Overview of Nuclear Fuel Cycle and Supply Chain Program

Andy Griffith
Deputy Assistant Secretary
Office of Nuclear Fuel Cycle and Supply Chain

U.S. DEPARTMENT OF ENERGY

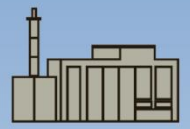
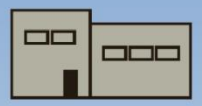
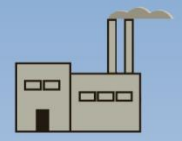
Overview Topics

- Overview – Fuel Cycle as a System
- Uranium Supply
- Advanced Fuels
- Material Recovery and Waste Form Development
- Materials Protection, Accounting and Control Technology (MPACT)
- Versatile Test Reactor
- Strategy Going Forward

Nuclear Energy Technologies: Functional and Program Components

Front End (NE-4)

Back End

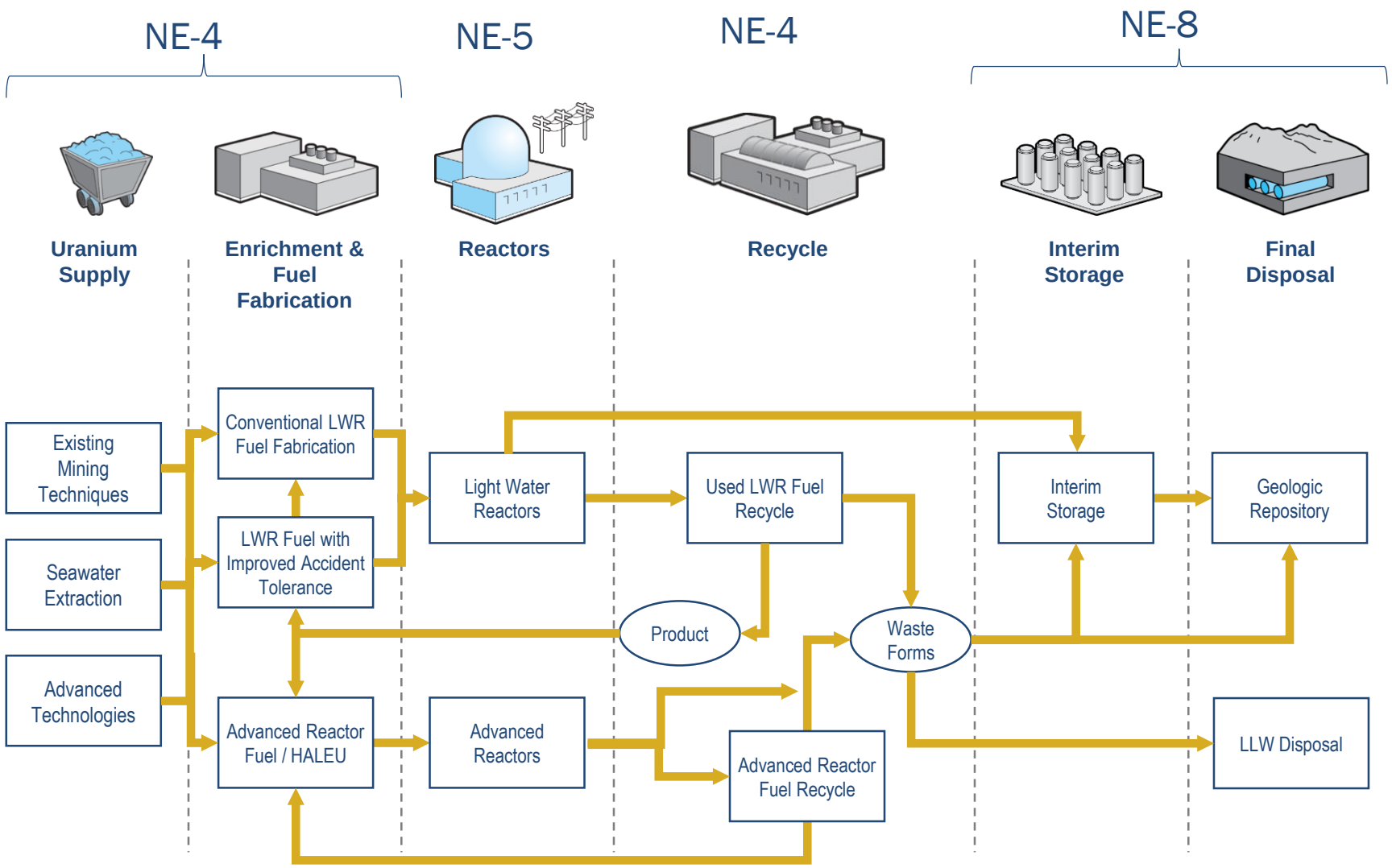
	NE-4	NE-5	NE-8	NE-4	NE-8
					
Uranium Resources	**Fuel Fabrication**	**Reactors**	**Interim Storage**	**Recycle**	**Disposal**
▪ Existing production techniques ▪ Innovative approaches – U Seawater – Production Improvements	▪ Safety enhanced LWR fuel – Accident tolerance ▪ Higher performance – Improved burnup	▪ Light Water Reactor Sustainability ▪ SMR support and R&D ▪ Advanced Reactors	▪ Evaluating extended time frames ▪ Transport after storage	▪ Separations ▪ Recycled fuel ▪ Secondary waste treatment	▪ Alternative geologies ▪ Alternative waste forms

NE-4/5 **Safeguards and Security By Design**

NE-4 **Optimize through Systems Analysis, Engineering, and Integration**

NE-3 **Research and Development Infrastructure/Security**

The Nuclear Energy System Could Include Many Components



High Assay Low-Enriched Uranium (HALEU)

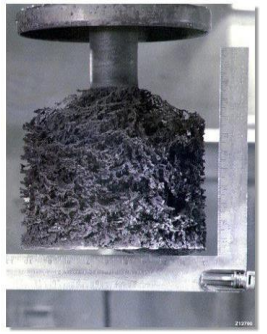
- To maintain economic competitiveness, it is vital that the U.S. secure and maintain a supply
- Establishing a HALEU supply chain will require effective execution of production, transportation, and fabrication activities
- Widespread use of HALEU can have significant implications across the entire nuclear fuel cycle
- HALEU workshop was held April 2020 to inform stakeholders on current HALEU related challenges and discuss where government and private roles connect
- Results from DOE Advanced Reactor Demo Funding Opportunity Announcement (ARD FOA) will provide more clarity to the near-term HALEU demand.

Industry Needs – Results of NEI 2020 Survey

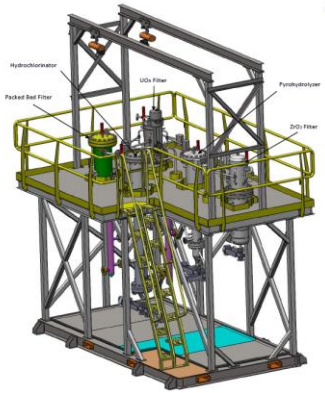
Year	Total (MT)	Cumulative (MT)
2021	2.8	2.8
2022	3.3	6.1
2023	9.7	15.8
2024	12.0	27.8
2025	32.0	59.8
2026	64.2	124.0
2027	32.7	156.6
2028	50.0	206.6
2029	81.7	288.3
2030	137.3	425.6
2031	170.4	596.0
2032	220.0	816.0

Pathways to HALEU

- HEU Recovery (plus down-blending)
  - Electrochemical processing of EBR-II fuel
  - Hybrid ZIRCEX processing of HEU containing (Naval and ATR) Fuels



- HALEU Demonstration Program
  - DOE/Centrus AC100M HALEU Cascade Demonstration
  - Demonstrate capability to produce HALEU with existing US-origin technology
  - Provide DOE with a small quantity of HALEU for its use in research and development of advanced reactor concepts
  - NRC License amendment allowing enrichment up to 19.75%
  - Provide a market signal that a U.S.-origin HALEU enrichment option is available



- HALEU from limited quantities of material in DOE Uranium inventory

Accident Tolerant Fuels (ATF)

- Following the accident at Fukushima, Congress requested the Department to start developing fuel with enhanced accident tolerance that can be used in existing light water reactors.
- DOE is working with industry to develop ATF concepts
  - Framatome: Cr-coated M5 cladding, Doped UO_2 for improved thermal conductivity and performance, SiC cladding
  - General Electric: Coated Zr cladding, High uranium density fuel, Iron-based cladding (FeCrAl), ODS variants for improved strength
  - Westinghouse: Cr-coated Zirlo cladding, Doped UO_2, SiC cladding, High uranium density fuel
- ATF Lead Test Rods (LTRs) are currently in 5 US power reactors
- First fully loaded lead test assembly (LTA) with ATF rods, from Framatome, scheduled for insertion into the Calvert Cliffs reactor in spring 2021.
- Industry Goals
  - Mid-2020s: batch reload(s) of near-term ATF concept(s) in commercial reactor(s)
  - Late-2020s: LTA's of 2nd Gen-ATF concept(s) inserted into commercial reactor(s)
  - 2030: ATF concepts operating in multiple commercial reactors to high burnup and with safety benefits realized
  - 2030+: Batch reload(s) of 2nd Gen-ATF concepts in commercial reactor(s)

Fuels with **enhanced accident tolerance** are those that, in comparison with the standard UO_2 – Zr system, can **tolerate loss of active cooling** in the core for a **considerably longer time period** (depending on the LWR system and accident scenario) while maintaining or improving the fuel performance during normal operations.

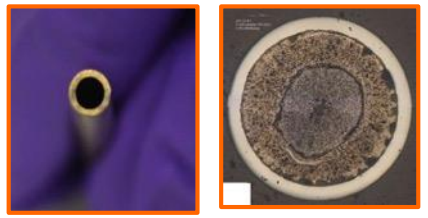
High Burnup/High Assay Fuels for LWRs

- Industry is interested in LWR fuel with >5% enrichment
  - Potential to enable PWRs to extend cycle lengths from 18 to 24 months
    - increased plant availability factor
    - increased electricity production over a 2 year period
    - increased revenue
    - reduced spent fuel
- *Industry Goals:*
  - 2023: Burnup extension to 68 GWd/t for current fuels with >5% enrichment
  - 2026: Burnup extension to 75 GWd/t for current fuels with >5% enrichment

Fast Reactor Fuel Development

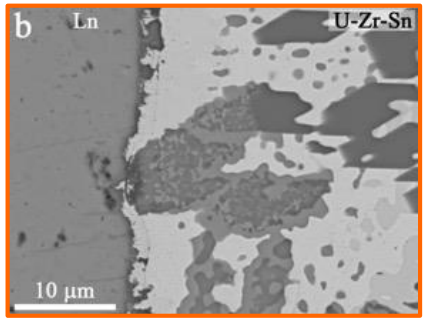
- Metallic Fuels for Closed Fuel Cycles and Actinide Transmutation for waste management missions
- Fuels for Once-through Fast Spectrum Reactors
  - Na-free, annular metallic fuel concepts (VTR, TerraPower)
  - Ultra-high burnup for enhanced resource utilization (TerraPower)
  - Non-traditional applications such as microreactors (Oklo, Westinghouse)
- Fuels for High Temperature, Fast Spectrum Reactors
  - Higher cladding temperature/performance (ODS alloys)
  - Metallic fuels with additives and/or cladding coatings/liners
  - UN, UO2 for LFR (Westinghouse)
  - UC for GFR (General Atomics)

Casting furnace used to fabricate recycled metallic fuels for IRT-1 (JFCS).



Annular U-10Zr metallic fuel: (1) as-fabricated, and (2) at ~5% burnup.

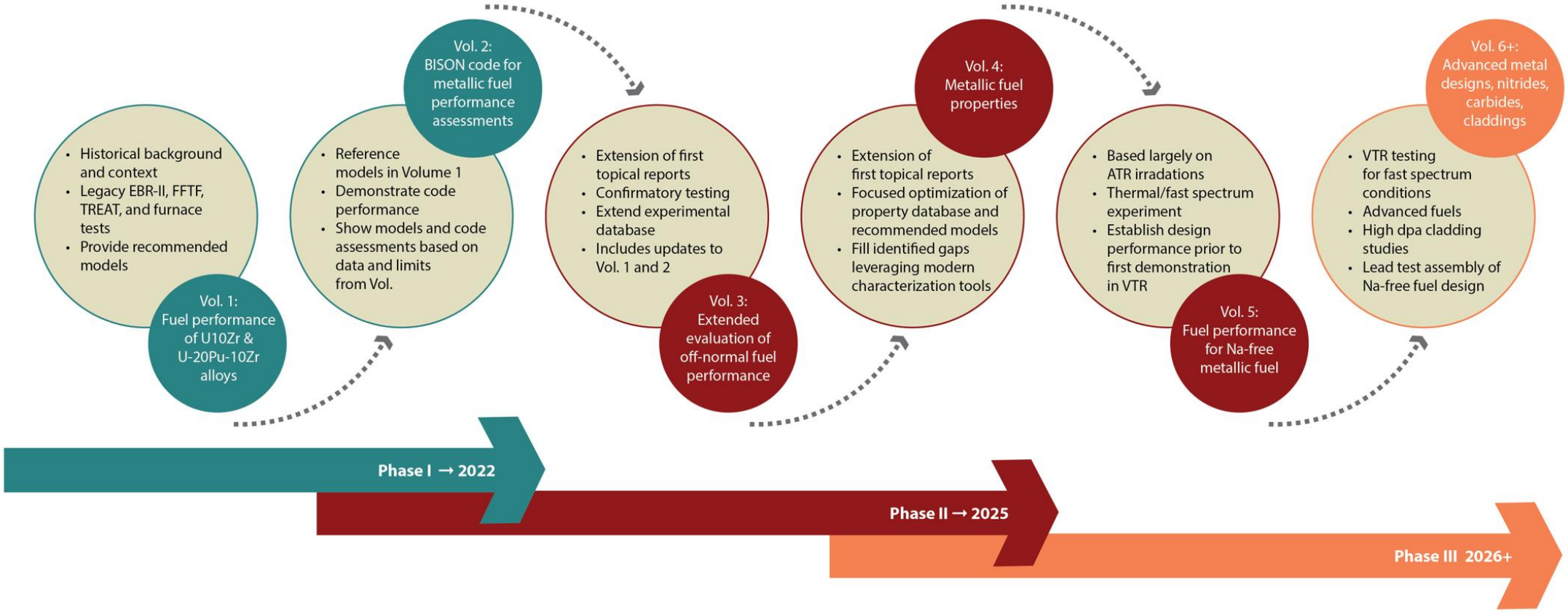
Metallic fuel cast into an expandable Zr sheath for FCCI mitigation.



Out-of-pile interdiffusion study showing addition of Sn to U-10Zr metallic fuel alloy shows promise for immobilizing lanthanide fission products.

LIFT Metallic Fuel Qualification Program (Proposed)

- Leading Innovation in Fuel Technologies (LIFT) Program will provide fuels R&D and qualification activities that support a series of Topical Reports submitted to NRC to establish design and performance basis of selected fuel technologies of cross-cutting interest
  - Metallic fuels are selected for the first qualification program due to the existence of data from EBR-II and FFTF and interest from U.S. vendors
  - Qualification of other fuel types will be possible after start up of VTR
- LIFT Program builds upon the metallic fuel database activity initiated by the NE-5 Fast Reactor Program



Material Recovery and Waste Form Development (MRWFD)

Fundamental Fuel Cycle Chemistry	Support studies in chemical speciation, complexation, radiation and process chemistry to predict and improve actinides separation efficiencies.
Domestic Molten Salt Process & Chemistry	Maintain U.S. leadership in e-chem and support transformative molten salt studies to enable tailoring and optimizing of salt properties and behaviors for molten salt technology applications.
Cross-Cutting for Aqueous & Salt-Processing	Develop advanced waste forms & off-gas capture and immobilization technologies with enhanced waste loading, durability and cost reduction.
Joint Fuel Cycle Study	Jointly with South Korea to assess the technical feasibility of electrochemical recycling for managing used fuels.
Hybrid ZIRCEX RD&D	Evaluate the feasibility of HALEU production from high-value excess federally owned nuclear fuels.
EBR-II Acceleration	Support the accelerated EBR-II fuel treatment to meet near term advanced reactor HALEU fuel R&D needs.

Molten Salt Chemistry

Objective:

Support fundamental salt chemistry research to enable innovation for enhancements of molten salt safety, functionality and affordability;

Our investment strategy is to leverage expertise and experiences in electrochemical separation to:

- Build robust core competencies and R&D capabilities in molten salt chemistry at DOE national laboratories and U.S. universities;
- Support molten salt research community to train broad-based next generation researchers and expertise;
- Improve the understanding of molten salt thermochemical properties and behavior to support molten salt reactor vendor needs; and
- Provide potential technology breakthrough for enhancing U.S. industry competitiveness in global deployment.

Materials Protection, Accounting and Control Technology (MPACT)

The MPACT campaign supports U.S. advanced fuel cycle technology developers to effectively and economically address international and domestic nuclear materials control and accounting (MC&A) requirements.

MPACT seeks to:

- Develop innovative technologies, analysis tools, and advanced integration methods;
- Engage with government and industry stakeholders early in the technology development process to enable a cost-effective implementation of safeguards by design.

Enhancing Capabilities: Versatile Test Reactor (VTR)

- VTR was formally launched in February 2019 as a part of the effort to modernize the nuclear research and development user facility infrastructure in the United States.
  - CD-0, *Approve Mission Need*, approved by then Deputy Secretary Brouillette February 22, 2019
  - CD-1, *Approve Alternative Selection and Cost Range*, expected September 2020

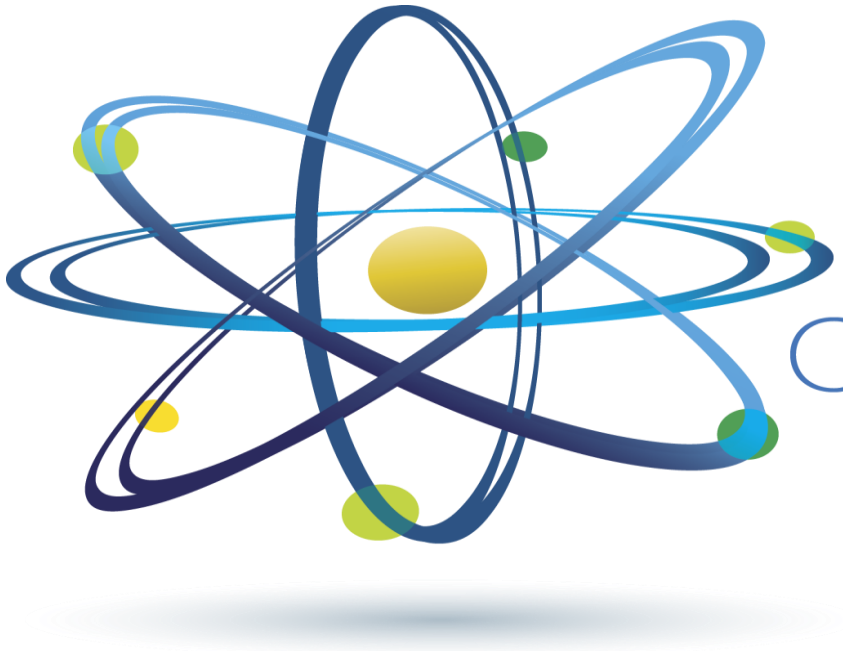
- VTR will provide a leading edge capability for accelerated testing and qualification of advanced fuels and materials, enabling the United States to regain and sustain technology leadership in the area of current and future reactor systems.

- VTR is proposed to be a 300MW_{th} sodium-cooled, fast spectrum reactor capable of testing advanced nuclear fuels and materials for the next generation of nuclear reactors.
  - High peak neutron flux of $\geq 4 \times 10^{15}$ n/cm^2-s and a high neutron dose rate of >30 dpa/year.

Fuel Cycle and Supply Chain Strategy Going Forward

- Currently in transition
  - FY 2020 Appropriations funding impacts
  - FY 2021 Budget uncertainty
  - Need to align program with Advance Reactor Demos for domestic deployment and U.S. global market competitiveness

- FY 2022 And Beyond Opportunities
  - Align the program with ARD FOA awards
  - Reestablish foundational R&D program for long term innovation to sustain U.S. nuclear technology leadership
  - Improved communication on the value of nuclear energy and the role of fuel cycle/supply chain technologies



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