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NANOFLUID-BASED ACCELERATOR-DRIVEN TRANSMUTATION RECYCLER (NATURE)

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- **Overview of ARPA-E NEWTON Call**
- **Introduction of Proposed Transmutation System**
 - Accelerator
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 - Nano fuel properties
- **Conclusions**

Executive Orders and Secretary Memorandum

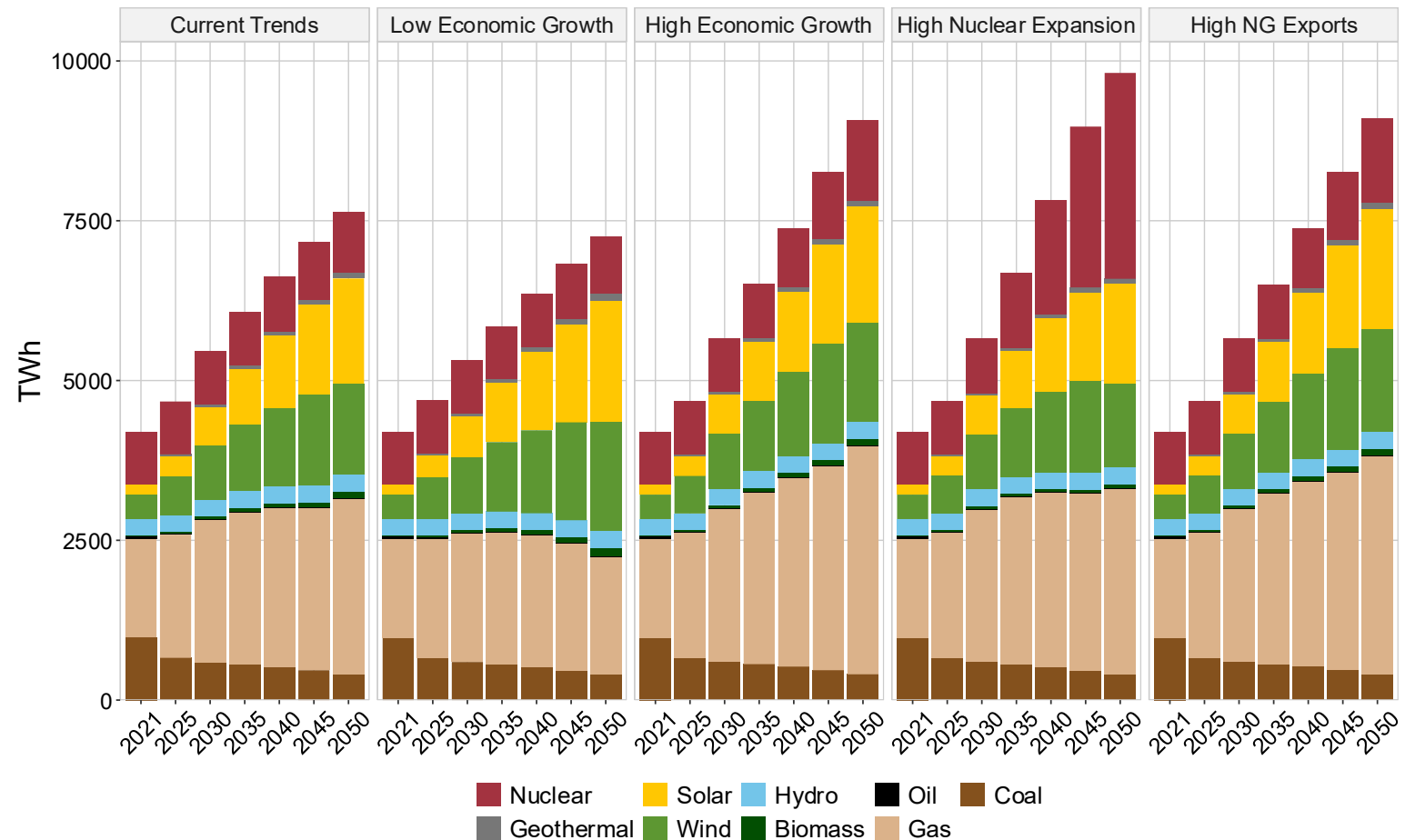
- **Secretary Wright's Memorandum (February 2025)**
 - Rapid deployment and export of next-generation nuclear technologies
 - Innovation R&D for affordable, reliable, and secure energy technologies, including nuclear
 - Explore recycling and reprocessing of used nuclear fuels
- **Four Executive Orders (May 2025)**
 - Expansion of nuclear capacity to 400 GW by 2050, 10 new large reactors under construction by 20230
 - Rapid deployment of advanced reactors through expeditious processes of DOE & NRC
 - Deployment of qualified test reactors (QTRs) at DOE sites and pilot reactors outside of national labs.
 - Reinvigoration of the industrial nuclear fuel cycle chains

SCENARIOS

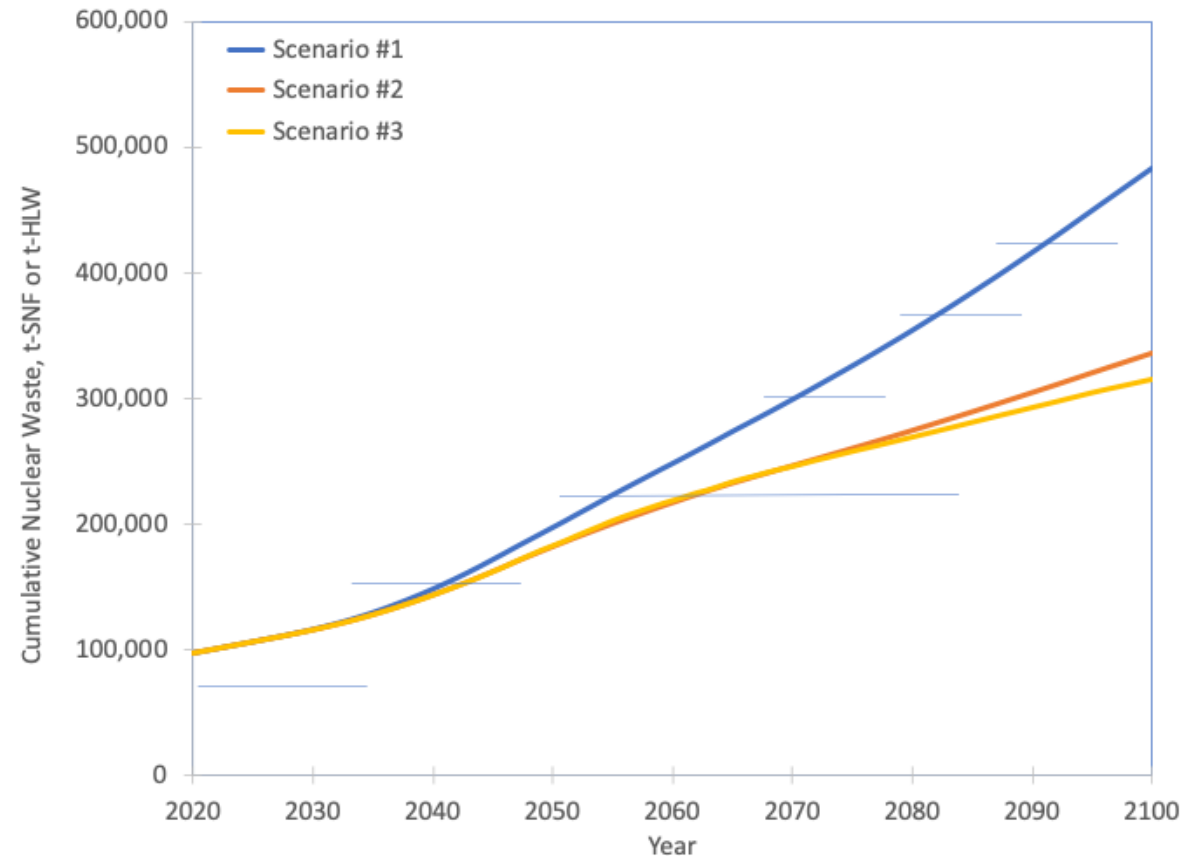
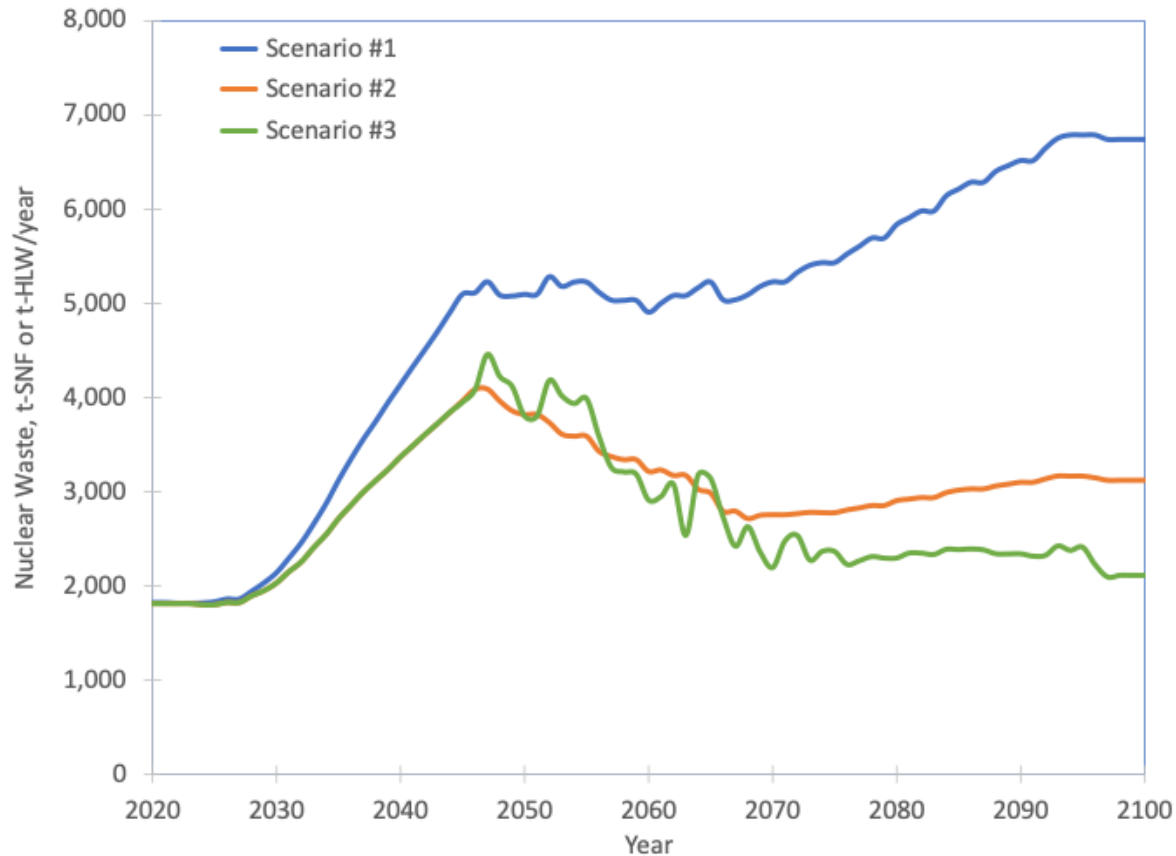
Abbreviation	Scenario	Population/ GDP Growth	Data Center Growth	CapEx of Generator	Fossil Fuel Supplies	Nuclear Policy
1 CT	Current Trends	Moderate (SSP2)	Moderate	Moderate	Reference	None
2 LEG	Low Economic Growth	Low (SSP4)	Low	Conservative	Low	None
3 HEG	High Economic Growth	High (SSP5)	High	Advanced	High	None
4 HNX	High Nuclear Expansion	High (SSP5)	High	Advanced	Low	4X in US, 3X globally by 2050
5 HNG	High Natural Gas Exports	High (SSP5)	High	Advanced	High + High U.S. LNG Exports	None

NUCLEAR ENERGY – U.S.

- U.S. electricity generation increases 74-230% in 2050
- Growth is driven by data centers, light duty vehicles, and other end-use electrification
- Nuclear electricity accounts for 12–33% of total U.S. electricity generation across scenarios in 2050 (19% in 2021).



Projection of Nuclear Waste



- The disposal option requires too many repositories

ARPA-E FOA / NEWTON

- **Nuclear Energy Waste Transmutation Optimized Now (NEWTON): DE-FOA-3418**
 - FOA release in July 2024, Awardees announced in Jan 2025
 - The NEWTON program seeks to enable the economic viability of transmutation at a scale that will **significantly reduce the mass, volume, activity, and effective half-life of the existing stockpile of commercial UNF** to be disposed of in a geological repository.
- **NEWTWON call consists of three categories**
 - Category A: Improved Efficiency and Reliability of Particle Generation and Acceleration
 - Category B: Transmutation Target

Technology Area	Objective
Transmutation goals	- 99.9% of minor actinides (MA) - 99% of intermediate- or long-lived fission products (ILFP, LLFP)
Throughput	30 MT combined MA, ILFP, and LLFP per year (900MT for 30 years)

- Category C: Capability Teams

Project Overview

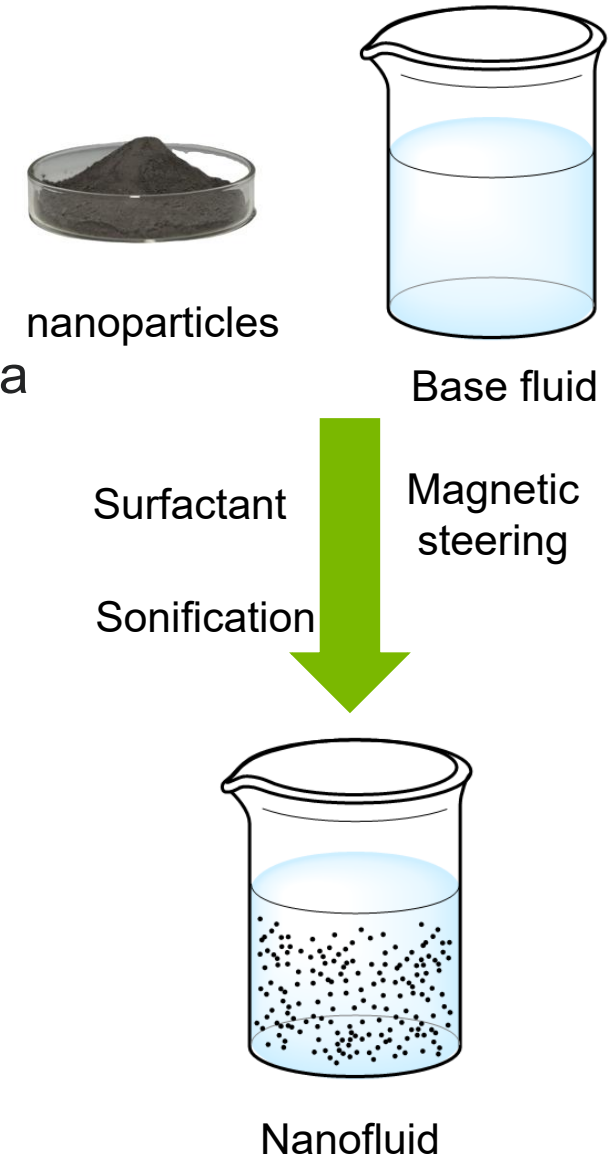
- **Title: Liquid Lead Suspended Fuel Subcritical Fission Blanket for Nuclear Waste Transmutation**
 - Nanofluid-based Accelerator-driven Transmutation Recycler (NATURE)
- **Period and funds: 2025 – 2028 (3 years) with \$7.35M**
- **Proposals**
 - Transmuting the entire US minor actinides (MAs) stockpile and long-lived fission products
 - Depletion of ~750 kg of MA (by fission) and ~kg of LLFP (by transmutation) per year,
 - Depletion of the entire MA stockpile within 30 years using a few proposed transmutation systems.
- **Contributing organizations**



- UIUC team as the capability team (Category C)

Innovations

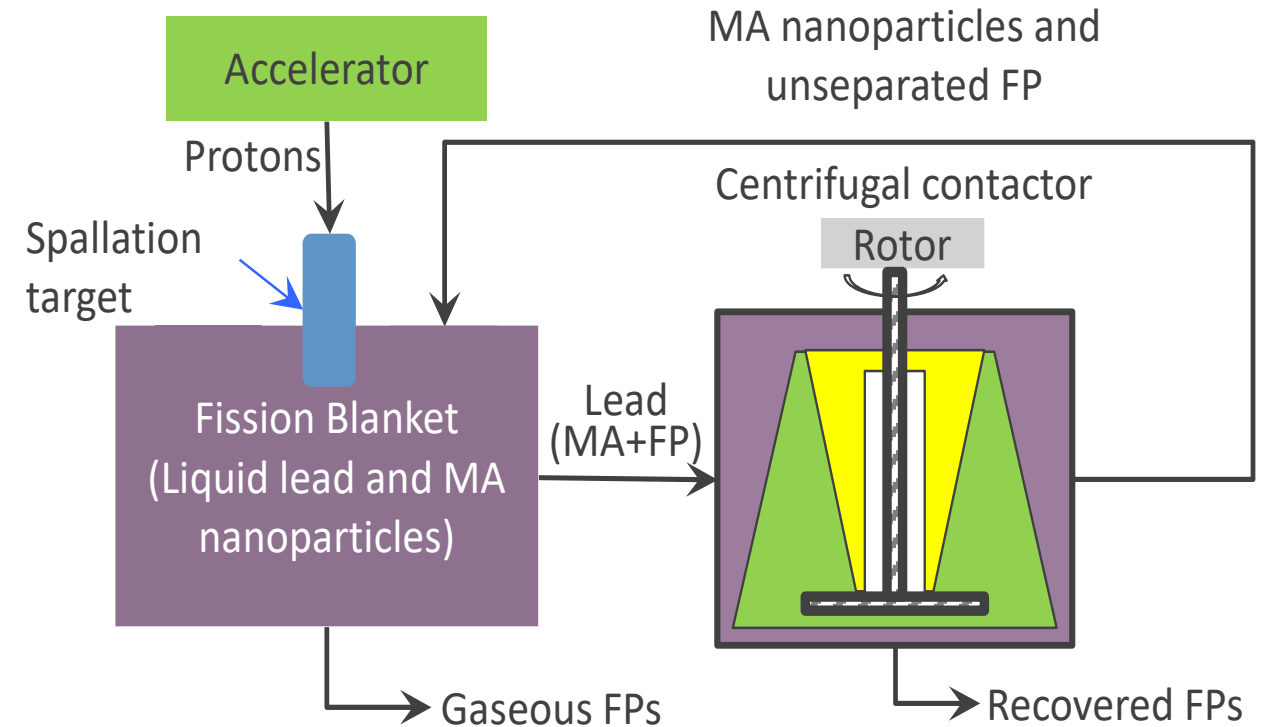
- Nanofluid: a stable suspension of nanoparticles in a base fluid
- Nanofluid enables several innovations
 - Nanoparticle size and recoil distance are equivalent to Moon's diameter and distance between the Moon and Earth when a neutron is prorated to a gold ball
 - Physical separation of FP using recoil distance
 - Nanofluid acts like a liquid fuel allowing :
 - **online separation**
 - **clean-up using centrifugal force**
 - A **proliferation-free** technology without separating actinides



	Values	Relative to neutron size
Neutron	$\sim 10^{-15}$ m	Golf ball $\sim 4.3 \times 10^{-02}$ m
Nano particle (100 nano-meter)	$\sim 10^{-07}$ m	Moon diameter $\sim 3.5 \times 10^{+06}$ m
FP recoil distance	$\sim 10^{-05}$ m	Moon and earth distance $\sim 4 \times 10^{+08}$ m

Transmutation System

- The proposed transmutation system consists of
 - **Subcritical fission blanket** contains nano-size MA and ILFP/LLFP targets in a liquid lead
 - 1 GeV 30 mA **proton accelerator**
 - **Fission products separator** based on centrifugal force



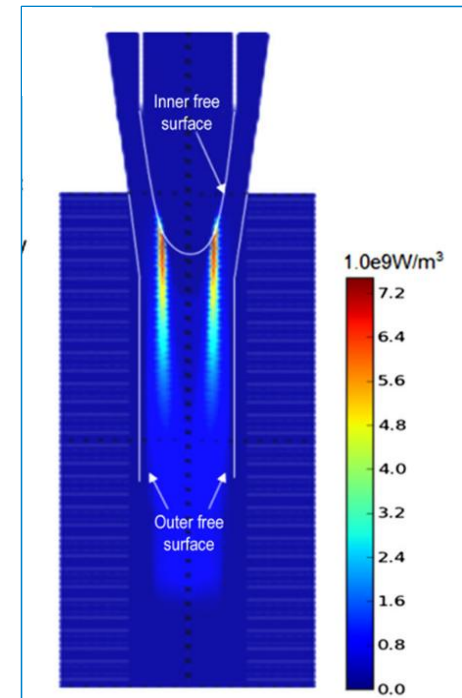
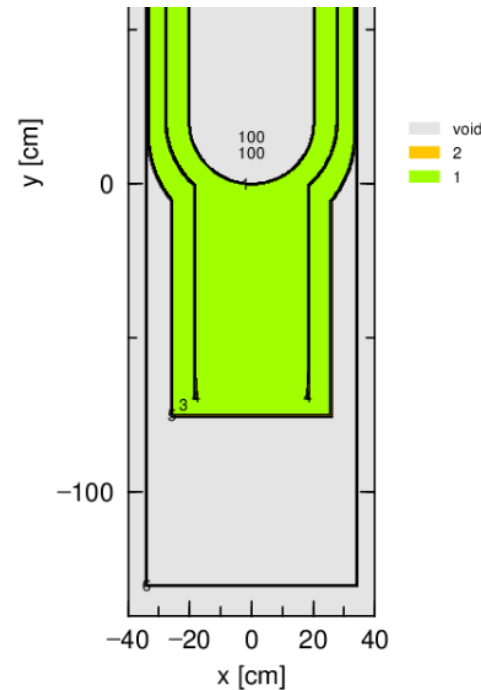
Accelerator

▪ Objective

- Fission Blanket is Intentionally subcritical, which requires extra neutrons
- Provide protons to the Fission Blanket for generating spallation neutrons

▪ 1 GeV energy 30 MW proton beam

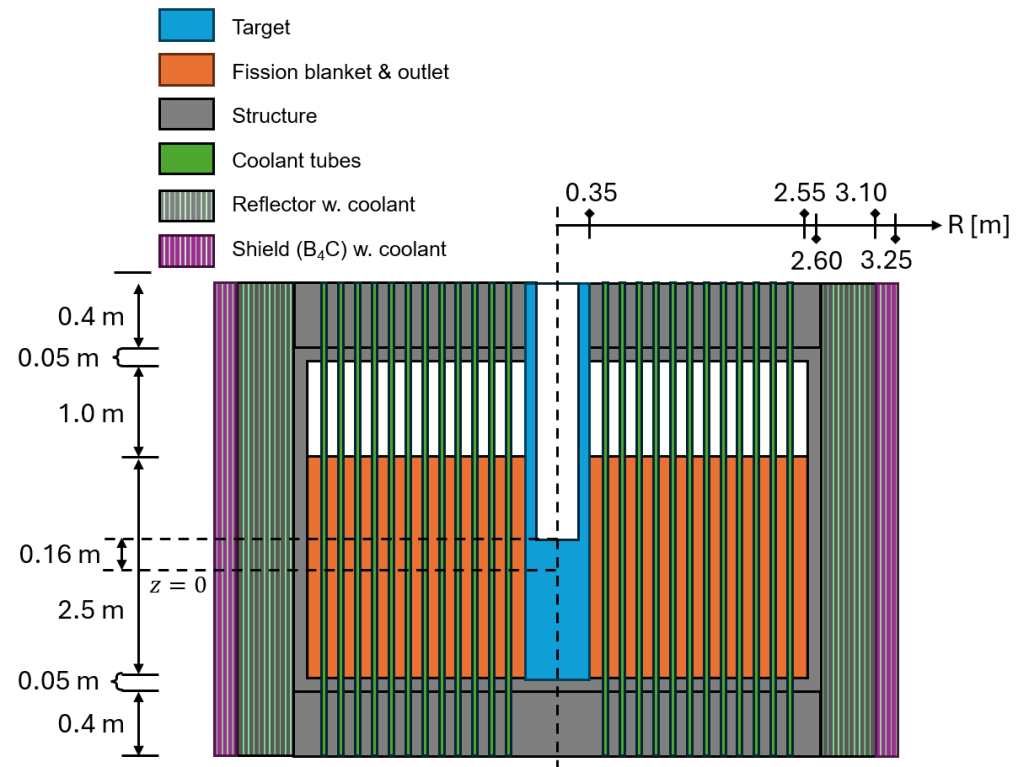
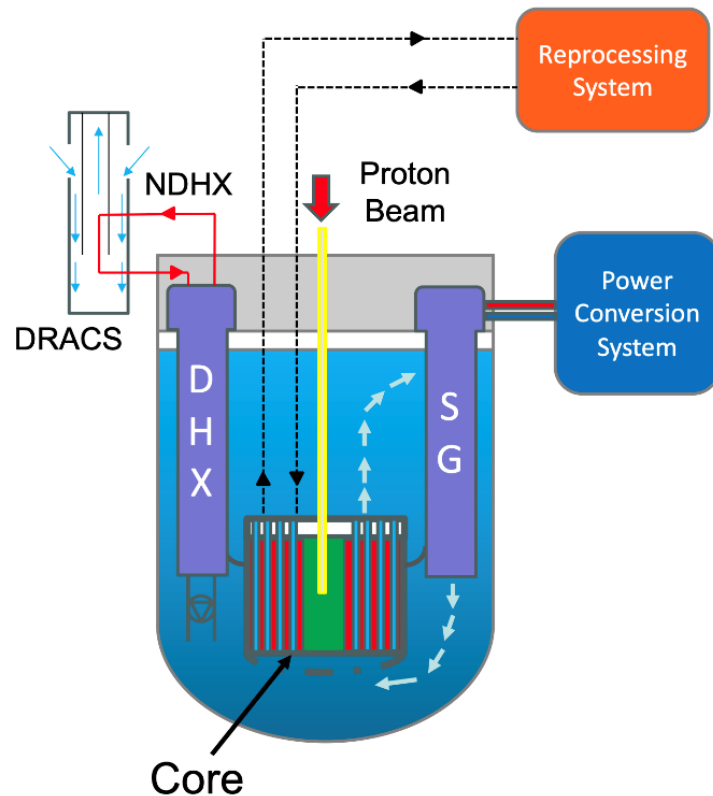
- Yield spallation neutrons
- Maximum achievable thermal power: ~3,000 MW with 1 GeV energy protons from 25 MW bea power at $k_{\text{eff}} = 0.98$
- Window & windowless design



Blanket

■ Design Configuration:

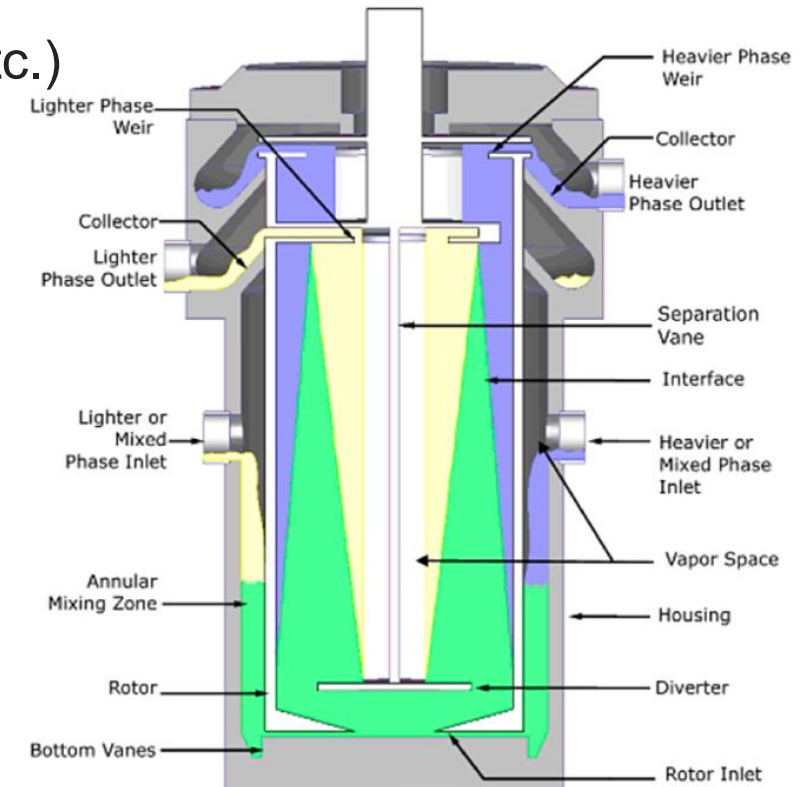
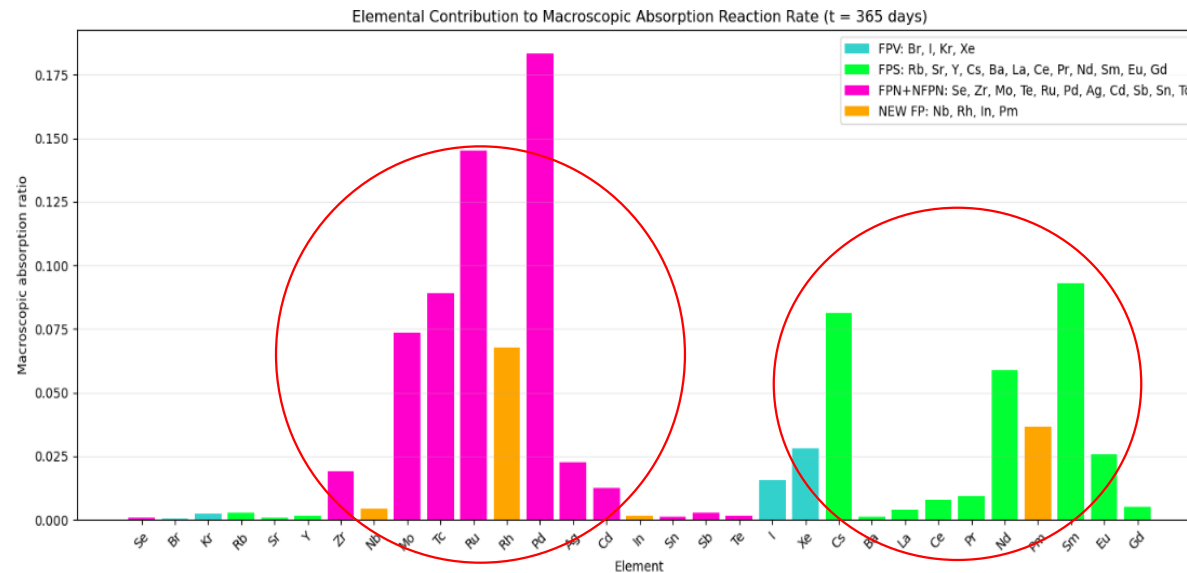
- 50%MA50%PuO₂, maximum 5% nanoparticles in Pb
- Nanofluid stay in a vessel and submerged in a coolant pool.
- Pb is also the primary coolant, passing through the core through in-core coolant tubes to remove



Clean up of FPs

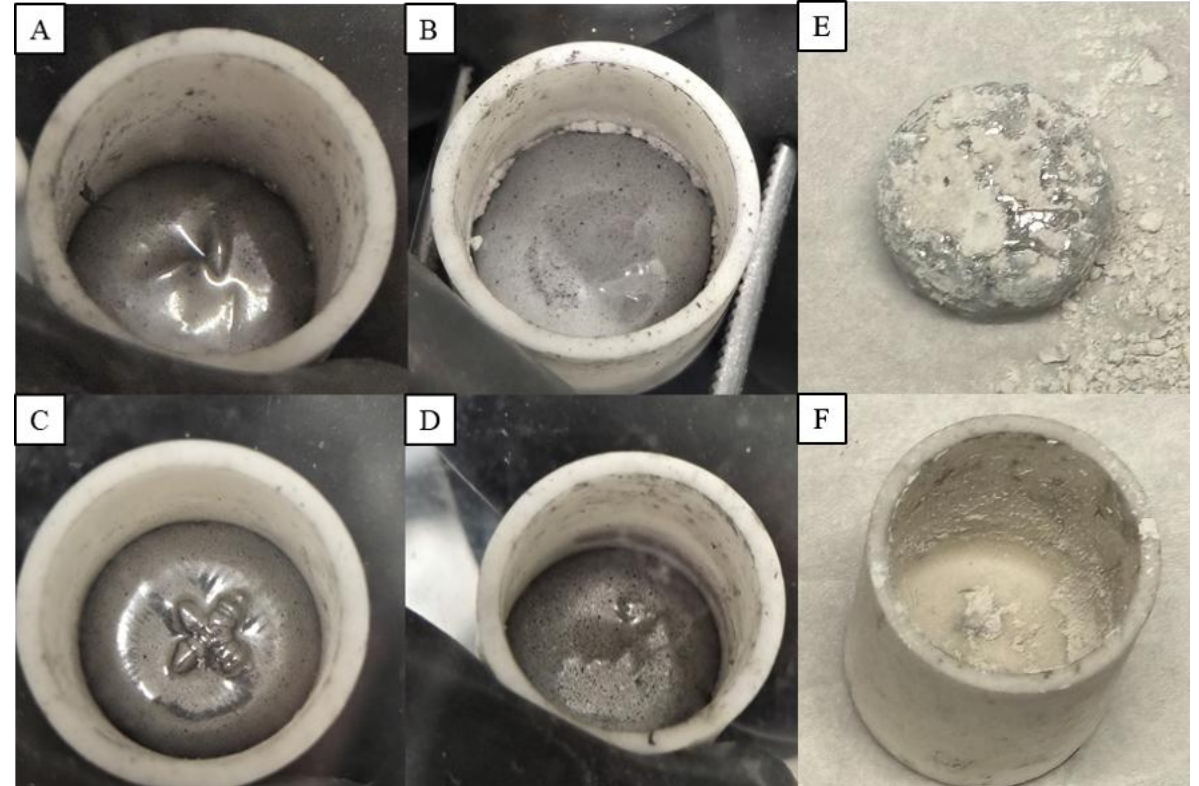
- Two FP groups having high neutron absorption rates
 - Group A: Noble and semi-noble metals (e.g., Ru, Rh, etc.)
 - Group B: Active metals and Lanthanides (e.g., Cs, Nd, Pm, etc.)
- Plan to demonstrate FP clean-up technology using centrifugal forces

Relative comparison of
macroscopic absorption rate



Nanofluid Properties

- **Lack information of nanofluid property data**
 - Thermo-physical properties with and without FPs
 - Under measurement using cerium dioxide and titanium dioxide nanoparticles
- **Oxygen purification and monitoring.**
 - A dissolved oxygen sensor is currently in development and undergoing testing
- **Synthesized 50-200 nm UO_2 nanoparticles**
 - Scaled-up study to isolate ~grams



: Surfaces of [A] 0.5 vol.% TiO_2 , [B] 1 vol.% TiO_2 , [C] 0.5 vol.% CeO_2 , and [D] 1 vol.% CeO_2 nanofluids. [E] solidified 1 vol.% TiO_2 nanofluid removed from [F] Al_2O_3 crucible

Conclusions

- **ARPA-E/NEWTON call for transformational technology for entire U.S. stockpile of MA**
- **ANL, with BNL, Univ. Michigan, MIT, Berkeley, and Virginia Tech, (UIUC – Cat C team) proposed a novel transmutation system**
 - The transmutation system consists of a fission blanket, a proton accelerator, and an FP separator
 - Unique in-core material, nanofluid with liquid-lead and MA nanoparticles, brings multiple innovations
 - Physical separation of FP using recoil distance
 - Proliferation-free FP clean-up using centrifugal force
 - Enhanced heat removal capacity and inherent safety features
 - The proposed system is transformational and low TRL, which requires technology demonstrations
 - Nanofluid characteristics
 - Fabrication of nanoparticles
 - FP separation rate using recoil distance
 - Demonstration of FP separation using centrifugal force

The background of the slide is an aerial photograph of a city skyline at night, with numerous illuminated buildings. A large, semi-transparent blue rectangle covers the middle portion of the image, serving as a backdrop for the text. The text "THANK YOU" is written in a bold, white, sans-serif font, centered within the blue area.

THANK YOU

Net Zero Cost for Transmutation (tentative)

Parameters for Revenue Estimation

Items	Value	Remark
Lifetime of the transmutation system, years	50.0	
Capacity factor, %	70.0	Combining accelerator, fission blanket and separation system
Full power operation, EFPY	35.0	
Proton beam current, mA	30.0	
Proton beam energy, GeV	1.0	
Consumed power, MW	50	
- For proton beam generation	30	Assumed operation power of accelerator and separation device
- Operation	20	
Fission blanket thermal power, MWt	3000.0	Design value
Fission blanket net electric power, MWe	1000.0	Assumed net thermal efficient of 33%
Available electricity for sale, MWe	950.0	
Average electricity price, \$/MWh	127.1	Average price in 2023
Lifetime total revenue, \$B	37.02	

Cost Estimation (need a detailed evaluation along with Category-C team)

	Accelerator	Fission blanket	Separation	Total
Capital	\$1.2B	\$18.4B	\$4.0B	\$23.6B
O&M	\$0.4B	\$5.5B	\$1.2B	\$7.1B
Fuel		\$3.7B		\$3.7B
Total				\$34.4B