR Burnup Extension*

Analysis was recently conducted by an LWR industry stakeholders' group to identify the economic advantages that would incentivize and accelerate utility adoption of ATF technology. Key areas of opportunity included extending burnup limits beyond the current regulatory limit of 62 gigawatt-days (GWD)/metric ton of uranium (MTU) and increased enrichment limits beyond 5%. Both changes are envisioned to be implemented in a stepwise fashion, starting with the existing technology (taking minimal gains) followed by ATF technology soon after (that could offer larger gains).

Over the last decade, and outside of the ATF program, fuel suppliers and U.S. utilities collaborated on HBU irradiations of lead test rods for existing fuel designs in commercial plants. These are currently under examination at the U.S. national laboratories to provide fuel suppliers with the data necessary for topical reports. Fuel suppliers and AFC staff are collaborating to resolve technical knowledge gaps associated with extended burnup by executing a consensus stakeholder-developed research plan that is highlighted by an improved understanding of HBU fuel behavior under LOCA conditions. Following examination of the HBU lead test rods, fuel segments will be subjected to fuel safety tests using both in- and out-of-pile test rigs. Fuel suppliers, Utilities, and the NRC will use the results of this work in the HBU core design and formulation of the HBU fuel performance criteria. Once these new criteria are established, the improved features of ATF fuel will allow utilities even greater flexibility in HBU core design and fuel utilization.

To take full advantage of higher burnup limits, increased enrichment is required to load additional fissile material into the assembly before insertion. A new enrichment threshold, LEU+, has been defined for this purpose, where LEU+ is defined as greater than 5% and less than 10%. NRC rulemaking for increased enrichment is underway and expected to be completed in 2026. Fuel suppliers are already preparing manufacturing plant and transportation infrastructure to implement this new capability. It is unlikely that increased enrichment will meaningfully alter fuel behavior but is essential to enable the generation of very HBU lead test rods. Lead test assemblies containing the first LEU+ elements, along with doped fuel and coated cladding, will begin irradiation in 2026 and will be carried to extended burnup conditions (>62 GWD/MTU). It is feasible to complete this full scope of research activities by the end of the decade and implement in support of commercial power generating capacity increases.

OBJECTIVE 3: *Develop the Fuel Performance Basis to Enable LWR Power Uprates*

Operators of the U.S. fleet of nuclear reactors have estimated that 70% of the reactors could uprate operating power to deliver an additional 6 GW of total electrical generation. A key barrier to implementing this strategy is access to the technical basis necessary to describe fuel performance under the higher stress and temperature conditions associated with increased plant power and, in some cases, the advanced fuel technology needed to expand the acceptable operating limits.

AFC provides critical support to this mission by deploying its unique capabilities, test beds, and expertise to generate the necessary fuel performance data. This objective focuses on reducing uncertainty in materials behavior, improving fuel behavior models, deploying advanced fuel technology, and enhancing fuel assembly design. By addressing these critical areas, AFC supports the nuclear industry's efforts to increase reactor output safely and efficiently, ultimately contributing to the broader goal of expanding nuclear energy capacity.

Improving fuel behavior models is a crucial and high-priority component of this objective. Accurate models are essential for predicting how fuel will perform under different conditions, enabling a more precise description of fuel design and operational limits. AFC collaborates with industry stakeholders, including utilities, fuel suppliers, and regulators, as well as partner DOE programs, such as the Light Water Reactor Sustainability (LWRS) program and the Nuclear Energy Advanced Modeling and Simulation (NEAMS) program, to identify, develop and validate these models. Through these partnerships, AFC ensures that the models incorporate the latest research findings and industry insights, resulting in more reliable and robust predictions. Near-term, focused research on critical challenges, notably the resilience of zircaloy cladding under short-term exposure to elevated temperatures (also known as *time at temperature[t@T]*), could yield uprates on the order of 3 GW by the end of the decade.

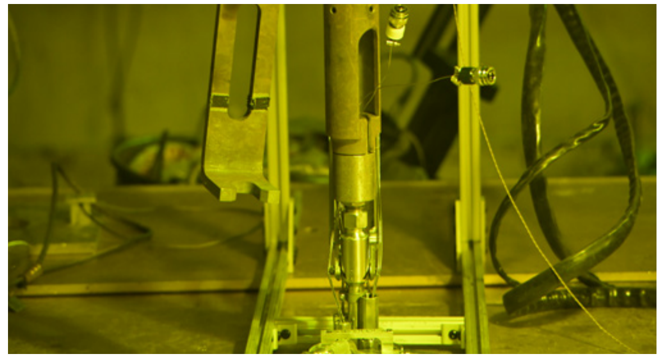
Deploying advanced fuel technology and improving fuel assembly design could enable even greater power uprates. AFC works closely with industry partners to identify and implement innovative fuel technologies that can withstand the demands of higher power levels. This includes optimizing fuel assembly design and materials selection to improve heat transfer, reduce the risk of cladding failure, and enhance overall reactor safety and performance.

Transient Water Irradiation System in TREAT (TWIST) experiment for LOCA testing.

OBJECTIVE 4: *Establish National LWR Fuels Test Bed to Deliver Steady State and Transient Irradiation Performance Data*

Execution of the AFC mission requires access to key irradiation testing capabilities to be successful. A robust national LWR fuels test bed has been established as part of the ongoing ATF program that includes key irradiation testing capabilities in ATR, HFIR, and TREAT and PIE capabilities at both INL and ORNL. This test bed is essential for conducting relevant R&D activities that keep the extensive U.S. commercial fleet of LWRs viable for the next 40 years. This test bed is dedicated to delivering crucial steady state and transient irradiation performance data for the most used nuclear fuels in the world.

The scope of the National LWR Fuels Test Bed was dramatically expanded following the unexpected closure of the Norwegian Halden reactor in 2018, which hosted the international Halden Reactor Project. The Halden gap assessment initiative was launched by the ATF stakeholder community in response to identify key capability gaps and threats to the integrated research capability. Implementing the Halden gap assessment recommendations was subsequently adopted as an essential element of the ATF project. The Halden gap assessment concluded that four key capability elements needed to be included at domestic facilities. These included the addition of new water loops in the ATR, the establishment of LOCA testing capability in TREAT, the development of commercial fuel pin remanufacturing capability, and the expansion of in-situ measurement capability. All these capability development projects are on track to be completed. Fuel pin remanufacturing and in-pile LOCA testing were performed at INL in 2025, significant modifications were made to the ATR to allow additional loops (to be installed in 2027), and the DOE-NE Advanced Sensors and Instrumentation (ASI) program has established the U.S. as a leader in advanced instrumentation.



Temperature Heat sink Overpower Response Metal Loss of Flow (THOR-MLOF) capsule torquing in the hot cell.

Ultimately, the National LWR Fuels Test Bed will serve as a cornerstone for the U.S. nuclear research infrastructure. It will enable researchers to conduct cutting-edge experiments, generate high-quality data, and develop predictive models that enhance the safety and efficiency of nuclear reactors. Annual review of the test bed capabilities will be performed to identify emerging gaps and will ensure that the U.S. remains at the forefront of nuclear fuel R&D.

GOAL 3:
Complete Qualification Basis for Advanced Reactor Fuel Technology

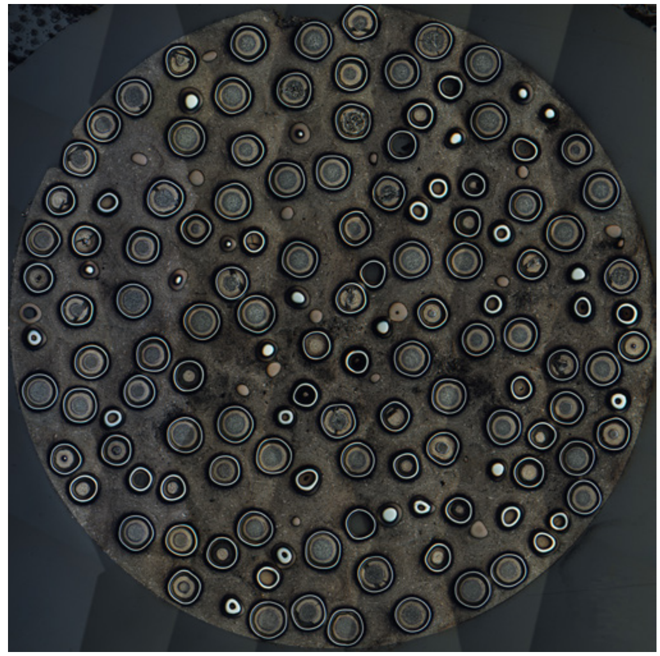
AFC is focused on delivering the nuclear fuel technology needed to drive the next generation of reactor systems, especially the technologies being constructed within the next decade.

This will be accomplished by completing the qualification basis for reference fuel technology required to launch demonstration projects and their immediate successors. Specifically, this includes the qualification of metallic fuels for SFRs, TRISO fuels for high-temperature reactors, and salt fuels for MSRs, which all began as long-term innovative DOE R&D programs. The qualification process for these fuels requires irradiation in test reactors to demonstrate fuel performance; safety testing in both test reactors and hot cell furnaces to establish design limits; advanced modeling and simulation tool development to support design, licensing, and operation; and the development and transfer of manufacturing technology and reliable fabrication specifications. This process typically requires over two decades to complete. In the case of both the metal alloy and TRISO fuel systems, completion is expected—and necessary to national nuclear energy goals—in the very near term.

OBJECTIVE 1: *Complete Qualification of AGR UCO TRISO Fuel Design*

AFC is pushing the frontiers of nuclear fuel technology by completing qualification of the uranium oxycarbide (UCO) TRISO fuel system. TRISO fuel is composed of uranium fuel kernels coated with multiple layers of carbon and ceramic materials, which provide exceptional containment of fission products and remain remarkably robust under extreme conditions. Successfully qualifying UCO TRISO fuel is a critical step toward ensuring the safe and efficient operation of high-temperature reactors, which are known for their high thermal efficiency and inherent safety features.

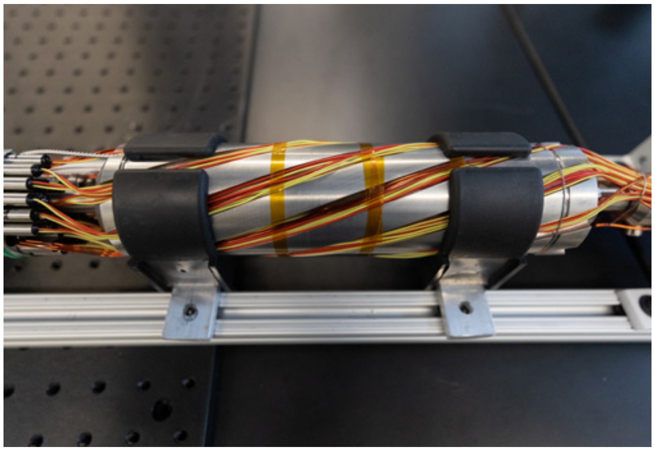
Following two decades of R&D, TRISO technology is approaching a sufficient maturity level to enable reliable adoption as the reference fuel in many emerging commercial and military applications. Fabrication technology was successfully developed



Cross-section of a 1/2-inch-diameter TRISO fuel compact containing poppy-seed-sized fuel particles.

at the national laboratories and transferred to an industrial partner, steady state irradiation performance was demonstrated in four test campaigns using the ATR, and safety testing has been performed to establish the response to transient conditions associated with hypothetical accidents. A highly influential topical report covering the fabrication and performance of the AGR-1 and AGR-2 fuel particles was submitted to the NRC, and a safety evaluation was issued in 2020. Additional topical reports covering subsequent program results will be generated and shared with the NRC for review and approval. These reports will provide the foundation for multiple industrial license submittals for advanced reactor demonstrations.

The TRISO fuel qualification effort must be urgently completed to meet the deployment timelines of several commercial reactor developers. The baseline research activities have been completed for fuel fabrication, and the necessary test materials have completed irradiation in ATR. However, in hot cells at both INL and ORNL, PIE of the final material set (i.e., AGR-5/6/7) is ongoing, and design basis accident safety testing in hot cell furnaces is progressing. The experimental scope will be completed in 2027 followed by completion of data analysis and documentation in 2028. Concurrently,



THOR-MOXTOP experiment investigates transient behaviors of fast reactor fuels.

advanced modeling and simulation tools are being developed in collaboration with the NEAMS program to accurately describe fuel behavior, thereby supporting design and licensing functions.

Additional research will be required to describe TRISO fuel performance limits under severe accident conditions. A new hot cell furnace has been designed and is being installed in 2026 to support this work. The Air-Moisture Ingress Experiment (AMIX) furnace will be operational in 2026 and will use remaining fuel specimens (particles, compacts, and larger fuel/graphite assemblies) irradiated in prior ATR test campaigns to support a 3-year test campaign. The system will subject specimens to high temperatures under oxidizing conditions to determine fuel and fission product behavior during high-temperature reactor air or steam ingress events. Results will be documented in a topical report or NUREG (e.g., a series of publications from the NRC).

OBJECTIVE 2: *Complete Qualification Basis for Metal Fuel Design (U-Zr, U-Pu-Zr)*

AFC is dedicated to advancing nuclear fuel technology including completing the qualification basis for metal fuel designs, specifically U-Zr and U-Pu-Zr alloys. These metal fuels are known for their excellent fuel performance, ease of fabrication, and fuel-reactor symbiotic behavior, leading to inherent safety features and making them ideal for SFRs.

Metallic fuel technology has long been the centerpiece of U.S. fast reactor technology. The reference metal fuel design, consisting of a cast metallic alloy slug bonded to stainless steel cladding by liquid sodium, was first developed to support the operation of the Experimental Breeder Reactor (EBR-II) as a high-flux fast-spectrum irradiation facility. This technology quickly became the foundation for closed fuel cycle concepts once it was complemented by the reactor system design and uranium recycle technology, all developed under the Integral Fast Reactor (IFR) program. This integrated system offered tremendous synergy that made the reactor operation, safety posture, and fuel cycle options (including proliferation resistance) highly attractive. The technology had so firmly supplanted oxide-based fuels by the late 1980s that conversion of the Fast Flux Test Facility (FFTF) to metal fuel had begun prior to cessation of U.S. nuclear energy research in the early 1990s, which resulted in the closure of both FFTF and EBR-II. Today, metal fuel is at the heart of the SFR-based advanced reactors being proposed by industry.

The qualification of metal fuel technology for future use requires completing a few research tasks that were halted in 1993. This includes finishing the PIE of legacy fuel pins irradiated at EBR-II and FFTF, conducting targeted safety testing in TREAT to reduce uncertainty in critical design and safety criteria, developing and validating modern fuel performance codes for design and licensing actions, and transferring fabrication technology and specifications to industrial manufacturers. These findings will be documented, along with legacy data, into comprehensive topical reports for submission to the NRC.

The metal fuel qualification effort must be urgently completed to meet the deployment timelines of commercial reactor developers as the AFC topical reports will provide the foundation for multiple industrial license submittals. The baseline research activities were completed over several decades of testing and use at EBR-II. However, the documentation of this history must be prepared in a format usable to industry and the NRC. Critical knowledge gaps are being filled through ongoing PIE of legacy fuel pins at the INL hot cells and transient testing in TREAT and hot cell furnaces. This scope must be completed and documented by the end of 2027. In parallel, advanced modeling and simulation tools are being developed in collaboration with the NEAMS program to sufficiently describe the fuel behavior in support of design and licensing functions.

OBJECTIVE 3: *Establish a Development and Qualification Strategy for Salt Fuel Technology*

Salt fuel technology is significantly less mature than the prior two technologies and will require more time to develop to the same readiness level. An R&D plan will be developed and executed to demonstrate salt synthesis techniques, determine material properties critical to system design (with emphasis on understanding irradiation effects), and development of fuel performance models to underpin system design and licensing.

MSR fuels require fundamentally different fabrication and qualification approaches than conventional solid fuels, as the "fuel" is a chemically engineered liquid rather than a manufactured solid form. Fuel synthesis begins with the production and purification of high-purity constituent salts—typically fluorides or chlorides of lithium, beryllium, sodium, or potassium—followed by the controlled incorporation of fissile and fertile materials such as uranium or plutonium. This process must achieve tight control over impurities, particularly oxygen and moisture, which can significantly alter salt chemistry and corrosion behavior.

Under irradiation, MSR fuels exhibit dynamic behavior that is closely tied to their liquid nature. Fission occurs within the circulating salt, producing fission products that remain dissolved, precipitate, or form gaseous species depending on their chemistry. The transport of these species through the system—along with their potential removal via online processing—must be well understood. Radiation also drives changes in salt composition and structure, including the formation of radiolytic species and shifts in redox balance. These effects can influence key properties such as viscosity, heat transfer, and actinide distribution, necessitating irradiation testing that captures coupled neutronic, thermal, and chemical phenomena.

Another important aspect of irradiation performance is the behavior of fission gases and noble metals. Gaseous fission products (e.g., xenon and krypton) can form bubbles within the salt, affecting reactivity and heat transfer, while also providing an opportunity for passive removal through off-gas systems. Metallic fission products may plate out on structural surfaces or form particulates, influencing both material degradation and radionuclide distribution. Qualification efforts must therefore address multiphase behavior in irradiated salt, including bubble dynamics, mass transport, and deposition processes under prototypic flow and temperature conditions.

Ultimately, demonstrating the performance of MSR fuels under irradiation requires an integrated experimental and modeling approach. Irradiation testing in representative environments—ideally with flowing salt loops—must be combined with advanced simulation tools to predict long-term behavior across a wide range of operating and transient conditions. Because the fuel is continuously evolving, qualification must focus on bounding the system's response rather than certifying a static material. This includes establishing acceptable limits on composition changes, validating control strategies for maintaining fuel chemistry, and ensuring that performance remains stable and predictable throughout the reactor's operational life.

GOAL 4:

Drive Innovation in Advanced Nuclear Fuel Technology

Fuel technology is the primary element of any nuclear reactor. Functionally, the entire reactor system is designed specifically around the unique strengths and weaknesses of this technology. Thus, continuous innovation in nuclear fuel technology is critical to advancing nuclear energy utilization as it enhances economics, performance, safety, and viability. Advanced fuel designs can significantly improve reactor efficiency by allowing longer operation and extracting more energy from the same amount of nuclear material, leading to better fuel utilization, reduced operational costs, and reduced waste generation. Moreover, nuclear fuel innovation contributes to the viability of nuclear energy by enabling the use of a broader range of fissile materials. This includes recycled used nuclear fuel, which enhances energy security by reducing dependency on raw resources like uranium. Ultimately, maintaining a diverse portfolio of advanced nuclear fuel technologies allows nuclear generating capacity to be more adaptable and resilient to evolving energy demands and external challenges. Due to its complexity, nuclear fuel technology development has the longest lead component in a new nuclear system, thus, AFC works anticipate future needs and actively seeks evolutionary and revolutionary concepts that expand the nuclear energy options of the future.

OBJECTIVE 1: *Demonstrate Methodologies to Accelerate Innovation in Nuclear Fuel Technology*

Accelerating fuel development and qualification is crucial to increasing the rate of innovation injection into nuclear reactor technology that is needed to meet the growing demand for safe and efficient energy. The massive capability enhancements recently made by the DOE at its national labs to implement modern material science techniques, enhanced experimental infrastructure for irradiation testing, and advanced modeling and simulation for nuclear applications play a pivotal role in establishing the methodologies expected to drive this acceleration.

Investment in nuclearization of material science instruments, including microscopy and material properties characterization, allows researchers to routinely interrogate the basic attributes of nuclear fuel materials in ways never before possible. Cutting-edge experimental infrastructure and methods, primarily expanded in-situ characterization,

Preparing to perform welds on the High-burnup Experiments in Reactivity Initiated Accidents (HERA-HBU-1) rod.

provide the time-dependent data necessary to truly characterize the dynamic response of nuclear fuel to complex, time-dependent irradiation environments. Advanced multi-scale, multi-physics modeling and simulation tools allow nuclear fuel researchers to integrate diverse data sources, collected from networks of experiments, and mechanistic behavior models into a simulation platform capable of predicting integral fuel performance. These predictive simulation tools can be used to identify potential failure modes, optimize fuel designs, and increase the impact of integral system testing. By systematically leveraging these three capabilities, the qualification process can be significantly shortened, opening the aperture for the identification, development, and deployment of innovative nuclear fuel technologies.

Collaboration between industry stakeholders, regulators, and the R&D community is essential for developing and implementing the full spectrum of this methodology effectively. Open communication and alignment of objectives among these groups can streamline regulatory reviews and address potential concerns more efficiently. Joint research initiatives and data-sharing agreements enhance the collective knowledge base, facilitating the validation and acceptance of innovative fuel technologies. This collaborative approach ensures that new fuel designs are not only developed more quickly but also meet the stringent safety and performance standards required for regulatory approval and commercial deployment.

International standardization is also necessary to streamline the export of advanced nuclear fuels developed through these accelerated methodologies. Establishing common standards and regulatory frameworks across countries ensures that innovative fuel technologies can be widely adopted and deployed. This harmonization reduces barriers to international trade, promotes global cooperation, and enables the U.S. nuclear industry to leverage the best practices and expertise from around the world.

OBJECTIVE 2: *Conduct Research that Advances TRL for Innovative Fuel Technologies*

The intention to quadruple nuclear energy generation by 2050 is being expressed worldwide. In response to this, a spirit of innovation has arisen within the U.S. nuclear energy industry that has not been present for roughly half a century. This has led to the emergence of a broad portfolio of advanced reactor concepts to support a variety of applications within the U.S. and abroad. This surge of deployable innovation is built on a foundation of nuclear fuel technology that is mature and available today. It is worth noting that this foundation was constructed on DOE-sponsored R&D that started a generation ago.

When challenged to envision the nuclear fuel cycle that will support the nuclear energy ecosystem of 2050 and beyond, it is clear, based on the timeframe necessary to develop new fuel technology, that it will inevitably reflect whatever technologies the DOE research community begins to work on today. However, the motivation for any industry to adopt innovation is built on the emergence of new technologies that deliver value that is sufficient to incentivize the radical change from the existing technologies. These families of “disruptive technologies” have become relatively common over the last 50 years and are emerging at an ever-increasing rate. Nuclear energy technology is generally under-innovated and is due to experience such a breakthrough.

To fuel this innovation cycle, AFC will seek out new ideas and concepts with the potential to make a dramatic impact on the nuclear fuel cycle through extreme performance, reduced cost, or the creation of entirely new applications. AFC will work with many sectors (e.g., academia, industry, and national labs) to identify and maintain a portfolio of research efforts aimed at identifying and maturing low technical readiness level (TRL) technologies. Through periodic technical review, promising concepts will be carried forward, and flawed concepts will be judiciously off-ramped.

OBJECTIVE 3: *Conduct Research that Improves the Utilization of Existing Fuel Technologies*

Nuclear reactor system developers, operators, and regulators must implement many criteria that reliably ensure effective and safe utilization of nuclear technology. Reactors are complex machines that typically apply conservative, simplified performance criteria to make deterministic analysis possible. This is particularly true in nuclear fuel technology, where the complexity of material performance was impossible to accurately describe using the computational tools available to early developers. Driven by goals to increase efficiency, reactor operators have consistently pushed to maximize the performance of their plants by reducing uncertainty and over conservatism in prioritized areas. This allows operators to continue using simple, yet conservative, performance criteria that are easy to demonstrate compliance in areas with large operating margin, while simultaneously implementing more precise, but often more costly to comply with, performance criteria in critical areas.

AFC performs targeted research that improves the utilization of existing fuel technologies by providing the scientific and engineering basis for these improved performance criteria. This objective focuses on extracting additional value, often termed *mining for margin*, from existing fuel technologies by gaining a deeper understanding of material behavior and their dynamic responses under complex operational conditions. By rigorously studying the behavior of nuclear fuels under relevant environmental conditions, researchers can identify opportunities to optimize fuel usage, extend fuel life, and increase reactor efficiency.

A core aspect of this objective is the development, validation, and integration of improved fuel behavior models for use in fuel performance codes. Accurate models are essential for predicting how nuclear fuels will perform under normal and accident conditions. These models require validation through experimental data and irradiation testing, ensuring they accurately reflect real-world behaviors. By incorporating these enhanced models into fuel performance codes, engineers and scientists can simulate and predict fuel performance with greater precision, leading to better-informed decisions on fuel management, reactor operation, and safety protocols.

AFC engages in comprehensive stakeholder collaborations to identify opportunities, inform the community on progress, and assist in implementing new knowledge. These partnerships, among national laboratories, academic institutions, and industry stakeholders, are vital for addressing complex challenges in fuel technology, as they bring together diverse perspectives and innovative solutions. Through joint research initiatives, workshops, and collaborative projects, AFC can leverage collective intelligence to refine fuel designs, enhance safety measures, and ensure the continuous improvement of nuclear fuel technologies. Notable ongoing collaborations include the CRAFT working group that brings the LWR stakeholders together and the annual DOE-led advanced reactor fuel technology workshops that promote engagement with LWR, metal, coated particle, and salt fuel stakeholders.

Section of the engineered SiC fiber-reinforced SiC matrix composite tube before (left) and after (right) the mechanical test. (General Atomics specimen.)

Ultimately, AFC's objective is to maximize the potential of existing nuclear fuel technologies, ensuring they are utilized to their fullest extent while maintaining the highest safety standards. By improving the understanding of material behavior, enhancing fuel performance models, and fostering collaborative efforts, the program strives to achieve more efficient, reliable, and safer nuclear fuel solutions. These advancements not only support the current fleet of nuclear reactors but also pave the way for future innovations in nuclear energy, contributing to abundant, economic, safe and secure energy production.

OBJECTIVE 4: *Conduct Research that Improves the Fissile Utilization and Integration of the Nuclear Fuel Cycle*

As deployment of nuclear energy grows over the next several decades, the demand for usable uranium resources will dramatically increase. Reliable access to this critical material will be increasingly important to the nation's energy security. At the same time, active management of the national inventory of used fuel will become increasingly important. The resilience and stability of this nuclear fuel supply chain would be greatly enhanced by developing a diverse portfolio of technologies to select from. AFC's research activities are aimed at expanding the pipeline of technology options available to future decision-makers.

AFC is working to develop technology that will maximize the value of uranium resources through demonstrating the use of recovered uranium in new nuclear fuels. To functionally recycle recovered uranium, it must be demonstrated that recycle-based fuels deliver equivalent performance to fuels produced with fresh uranium, despite inherent isotopic shifts and potential carried over impurities. Utilization may also require development and demonstration of new manufacturing methods that mitigate higher potential dose to workers and simplify contamination control.

In addition to better fuel designs, AFC is dedicated to identifying future fuel cycle options that incorporate expanded fissile material recovery and recycling processes. By reprocessing spent nuclear fuel, additional fissile material, such as plutonium, can be co-extracted along with the uranium and reused in new fuel assemblies. This would further reduce the need for fresh uranium while simultaneously minimizing the volume of high-level radioactive waste. This approach not only conserves natural resources but also improves long-term waste management.

Commercial advanced nuclear fuel arriving in Idaho for testing.

It is also clear that a robust, reliable, and economic nuclear fuel cycle must be fully integrated and collectively optimized across every stage from uranium mining to fuel utilization to final disposition. This holistic approach ensures that each phase of the fuel cycle is optimized for efficiency, safety, and environmental stewardship. AFC will work closely with partner DOE programs including the Uranium Fuel Supply (UFC), Materials Recovery and Waste Form Development (MRWFD), Used Fuel, and Systems Analysis and Integration (SAI) programs to collectively identify and prioritize research activities.

GOAL 5:
Enable a High-Performing Organization

To deliver on our mission, AFC must enable a high-performing organization with a capable workforce, well-managed programs, and regular stakeholder communications. A high-performing organization is key to providing the greatest value to the nation.

OBJECTIVE 1: *Support and Invest in AFC Program Staff*

People are the most important asset in executing the AFC mission. To be successful, AFC must attract and retain a highly capable workforce with the technical skills and experience required to accomplish its science-driven programs. AFC must compete with other technical organizations and DOE-NE programs for top scientists, engineers, and management professionals. To ensure the continued excellence of its workforce, AFC is committed to proactively recruiting highly qualified employees from universities and adjacent industries. AFC has engaged with the DOE-NEUP program for many years to encourage university faculty, and by proxy students, to engage in AFC-related research activities. By actively engaging AFC staff in these projects and encouraging students to participate in AFC direct-sponsored internships, students develop more rapidly and are identified as potential national laboratory staff. AFC will maintain a roster of active fuels-related university projects and treat them as integral mission elements, develop enduring relationships with targeted faculty teams at core universities, and will invest in student development through onsite, collaborative research.

Our team leverages advanced technical skills and expertise to achieve AFC goals.

AFC will also invest in its existing workforce to ensure it maintain worldclass expertise in executing its programs. This will include supporting continued education and training for staff, as well as working with laboratory line leadership to communicate career plans, succession planning, and inclusion in employee recognition programs.

Overall, AFC is fortunate to have outstanding technical staff that demonstrate commitment to the mission and goal sharing that transcends laboratory affiliation and specific technical expertise. This unique mix of staff routinely demonstrate a willingness to put in extra effort, embody a commitment to work/life balance, and treat colleagues with respect. This sensibility is not always natural and requires conscious commitment from the full program staff to realize.

OBJECTIVE 2: *Effectively Manage Program, Projects, and R&D Investments*

AFC maintains a diverse portfolio of R&D programs. To be successful in executing its mission, AFC must manage programs effectively and efficiently with a constant focus on technical excellence and overall performance. Technical scope is managed within a structured, multiyear program execution plan that responds to the objectives laid out in the *AFC Strategic Vision* and is informed by detailed multiyear R&D plans.

The *AFC Program Execution Plan* documents the multiyear program schedule and estimated cost, as well as the organizational structure including roles and responsibilities and project management expectations. AFC uses the Program Information Collection System for Nuclear Energy (PICS:NE) to provide a clear picture of performance to DOE-NE. PICS:NE is a web-based program management tool that describes the planning basis (i.e., objectives, assumptions, technical scope, deliverables, and milestones) for NE's R&D programs. Nearly 100 individual AFC work packages are assigned directly to a specific site and organization under the technical oversight of the National Technical Director, Qualification Lead, Technical Area Lead, and Work Package Manager. Cost and schedule data is tracked each month to measure against milestone performance. AFC aims to meet the DOE-NE target of 90% of Level 2 milestones on time and within budget.

R&D plans are prepared and maintained, in accordance with the provided federal priorities, by the AFC Qualification Leads and are integrated under the *AFC Execution Plan*. Several AFC activities are considered capability or infrastructure development efforts. Due to fundamental difference in management approaches required for research activities, capability development efforts are coordinated in a projectized fashion by a technical lead/project manager team. AFC continuously assesses the risk to program objectives and, when detected, develops mitigation plans in collaboration with program leadership and federal staff to manage them. *The AFC Execution Plan* is updated annually to reflect changes in federal direction, incorporate lessons learned, and document annual progress toward program goals.

OBJECTIVE 3: *Enhance Communication with Stakeholders*

AFC will continue to communicate its plans, program priorities, and activities both internally and externally. Managing successful R&D programs necessitates regular prioritization of activities with the greatest potential and the highest likelihood of impact. As AFC reprioritizes activities and shifts focus to meet its mission and goals, leadership will reflect those changes in updates to this *Strategic Vision*. AFC will deliver an updated version of the *Strategic Vision* every year.

Building on the goals, objectives, and performance indicators laid out in this plan, each AFC program element will develop and maintain a multiyear R&D plan that is updated annually. The multiyear program plans will describe program goals, R&D priorities, and roadmaps for success.

AFC and its staff also serve an important role as an authority on nuclear fuel technology. Commercial nuclear power has suffered from a public perception problem for decades. AFC is committed to providing accurate, fact-based information about nuclear fuel technology through its technical publications, social media, and stakeholder outreach efforts to educate the industry and public on the uses and benefits of fuel technologies for nuclear energy. These efforts are pivotal to the success of the mission to advance nuclear energy science and technology to meet U.S. energy, security, and economic needs. AFC will maintain a detailed *Communications Plan* that provides a structured approach to stakeholder engagement which will be updated annually.

OBJECTIVE 4: *Implementation of AI to Enhance Data Perseveration and Institutional Memory*

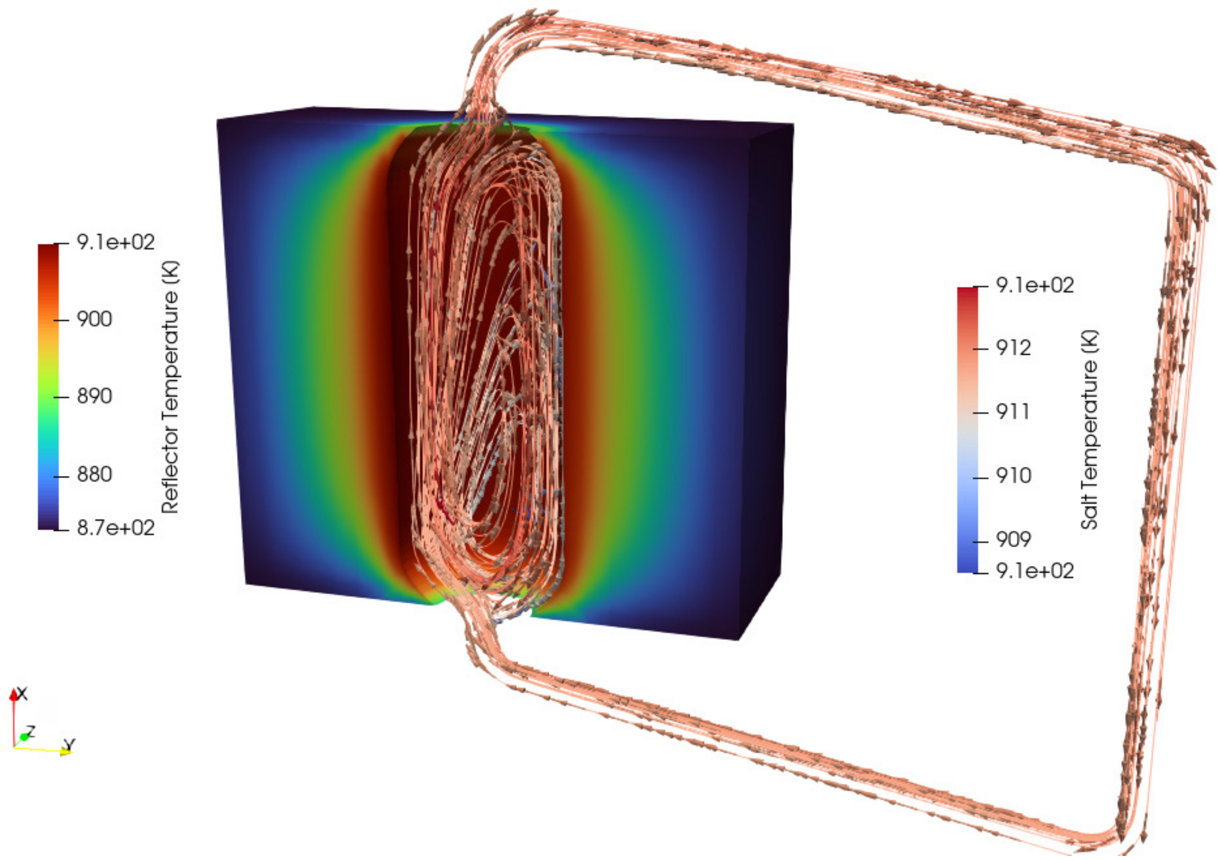
AFC's long-term success—and U.S. leadership in nuclear fuel technology—rests on more than experimental capability and modeling excellence. It depends on the ability to systematically preserve, integrate, and deploy decades of institutional knowledge accumulated through irradiation testing, post-irradiation examination (PIE), fuel fabrication development, modeling validation, safety testing, and regulatory engagement.

This knowledge base is one of DOE's most strategically valuable national assets. However, much of it remains distributed across legacy reports, siloed databases, and individual expertise. As fuel qualification timelines compress and advanced reactor deployment accelerates, AFC must ensure that this knowledge is structured, traceable, and rapidly accessible in order to sustain technical rigor while increasing execution speed.

To meet this challenge, AFC will implement a secure, governed Institutional Memory and Digital Acceleration framework that transforms historical data and expert insight into an integrated, enterprise-ready knowledge ecosystem.

This effort will:

- **Strengthen qualification defensibility** through structured provenance, traceability, and quality classification of data
- **Reduce development timelines** by accelerating data synthesis, report preparation, and model validation workflows
- **Enhance regulatory confidence** through reproducible, auditable documentation pathways
- **Preserve critical expertise** across workforce transitions
- **Enable data-informed decision-making** across the full fuel lifecycle



Temperature fields and conjugated heat transfer during the steady-state operation of pool-type molten salt reactor.

Digital modernization within AFC is not a technology initiative — it is a mission acceleration strategy. By embedding structured data governance, metadata standards, and AI-assisted knowledge retrieval into existing workflows, AFC will shorten iteration cycles between experiment, modeling, and qualification while maintaining licensing-grade integrity.

Artificial intelligence and advanced analytics will be deployed under disciplined human oversight, with clear data quality controls and audit mechanisms. These tools will augment expert judgment, reduce manual bottlenecks, and improve analytical consistency—without compromising safety or regulatory credibility. Over the next five years, AFC will lead foundational implementation of standardized data architectures, quality-governed knowledge systems, and AI-assisted qualification workflows.

These capabilities will align with DOE-wide modernization initiatives, such as GENESIS, while remaining anchored in AFC's goal-oriented, science-based methodology.

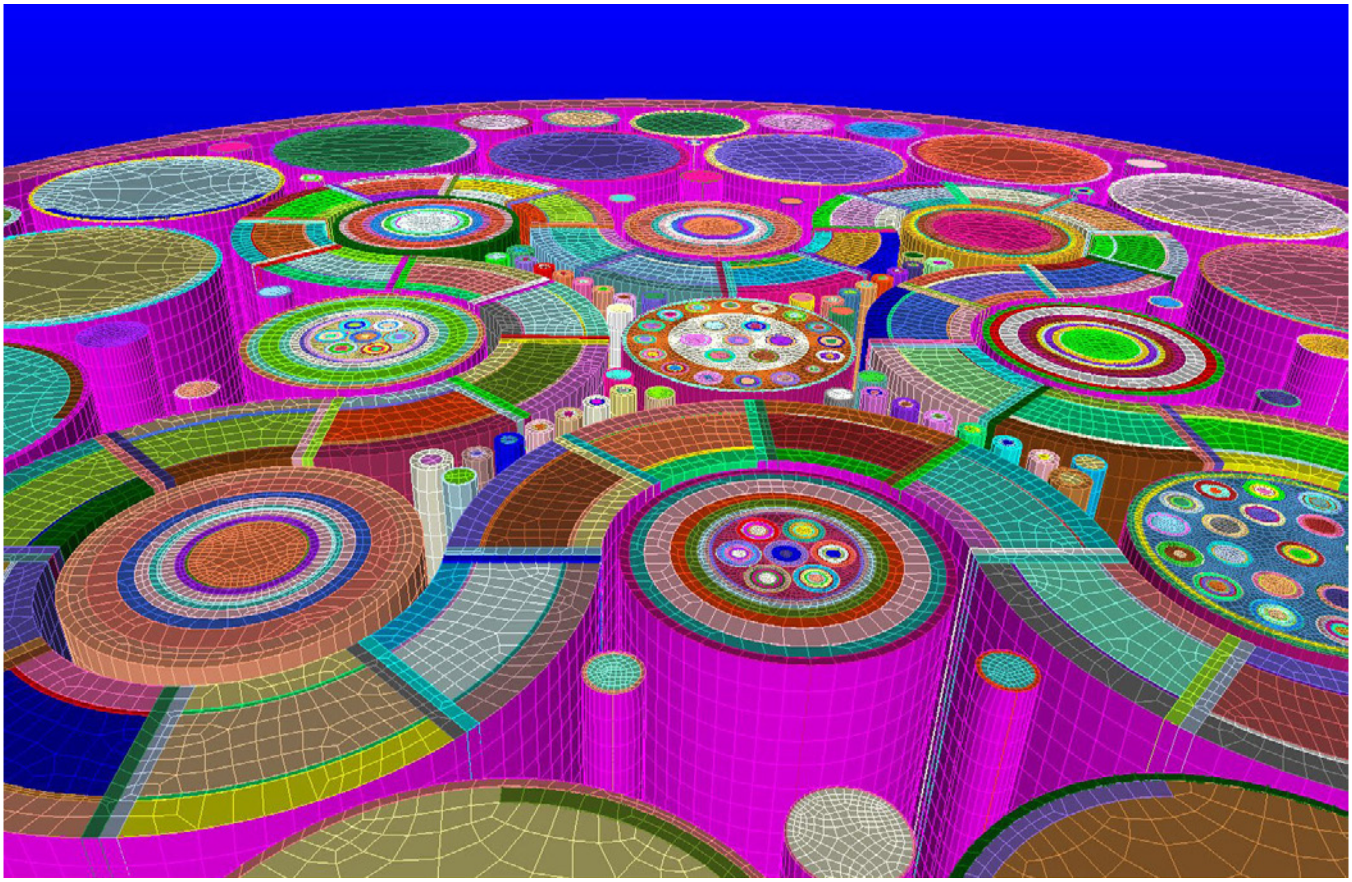
By transforming institutional memory into a strategic asset—structured, governed, and deployment-ready—AFC will demonstrate how digital integration can responsibly accelerate nuclear fuel development in a high-consequence regulatory environment. This effort positions AFC not only to meet near-term deployment milestones, but to establish a repeatable innovation model that strengthens U.S. nuclear energy leadership for decades to come.

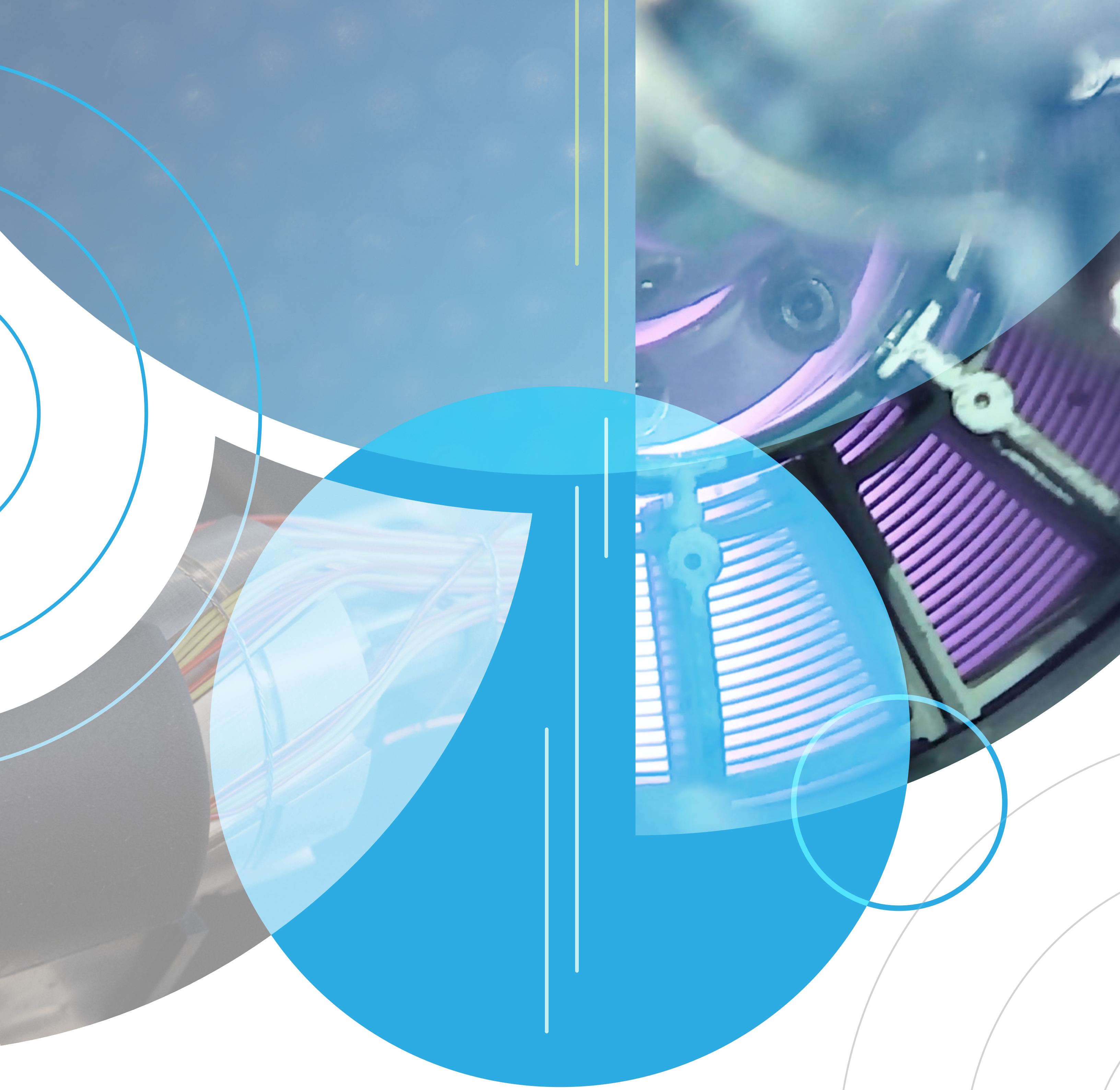
CONCLUSION

In conclusion, the AFC Strategic Vision is dedicated to achieving several critical goals that will move the U.S. nuclear energy sector forward.

By focusing on driving U.S. leadership in nuclear fuel technology, expanding nuclear energy produced by the existing fleet, and completing the qualification basis for advanced reactor fuel technology, AFC will ensure a strong foundation for future advancements.

Furthermore, by driving innovation in advanced nuclear fuel technology and enabling a high-performing organization, AFC is poised to create the foundation for a dynamic and resilient nuclear energy sector. This commitment will not only reinforce U.S. technology leadership but also contribute to a cleaner, more secure, and prosperous future for the nation.





AFC

Advanced Fuels Campaign

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