INL HALEU Program

Advancing Tomorrow's Nuclear Supply Chain

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Micro-Reactor Workshop

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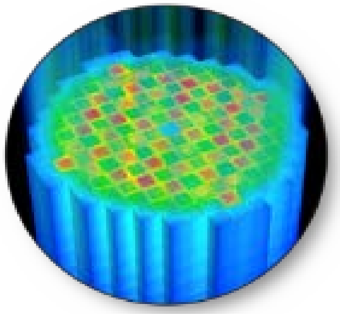
How is INL Supporting the Development of Advanced Reactors?

- **Conducting R&D to address reactors technical feasibility**
  - Materials and fuels
  - Experimental capabilities
  - Validated predictive modeling and simulation

- **Supporting the development of HALEU fuel cycle infrastructure**
  - HALEU Interim supply
  - HALEU fuel development
  - UF_6 and HALEU fuel transportation





Bringing Advanced Reactors to Market Requires
LEU → HALEU

- **Why are HALEU fuels needed ?**
  - Improve fuel utilization and support better plant economics
- **When are they needed?**
  - Mid-2020s - start-up fuel for prototype and test reactors
  - Early 2030s - HALEU fuel cycle infrastructure

Current fuel cycle infrastructure needs to be modified to support HALEU reactors

How Much HALEU is Needed?
NEI Estimated Annual Commercial Demands

- **Commercial reactor concepts require HALEU for startup core**
- **A sustainable supply of HALEU is needed to support deployment**

Expected commercial demands for HALEU are very significant

NEI Estimated Annual Commercial Requirements for HALEU to 2030 (MTU/yr)

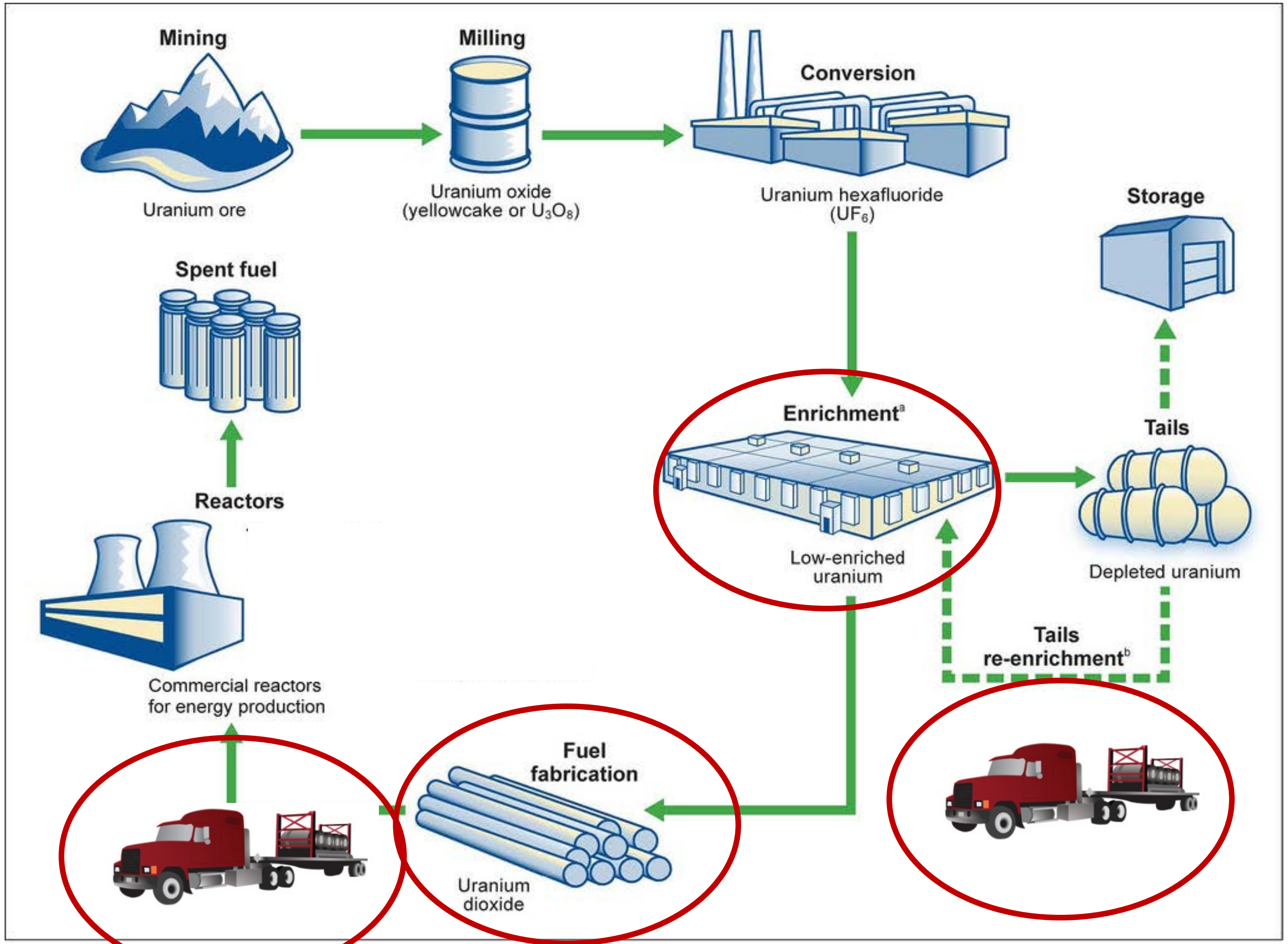
Company	A	B	C	D	E	F	G	H	Total	Cumulative
Enrichment Range	13-19.75%	19-19.75%	10-19.75%	15.5%	19.75% and 12.6%	19.75%	17.5%	14.4%		
Year										
2018	0.001			0.025					0.026	0.026
2019	0.006	1.5							1.506	1.532
2020	0.7	1.5	0.01						2.21	3.7
2021	0.7	2.5				1.0			4.2	7.9
2022	0.7	3.0							3.7	11.6
2023	0.7	3.5	1.1		13.5				18.8	30.4
2024	0.7	5.0	1.1			3.0		0.5	10.3	40.7
2025	0.7	6.0	1.8	0.4		3.0		0.5	12.4	53.1
2026	23.3	7.0	1.8	0.4		3.0	21.4	0.5	57.4	110.5
2027	35.0	9.0	1.8	0.9		5.0	21.4	0.5	73.6	184.1
2028	46.6	11.0	1.8	1.8		25.0	21.4	0.5	108.1	292.2
2029	58.3	13.0	1.8	1.8		15.0	21.4	0.5	111.8	404.0
2030	70.0	13.5	1.8	1.8	61.0	15.0	21.4	1.0	185.5	589.5

https://www.nei.org/resources/letters-filings-comments/nei-letter-perry-need-haleu

Infrastructure Updates Needed to Support HALEU Reactors

- **Enrichment**
  - Domestic capability to enrichment HALEU (U-235 between 5 and 20 wt.%)
- **Fuel Fabrication/De-conversion**
  - Multiple HALEU fuel form options (metallic, oxide, liquid, etc.)
- **Transportation**
  - HALEU as UF_6 to fuel fabrication facility
  - HALEU as fuel to reactor facility

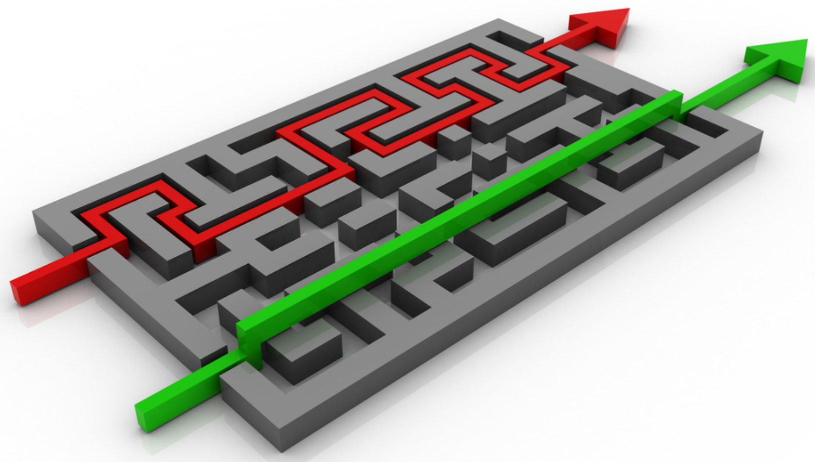
Infrastructure updates address safety, safeguards and security



Sources: GAO analysis of International Atomic Energy Agency, Nuclear Regulatory Commission, Congressional Research Service, Department of Energy, and TVA documents. | GAO-15-123

DOE Research and Bridge Role

- **Infrastructure updates are needed to address safety, safeguards, and security.**
- **Companies making investments need a robust HALEU market.**
- **Advanced reactor developers require HALEU to test their concepts which in turn creates the HALEU market.**



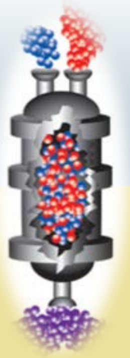
This research-and-bridge role is a familiar one for DOE.

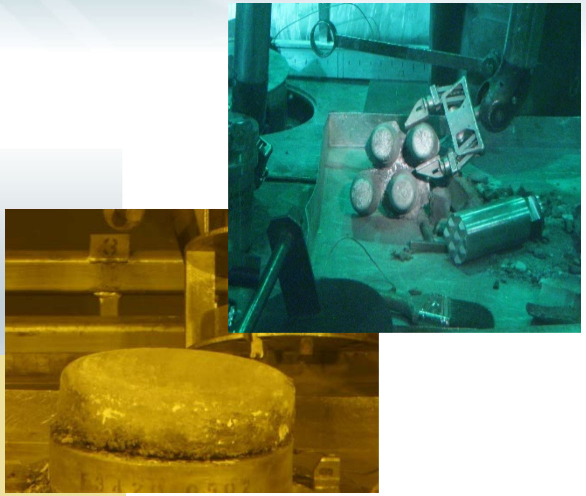
INL and its laboratory partners are using their expertise to support DOE in providing a HALEU interim supply

HALEU Interim and Long-term Sources

HALEU

- ***Interim*** – ***Downblending*** **current and/or recovered HEU in the federal complex**
  - Multiple physical forms (metallic, oxide, etc.)
  - An array of U-235 enrichments (10-19.75 wt.%)
  - Fast and thermal-spectrum reactor concepts
  - Limited stocks available today

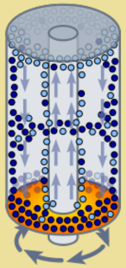




time

HALEU

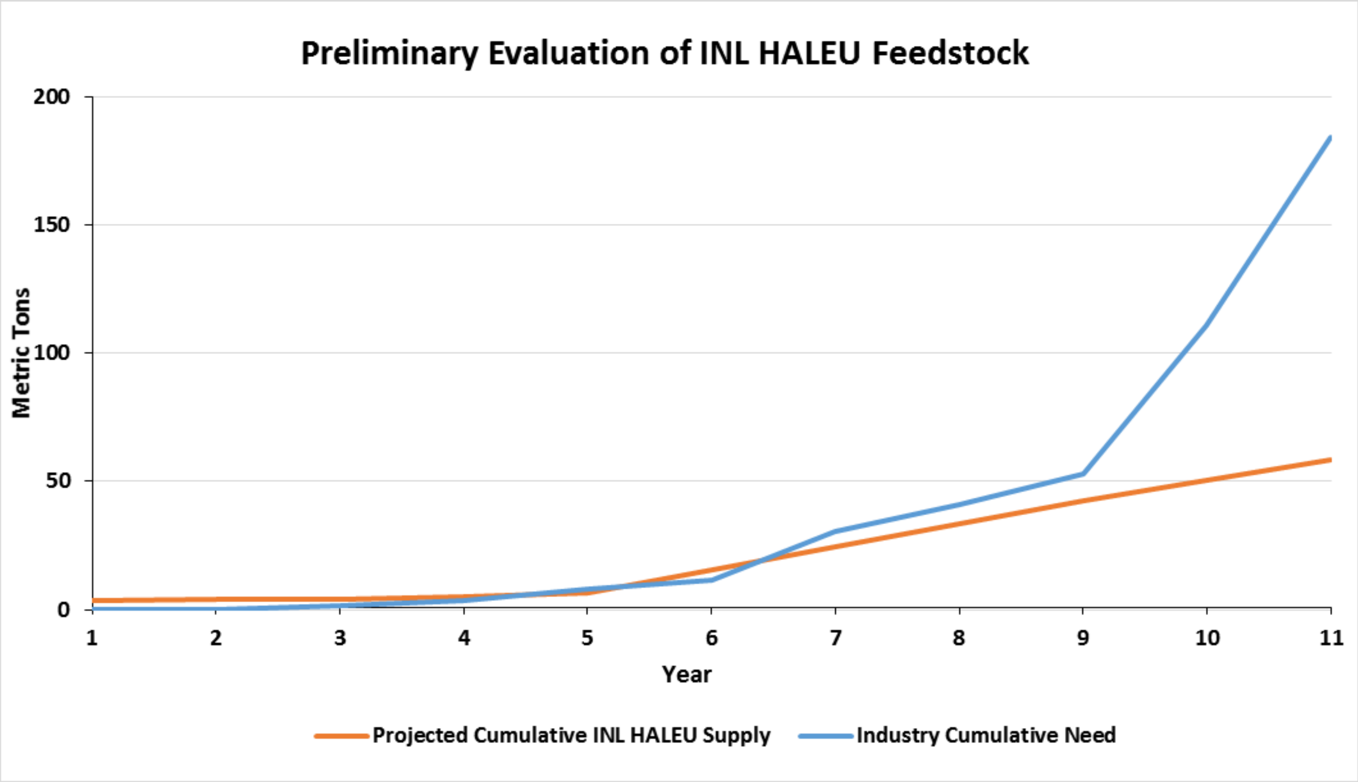
- ***Long-term*** **-** ***Enrichment***
  - UF_6
  - By 2021 demonstration quantities
  - Commercial domestic source of HALEU



time

INL HALEU R&D Program Objectives

- **Evaluate the feasibility of providing an interim supply of HALEU to support fuel-fabrication needs for R&D, and potential demonstration of advanced reactor concepts**
- **Support the development of HALEU R&D infrastructure to include transportation, fuel fabrication, and advanced reactor testing**



HALEU R&D Program Strategy

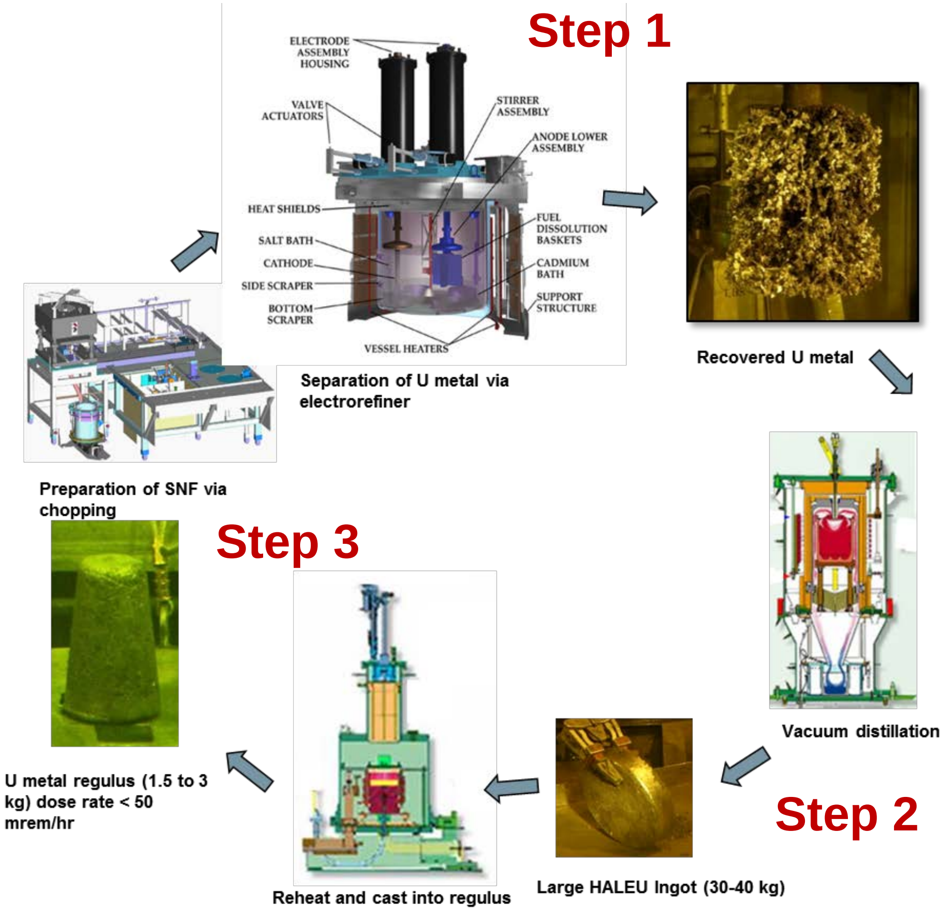
INL is looking into the feasibility of recovering and down-blending HEU from feedstocks with large ratios of HALEU/HEU that otherwise will be disposed at a cost to tax payers

- **Possible feedstocks include fuels from diverse irradiation origins**
  - EBR-II
  - ATR/Naval
  - Orphan materials
- **Down-blending feedstocks varied and may include:**
  - 5 wt.% enriched LEU
  - Depleted Uranium
  - Natural Uranium
- **Recovery processes *(all available/under development at INL)* are determined by characteristics of the feedstock and may include:**
  - Electrometallurgical Process
  - Hybrid Process (ZIRCEX)
  - Others
- **Final HALEU form is determined by fuel specifications and fabrication needs**

Electrometallurgical Treatment Process

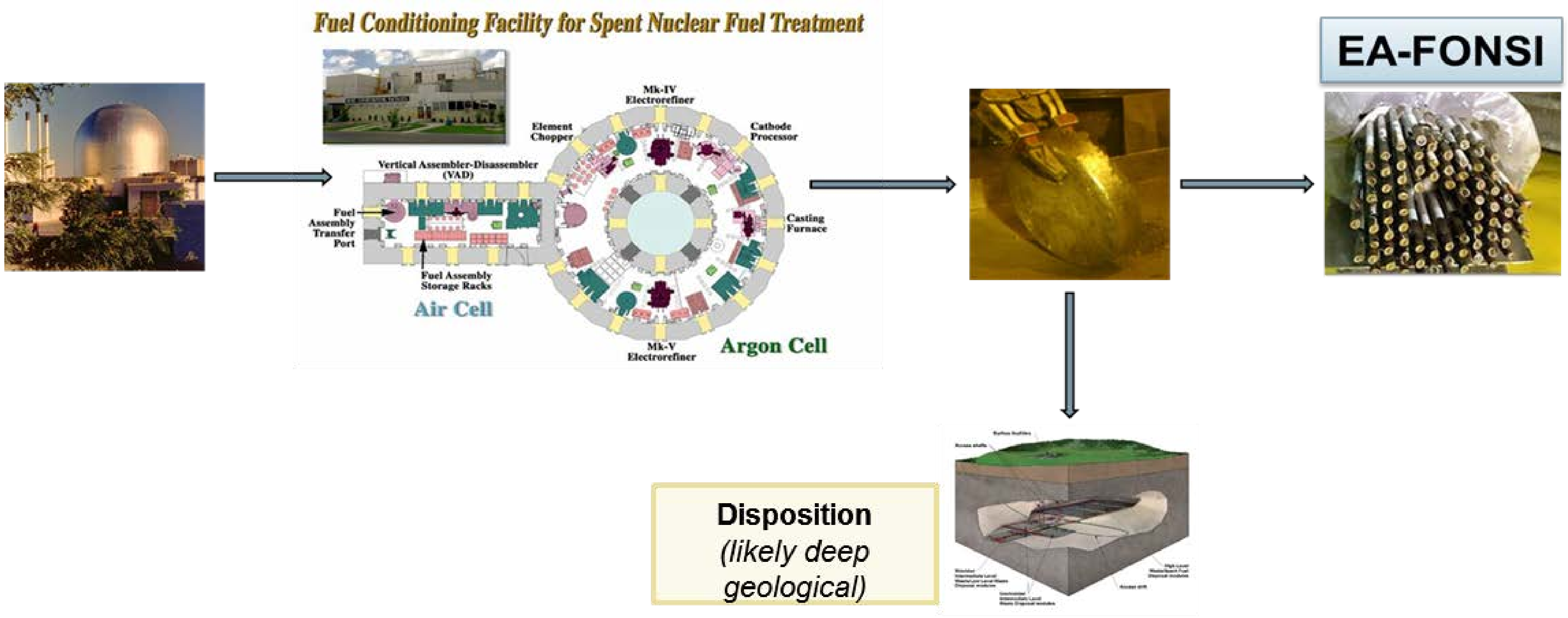
Batch process that recovers uranium metal from used HEU nuclear fuel and down-blends to HALEU

- **Step 1 – Irradiated fuel is prepared and placed into a molten salt electrorefiner which facilitates recovery of uranium metal from fission products and transuranics.**
- **Step 2 – Recovered uranium undergoes vacuum distillation to remove electrorefiner salt and is downblended to an enrichment less than 20 percent U-235.**
- **Step 3 – The recovered uranium metal is configured to support fuel fabrication by reheating and casting into low-dose, reduced size HALEU regulus.**



HALEU Produced from EBR-II Inventory - Status

- **September 2018 - 1.4 MT of irradiated HEU fuel treated for disposition**
  - 3.86 MT of HALEU
- **January 2019 - Environmental Assessment completed for fuel fabrication**
  - Finding of No Significant Impact (FONSI).



HALEU Produced from EBR-II Inventory - Status (Cont.)

- **Product refining – Evaluating methods for fuel fabrication using gloveboxes**
  - Identify optimal physical size of metallic ingot
  - Identify additional polishing steps

U metal dendrite recovered during fuel treatment

HALEU metallic ingots

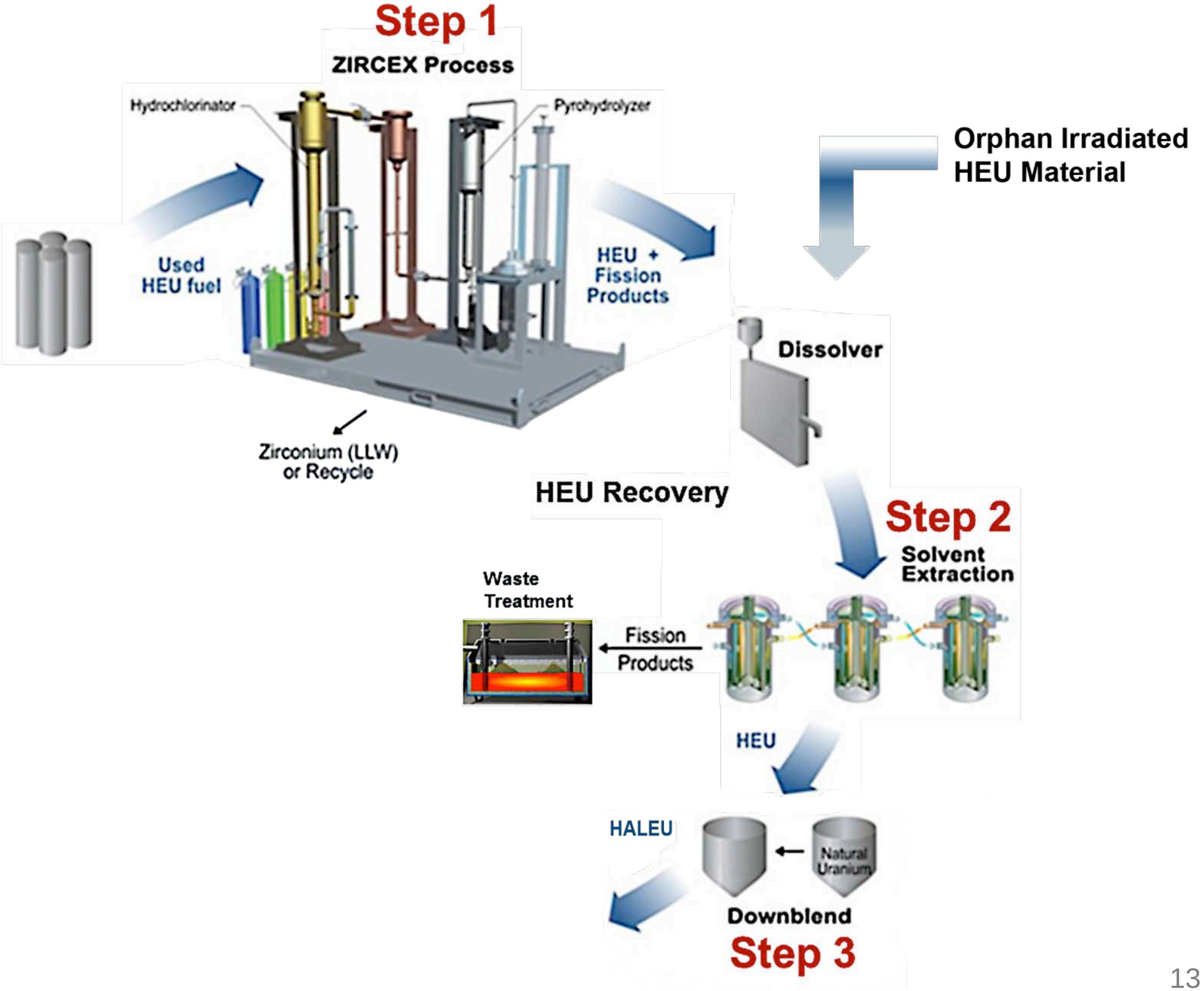
Polishing Step (if needed)

HALEU fuel

Hybrid Zirconium Removal Prior to Extraction (ZIRCEX) Process

A three step process that recovers HEU from nuclear fuel and down-blends it to HALEU

- **Step 1 – ZIRCEX is a dry head-end process to remove cladding (zirconium or aluminum) from nuclear fuel**
- **Step 2 – Uranium is purified from fission products by a very compact, modular solvent extraction system. The fission products are immobilized in glass using a small in-can melt.**
- **Step 3 – The uranium is down-blended to <20 wt.% U-235 prior to solidification and fuel fabrication**



Why ZIRCEX?

Past recovery of HEU from naval fuel (1957-1988) utilized liquid headend processes that dissolved the entire fuel element (including zirconium cladding material)

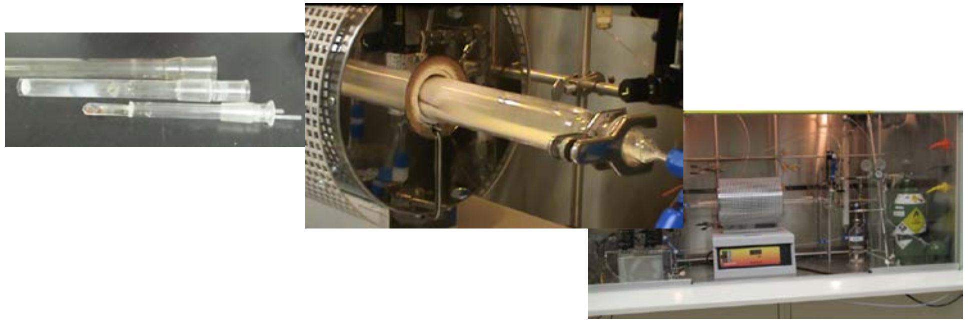
	Previous Naval Fuel Processing	With ZIRCEX Headend
Throughput (headend)	0.7 MTU/yr in 3 parallel trains	3-4 MTU/yr in 2 parallel trains
RCRA reagents used	HF, Cd	none
U concentration in feed to extraction	1.09 g/L	285 g/L
Zirconium (majority of fuel element mass)	Repository (HLW)	WIPP (TRU), or LLW
Solidified HLW	Calcine bins, repository	WIPP (TRU), or repository (HLW)
Volume of Solidified HLW per MTU	350 m^3 calcine/210 m^3 glass-ceramic	0.48 m^3 glass/0.2 m^3 glass-ceramic

Hybrid ZIRCEX Program Development

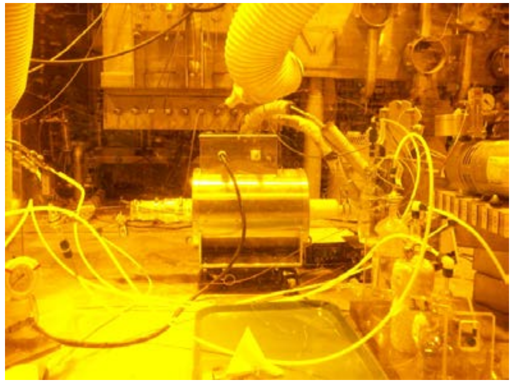
Laboratory Scale

ZIRCEX Head-end → Uranium Recovery → Uranium Solidification

- ✓ **Completed testing with unirradiated Zircaloy**
  - Developed equipment and procedures for hot cell use
  - Determined operating parameters for irradiated fuel samples
  - Initial investigations on methods for ZrO_2 coating removal



- ✓ **Completed laboratory tests with 14 irradiated fuel samples indicating:**
  - Reaction rates for irradiated and unirradiated fuel were comparable
  - ZrO_2 layer on irradiated fuels did not inhibit Zr chlorination reaction



Hybrid ZIRCEX Program Development (Cont.)

Pilot Scale

ZIRCEX Head-end → Uranium Recovery → Uranium Solidification

ZIRCEX Pilot Plant - Testing Ongoing

- Show ability to control process while maximizing reaction rates
- Demonstrate method to $ZrCl_4 \rightarrow ZrO_2$
- Complete corrosion studies to support the choice of materials of construction
- Determine best equipment designs for a full-scale process (filters, gas fluidizing plates, heating and cooling methods, etc.)

National Laboratory Partnership

Solvent Extraction (**ANL**)
- AMUSE flowsheet development
- Contactor unit set up

Waste Treatment (**PNNL**)
- In-can vitrification unit development
- Glass formulation
- Vitrification unit set up
- Product conversion

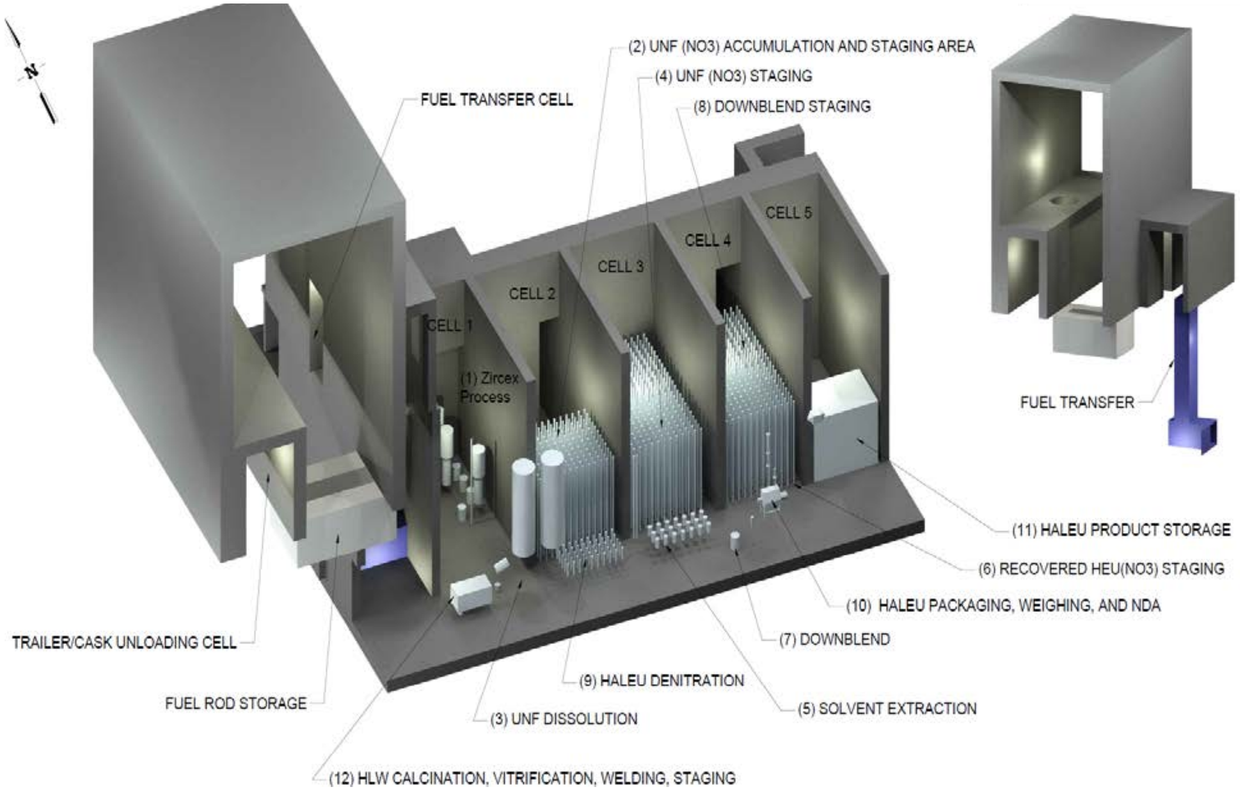
Downblend (**ORNL**)
- Zirconium chemistry
- Downblend to targeted U-235 enrichment
- Product solidification

Hybrid ZIRCEX Program Development (Cont.)

Engineering Scale

ZIRCEX Head-end → Uranium Recovery → Uranium Solidification

- **Began engineering studies to better understand costs and schedule**
  - Integrated process configuration
  - In-can melt design
  - Contactors flowsheet design
  - Downblending units design
  - S&S evaluation and strategy



HALEU Needed to Support Testing of Advanced Reactors

2022 – 2025

Demonstrate hybrid HEU recovery process from SNF	• Design, fabricate, and install full-pilot scale ZIRCEX pilot plant • Initiate recovery of HEU from irradiated ATR/Naval fuels utilizing hybrid (ZIRCEX/solvent extraction) process • Initiate HALEU fuel operations to support advanced reactor start-up cores
HALEU transportation	• Support development of UF_6 transportation packages to fuel fabrication facility • Support development of HALEU fuel transportation to reactor facility
HALEU Interim	• Electrochemical treatment of used EBR-II fuel up to 1 MT/yr • Hybrid process (ZIRCEX/Solvent Extraction) up to 5 MT/yr

Summary

- **Advanced Nuclear Technologies supports**
  - Clean, reliable energy
  - Access to power beyond the grid
  - Applications beyond electricity generation
- **INL is supporting the development of Advanced Reactors by**
  - Conducting R&D to address reactors technical feasibility
  - Supporting the development of HALEU fuel cycle infrastructure
    - Addressing HALEU interim supply needs by
      - Evaluating the feasibility of recovering and down-blending HEU from EBR II and ATR/Naval fuels

Questions ?

INL HALEU Program

Between
5% and 20%

Idaho National Laboratory