Understanding and Solving HALEU Nuclear Fuel Supply Chain Challenges

NARUC-DOE Nuclear Energy Partnership

FRIDAY, JANUARY 7, 2022

2:00 – 3:00 P.M. (ET)

WELCOME

- **Commissioner John Gavan**, Colorado Public Utilities Commission

NARUC-DOE NUCLEAR ENERGY PARTNERSHIP

- Launched in March 2021 with support from the U.S. Department of Energy Office of Nuclear Energy
- An educational partnership that provides opportunities for state public service commissioners and commission staff to better understand barriers and possibilities related to the U.S. nuclear fleet, the nation's largest source of zero-carbon power
- Includes commissions and commission staff representing 20 states and territories
- Associate members from the Coalition for Advanced Reactor Solutions, University of Michigan Nuclear Engineering and Radiological Sciences

PANELISTS

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January 3, 2022
NARUC HALEU Webinar

The Evolving Nuclear Fuel Cycle HALEU Opportunities and Challenges

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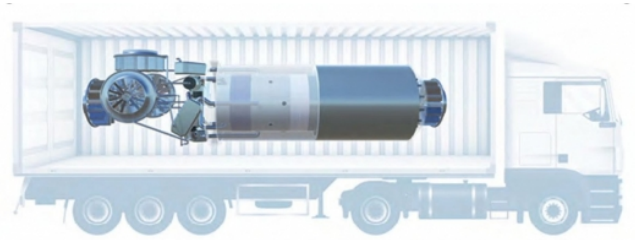
Director, Integrated Fuel Cycle Strategy

Idaho National Laboratory

Fuel Cycle of the Future



Today's fuel cycle is bounded by LWRs

Emerging advanced fuel cycles

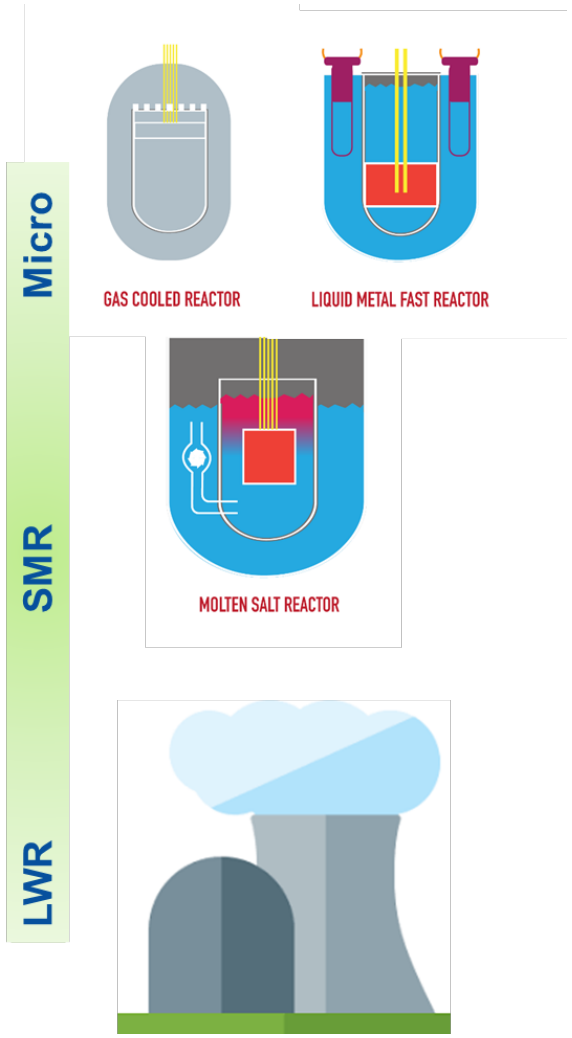
We don't know what it will look like, but we know what attributes are needed.

- Cost competitive
- Manage proliferation risk
- Manage of waste
- Address safety and security

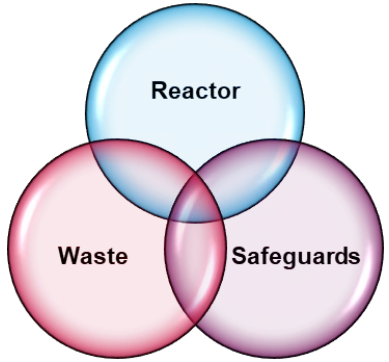
Departure from Current LWR Fuel Cycle

- Fuel characteristics
  - **Enrichments: HALEU, HEU**
  - Other fissile materials: plutonium, thorium (U-233)
  - **Composition: oxides, metal, molten salts (U, F, Cl, Li, Be)**
  - **Forms: assemblies, pebble bed/TRISO, liquid**
- Coolant/moderator
  - HW, sodium, lead, graphite, helium, etc.

- Overall characteristics can include
  - **Less frequent/continuous refueling**
  - Closed fuel cycle
  - Inherent or passive safety features
  - Simplified or modular designs
  - Stationary or mobile units
  - Lower power
  - Thermal and fast neutron spectrums



Challenges from Emerging Advanced Fuel Cycles



Front-End

- HALEU availability
- UF_6 de-conversion/fuel fabrication
- Transportation

Back-End

- Spent fuel direct disposal/treatment
- Other secondary wastes

Proliferation Risk

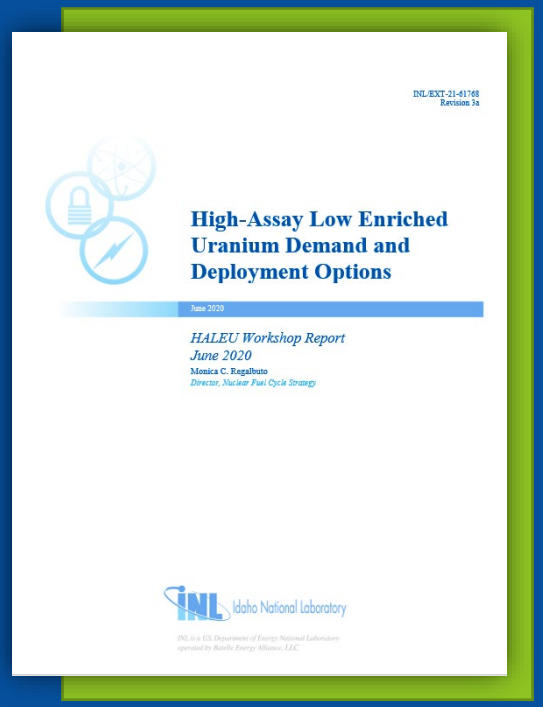
- Security category II facilities
- Bulk material accountancy

Addressing HALEU Availability 2020 Workshop

Objective – Convey a team of experts from industry and national laboratories to evaluate the anticipated HALEU demand, the timing, and options.

- Co-hosted by NEI, GAIN, and EPRI with over 300 participants from 70 organizations*
- INL developed the workshop report with contributions from U.S. uranium enrichment and downblending organizations

*https://gain.inl.gov/HALEU_Webinar_Presentations/Forms/AllItems.aspx
https://gain.inl.gov/SiteAssets/2020HALEU_Workshop/GAIN-EPRI-NEI_HALEU_WebinarRegistration.pdf



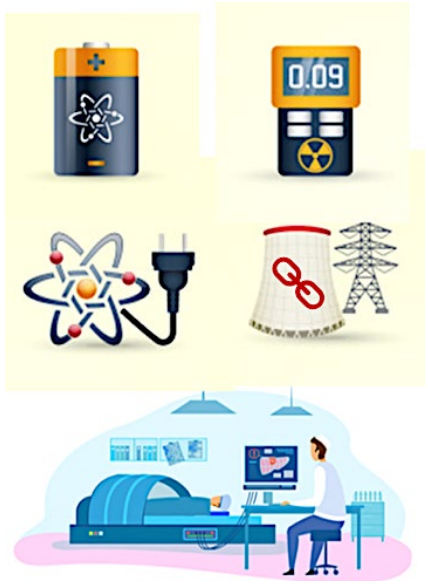
2020 HALEU Workshop Outcome

- Anticipated Demand
- Addressing Timing
- Near-Term Options
- Integrated Supply
- “Right-Sized” Initial Capability
- Recommendations

HALEU Anticipated Demand

Applications

Variety of reactor designs and fuel forms



U.S. Commercial Nuclear Industry

NEI 2020 survey HALEU results*

* 2021 update available at https://www.nei.org/resources/letters-filings-comments/updated-need-for-haleu

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Annual HALEU MTU	2.8	3.3	9.7	12	32	64.2	32.7	50	81.7	137.3

Government Needs

- Potential DoD mobile microreactor needs
- DOE-NE's advanced reactors demonstrations
- DOE-NE's advanced test and research reactors
- Long-term NNSA mission

Findings

- Industry needs are the fastest growing demand for HALEU
- Government needs are predictable, High-fidelity demand is driven by medical isotope production, HEU to HALEU reactor conversions, and DoD and DOE advanced reactor demonstrations.
- Anticipated demand for HALEU comes from a variety of applications requiring a variety of uranium fuel forms including oxides, metal and alloys, and nitrides and carbides

Timing - Transitioning to a Sustainable Market

What is needed for a Sustainable Market?

- A large enough customer base
- Securing long-term purchase agreements
- Fuel procurement models
- Infrastructure financing tools

Findings

- The timing is influenced by when and which reactor concepts mature toward commercialization
- Transitioning from “early movers” to a “sustainable” market would be a gradual evolutionary approach
- The timing is not predictable

Limited Near-Term Domestic Options ~ 20MT (mid 20's)

Supporting Early Movers - An aggressive deployment schedule is being pursued by advanced reactor developers eager to penetrate an evolving world market

Recovery and Downblending	
INL	1MT of HALEU per year until 2035. HEU downblending from EBR-II and ATR origin yields 10MT and 20MT
SRS	Potential 20MT HALEU available from fuel take back processing
BWXT	Potential 10MT by 2022 and 40MT by 2025. Downblending excess/surplus HEU
Enrichment	
American Centrifuge Operating LLC	600 kgs of UF_6 ongoing 16 machine cascade demonstration
URENCO USA	Commercial enrichment facilities for HALEU enrichment between 5% and 10%

Limitations

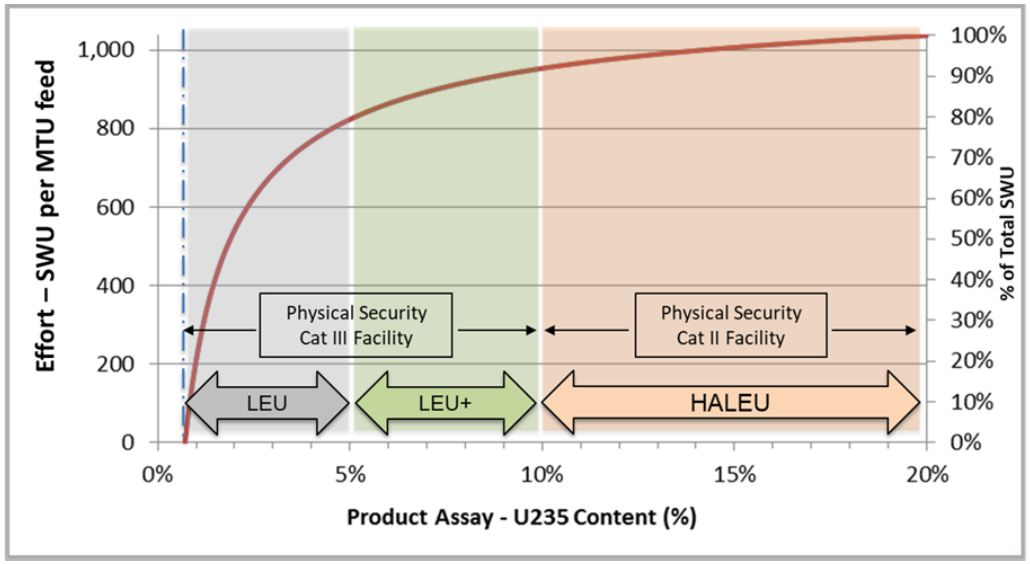
- Some early movers are not able to use recovered materials
- Some early movers are not able to receive UF_6 as the feedstock
- Near-term options have limited or no funding

Enrichment is key to long-term HALEU supply

Integrated Supply Enrichment Option

Production of HALEU enriched above 10% requires significant investments to support license, build, secure and operate HALEU fuel cycle infrastructure.

- Impacted facilities that support a HALEU fuel cycle economy are enrichment, deconversion, and fuel fabrication
- If facilities are not co-located, there is also a significant impact from transportation



U235 Enrichment Levels

- Feed 0.711% Natural Uranium
- LEU <5% Existing LWRs
- LEU+ 5% - 10% Metallic Fuels & ATFs
- HALEU 10% - 20% Test, Research and Gen IV Reactors

Findings

- Maximizing utilization of LEU (expanded to LEU+) enrichment infrastructure will significantly decrease the size of a HALEU Category II enrichment facility, resulting in lower costs and more competitive production of HALEU.
- Deconversion of HALEU enriched above 10% must also be conducted in a physical security Category II facility. Co-location of HALEU facilities (enrichment, deconversion, and fuel fabrication) with an LEU enriching facility decreases the cost of transportation and leverages security costs. Co-location of facilities will result in the most economic HALEU production model.

“Right-Sized” Initial Capability

Initial HALEU capability could “prime the pump” for a future market driven by commercial needs and sized to meet the “high-fidelity” market demand and a portion of the initial commercial needs.

Findings

- Although a portion of the high-fidelity demand is currently being addressed by downblending government-owned HEU stocks, these stocks are valuable assets.
- If another source of HALEU existed today, government-owned stocks would be preserved to support and extend government missions.
- Commercial demand for HALEU in the next 10 years could be much larger but is more uncertain. Modular design concepts could accommodate future growth.
- Enrichment technology is well suited for future modular expansion

Near-term, predictable HALEU “high-fidelity” demand mainly supports government agencies’ demonstration projects and mission needs driven by:

- *Medical isotope production*
- *HEU to HALEU research reactor conversion*
- *DoD microreactor demonstration*
- *DOE’s advanced reactor demonstrations, test and research reactors*

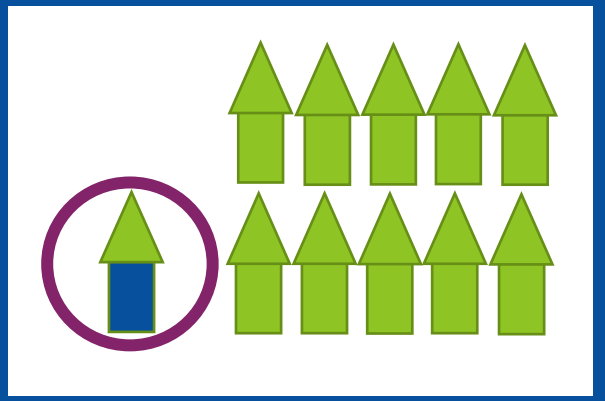
Some needs are currently met by downblending limited HEU government-owned stocks.

Recommendations

An initial public/private partnership is recommended to address the high-fidelity HALEU market, plus a percentage of the projected commercial demand.

- It is predicted that by the mid-2020's approximately 22 MTU will be needed for initial core loadings to support DoD and DOE's reactor demonstrations and DOE test and research reactors*.
- The high-fidelity HALEU demand is estimated to be between 8-12 MTU annually for the next 10 years.
- A pricing model that accounts for the added cost of going from LEU (or LEU+) to HALEU should be established.
- A mechanism such as a lease model, wholesaler, or reserve should be developed to make HALEU available to support commercial needs.

* As of June 2020, quantities may vary, but will not differ significantly to change the initial HALEU capability recommendation.



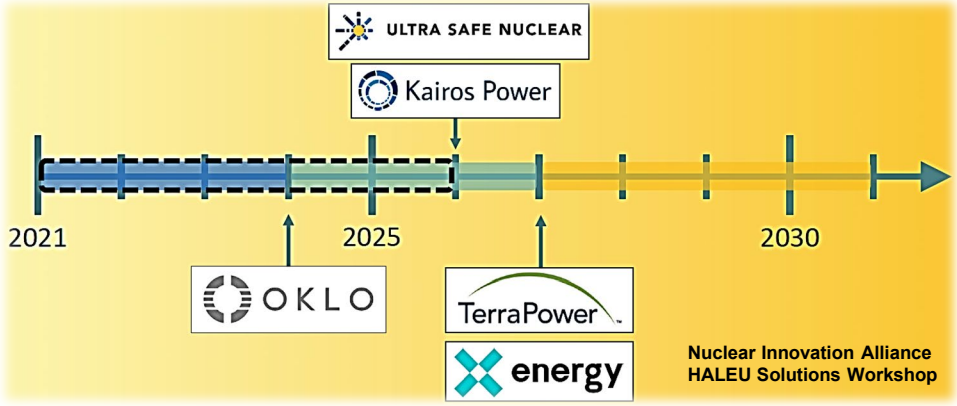
Given the variety of HALEU applications, the initial HALEU capability must be flexible and able to accommodate:

- Uranium enriched up to 10% U-235 as the feed
- Enrichments of U-235 varying from 10 to 19.75%
- Supply HALEU at a minimum annual rate of 12 MTU
- Modular design concepts to accommodate future growth
- Deconversion of UF_6 to a form (e.g., uranium oxide) suitable for production of a variety of uranium fuel forms, to include oxides, metal and alloys, and nitrides and carbides.

HALEU Path Forward

The HALEU fuel cycle represents an opportunity to reinvigorate domestic mining, conversion, enrichment, deconversion, and fuel fabrication in the U.S.

- Commercial investment in the front end of the fuel cycle to support HALEU production will not be made on a speculative basis.
  - Relying upon market forces and demand will not be enough to create the needed HALEU fuel cycle capabilities at the time the industry will require it, leaving imports as the only choice.
- Stakeholder and policymaker alignment is needed for HALEU program success.
  - Congress, DOE, enrichers, reactor developers/owners, fuel fabricators, transportation and infrastructure services providers.



Idaho National Laboratory

ANDREW GRIFFITH

Office of Nuclear Fuel Cycle and Supply Chain

U.S. Department of Energy

Understanding and Solving the HALEU Challenge

Dan Poneman

January 7, 2022

Forward Looking Statements

Disclaimer: My commentary and responses to your questions may contain forward-looking statements, including my outlook on the remainder of the year and future periods, and Centrus undertakes no obligation to update any such statement to reflect later developments. Factors that could cause actual results to vary materially from those discussed today include changes in the nuclear energy industry, pricing trends and demand in the uranium and enrichment markets and their impact on Centrus' profitability, the competitive environment for Centrus' products and services, the impact and potential extended duration of the current supply/demand imbalance in the market for low-enriched uranium, risks related to trade barriers and contract terms that limit Centrus' ability to deliver LEU to customers, risks related to actions that may be taken by the U.S. government or other governments that could affect Centrus' ability or the ability of Centrus' sources of supply to perform under contract obligations, including the imposition of sanctions, restrictions or other requirements, as well as those provided in Centrus' most recent Annual Report on Form 10-K and subsequent reports as filed by Centrus with the SEC.

Industry / Market Data: Industry and market data used in this presentation have been obtained from industry publications and sources as well as from research reports prepared for other purposes. We have not independently verified the data obtained from these sources and cannot assure you of the data's accuracy or completeness.

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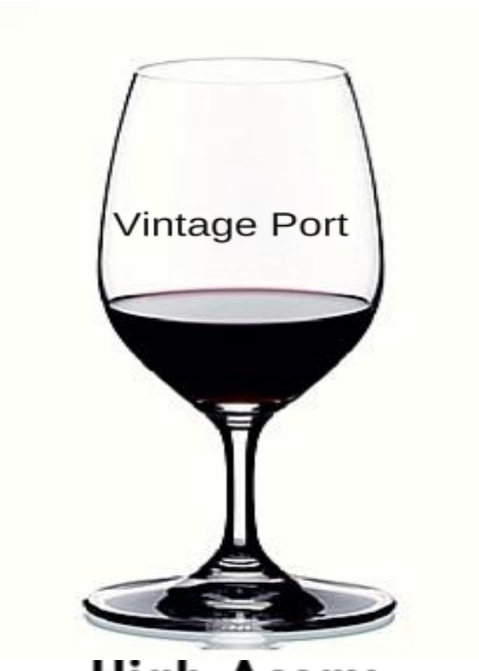
What Is HALEU?

Uranium Isotopes

- **U-238**
- **U-235**

Uranium (LEU) 3-5% U-235

Today's commercial reactors



High Assay, Low Enriched Uranium (HALEU) 5-20% U-235

Advanced reactors

Highly Enriched Uranium (HEU) >90% U-235

Naval reactors

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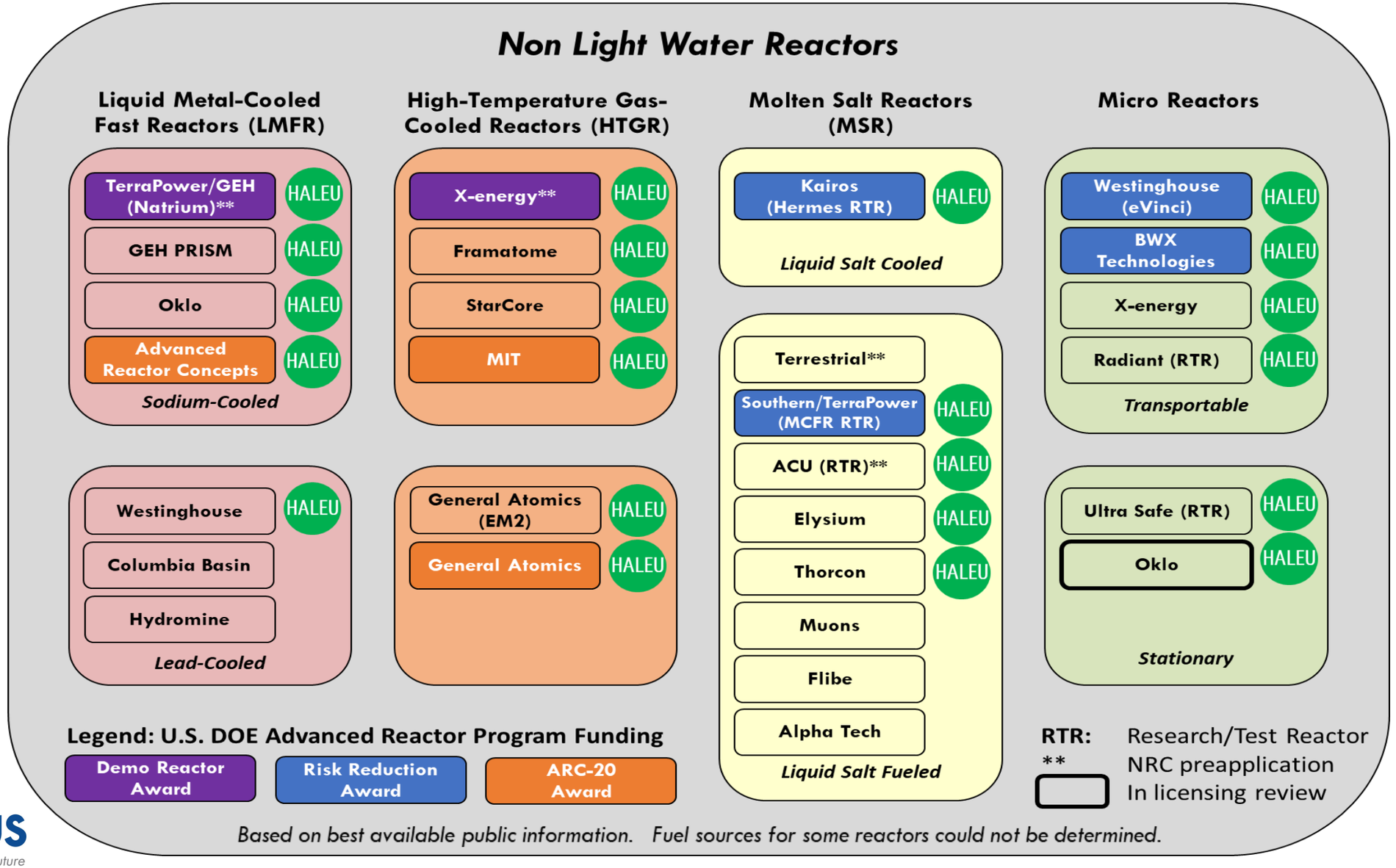
Most Advanced Reactors Require HALEU



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U.S. HALEU Production Later This Year

First-of-a-Kind, NRC-licensed HALEU production capacity under construction in Piketon, Ohio with support from U.S. DOE.

- ✓ Completed assembly of 16 centrifuges. Construction of "balance of plant" systems well underway.
- ✓ NRC License Amendment approved – first NRC licensed HALEU production facility.
- ✓ The existing contract covers cascade construction. Centrus plans to compete for additional funding later this year to operate the cascade.

Centrus' goal is to expand the plant to commercial-scale production.

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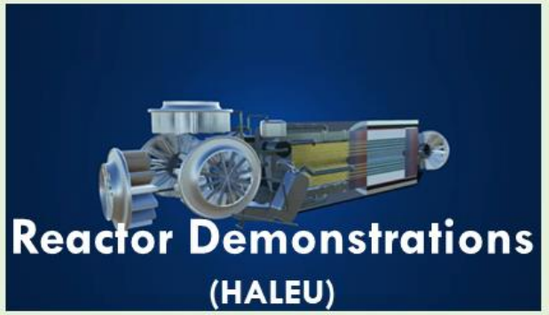
U.S. Government Also Needs Uranium Enrichment

Defense Missions			
Other Missions			

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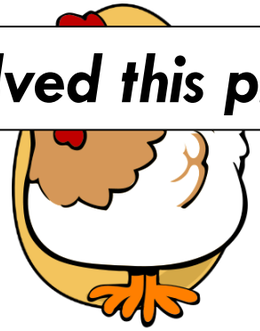
Which Will Come First?

The U.S. has solved this problem before…



<u>U.S. Advanced Reactors:</u>

Who will buy them if the U.S. lacks a guaranteed fuel supply?

<u>High Assay Enrichment:</u>

Who will invest in HALEU licensing/production without a guaranteed customer base?

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Proven Model: Leverage Government Demand to Promote Civilian Nuclear Leadership

The Paducah Sun-Democrat

Paducah, Ky., Friday Evening, December 15, 1950 — 4 Editions Daily—2 Sunday

AEC To Build A-Plant At KOW Site

Chinese Reds Drive Into UN Beachhead

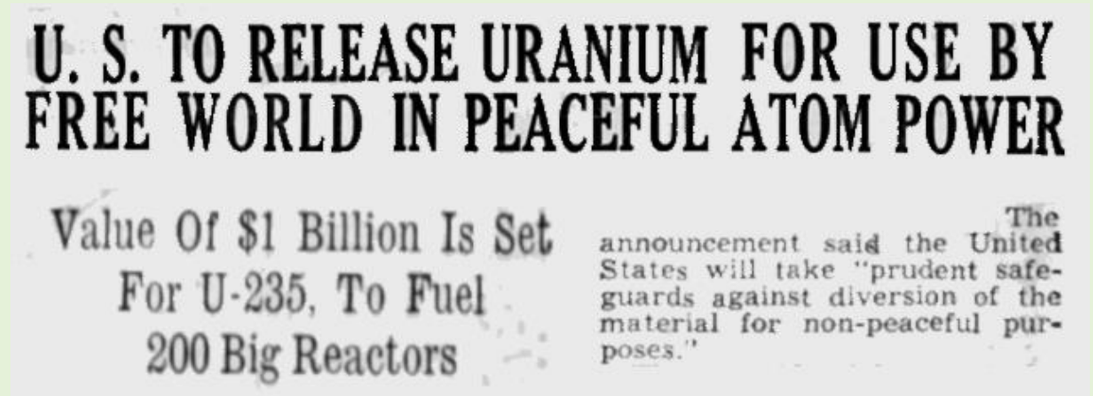
Activity Expected On Northwest Front

Building Force Of 10,000 May Be Required

Cost Set At $500,000,000;

1940s-1950s:

U.S. built enrichment plants for military use.



U. S. TO RELEASE URANIUM FOR USE BY FREE WORLD IN PEACEFUL ATOM POWER

Value Of $1 Billion Is Set For U-235, To Fuel 200 Big Reactors

The announcement said the United States will take "prudent safeguards against diversion of the material for non-peaceful purposes."

1956:

Ike makes fuel available for commercial reactors.

This approach could work again for the next generation of reactors and fuel.

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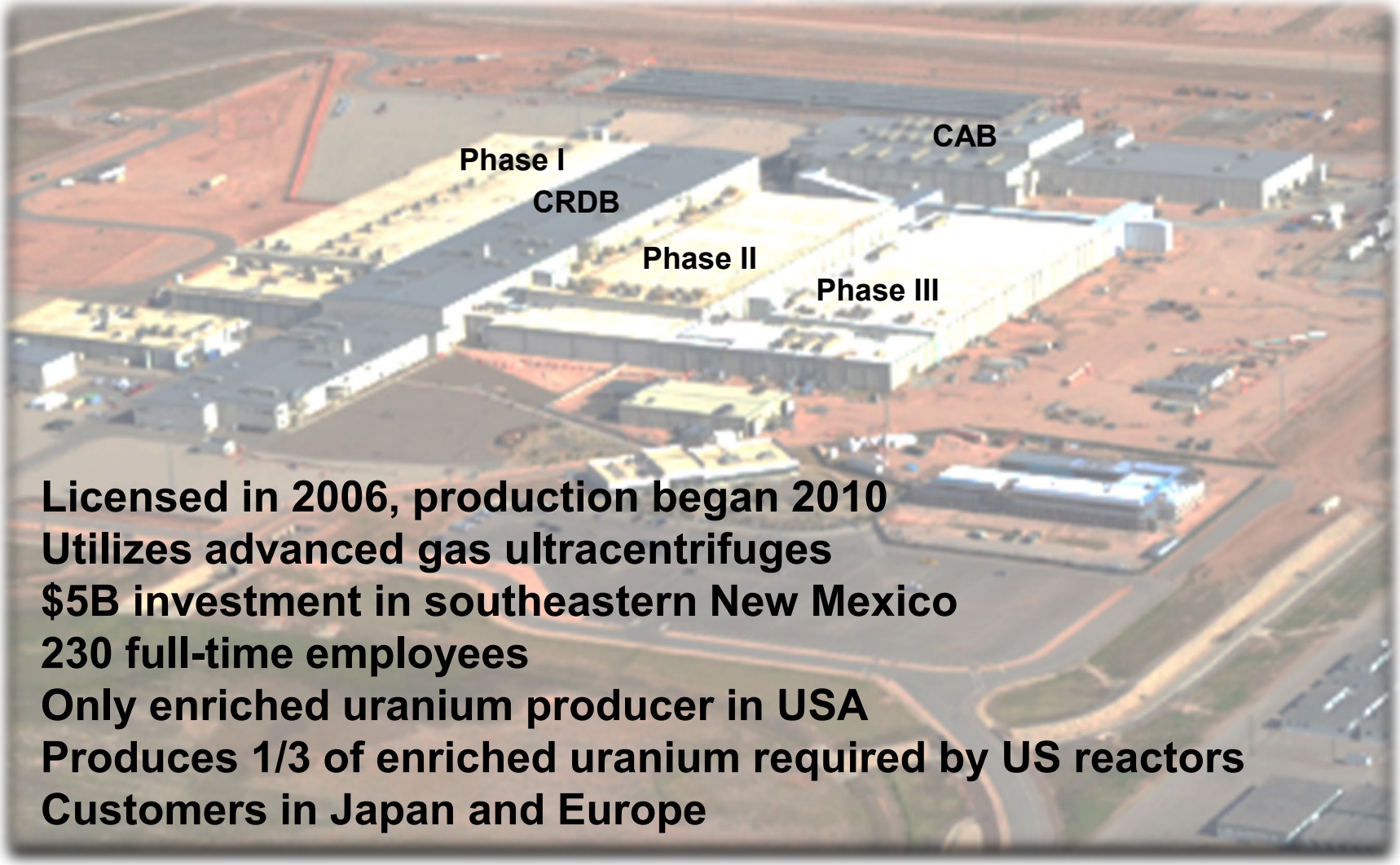
urenco
The Energy to Succeed

50 YEARS

Kirk Schnoebelen, Urenco

URENCO USA
Lea County, New Mexico



Licensed in 2006, production began 2010
Utilizes advanced gas ultracentrifuges
$5B investment in southeastern New Mexico
230 full-time employees
Only enriched uranium producer in USA
Produces 1/3 of enriched uranium required by US reactors
Customers in Japan and Europe

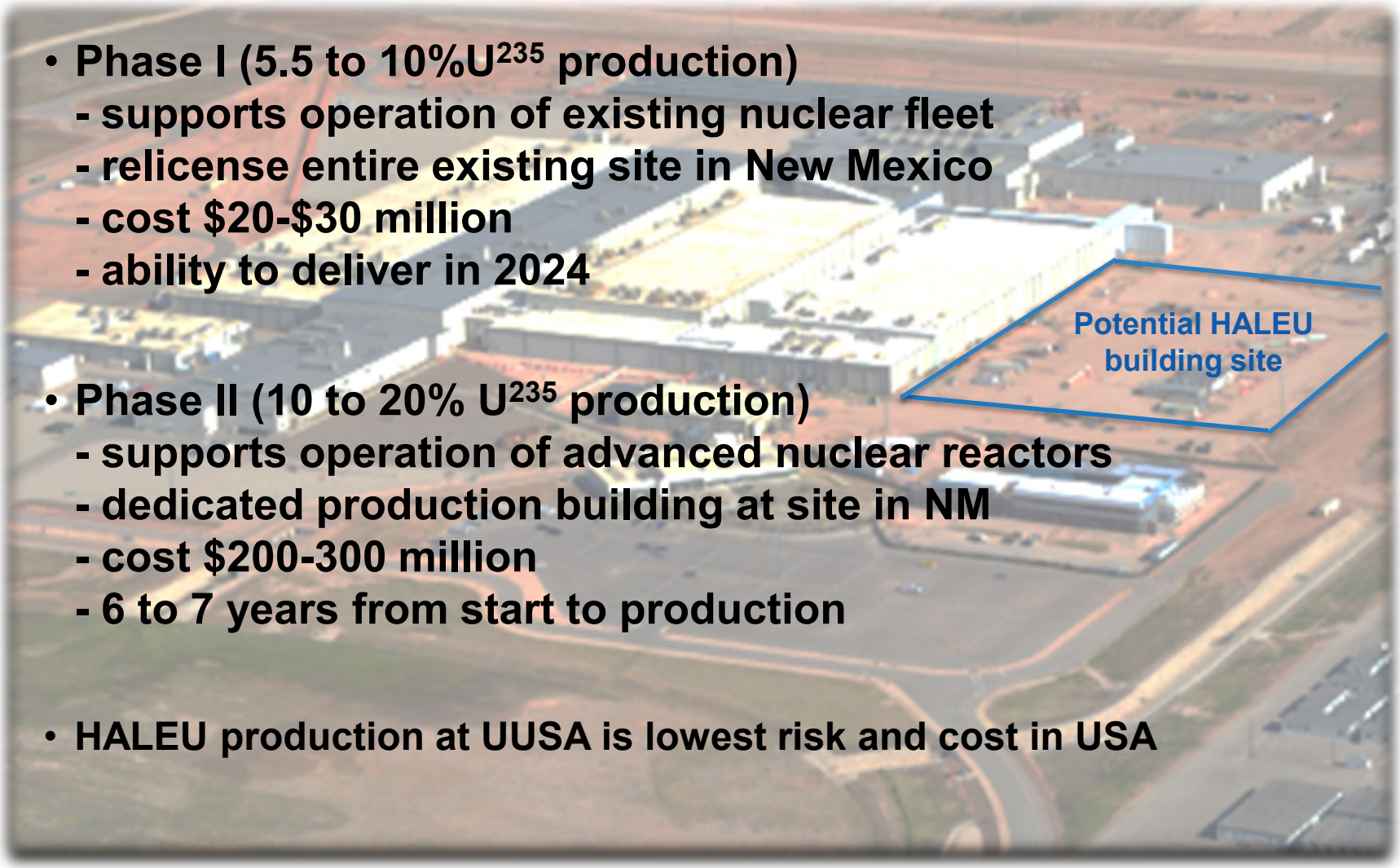
>5% U_{235} NEXT GENERATION FUELS

urenco The Energy to Succeed

- Phase I (5.5 to 10%U^{235} production)
  - supports operation of existing nuclear fleet
  - relicense entire existing site in New Mexico
  - cost $20-$30 million
  - ability to deliver in 2024

- Phase II (10 to 20% U^{235} production)
  - supports operation of advanced nuclear reactors
  - dedicated production building at site in NM
  - cost $200-300 million
  - 6 to 7 years from start to production

- HALEU production at UUSA is lowest risk and cost in USA



UPCOMING PARTNERSHIP WEBINARS

- February 13-16, 2021 – NARUC Winter Policy Summit in Washington, D.C. and online
  - February 13, 3:30-5:00 p.m. (ET) – Subcommittee / Staff Subcommittee on Nuclear Issues – Waste Disposal
  - *Tentative* - February 16, 2:00-5:00 p.m. (ET) – Nuclear Regulatory Commission – NARUC Information Session, open to NARUC members only

naruc.org/cpi-1/energy-infrastructure-modernization/nuclear-energy

THANK YOU

Chair Tim Echols, Georgia

Chair Anthony O'Donnell, Maryland

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