



High Assay Low Enriched Uranium - A material in demand and the supply efforts underway

March 2023

Changing the World's Energy Future

Michael N Patterson



INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

DISCLAIMER

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

High Assay Low Enriched Uranium - A material in demand and the supply efforts underway

Michael N Patterson

March 2023

**Idaho National Laboratory
Idaho Falls, Idaho 83415**

<http://www.inl.gov>

**Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517**

February 2023

Waste Management
Symposium 2023

Michael N. Patterson

Program Manager, Used
Fuel Treatment

High Assay Low Enriched Uranium

A Material in Demand and the Supply Efforts Underway

INL/CON-23-71170

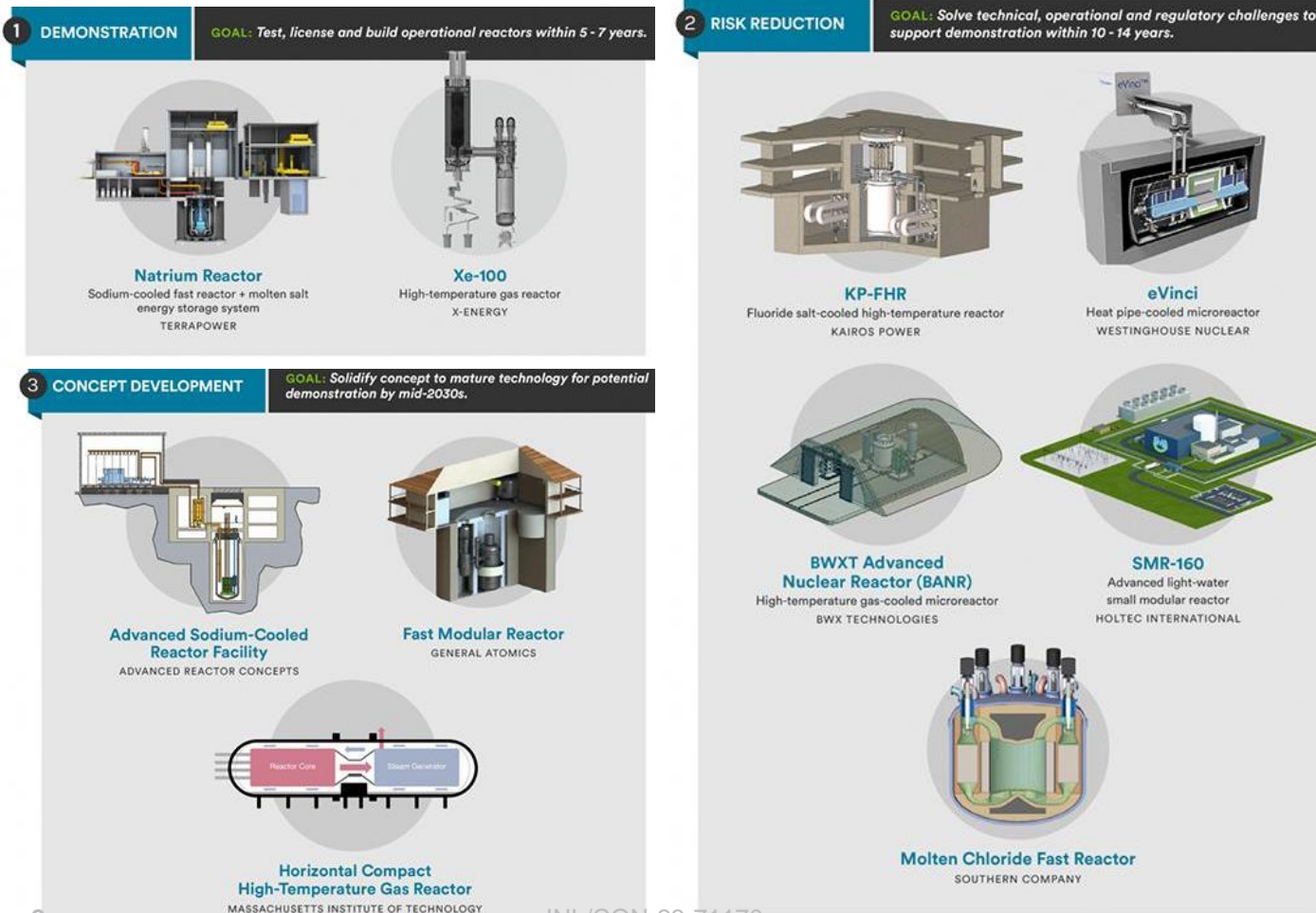
Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy



Idaho National Laboratory

Advanced Reactor Developers Require HALEU: Commercial Demonstrations & Research Needs

ARDP



DOE Advanced Reactor Demonstration Program (ARDP) & privately funded ventures require near term HALEU supplies to support advanced reactor concepts

Others

- *DOE MARVEL*
- *DOD Project Pele*
 - *BWXT*
- *Privately funded*
 - *OKLO*
 - *USNC*
 - *Others*

Domestic Sources of HALEU Supply

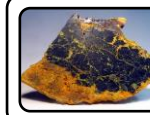
New Enrichment



Advanced centrifuge cascade, Piketon , OH
Centrus Energy Corp

U.S. DOE funding production demonstration at Piketon, OH

- 20 kg by end of 2023
- 900 kg / yr beginning in 2024



Natural Uranium (NU)

- 99.28% U-238
- **0.71% U-235**
- 0.005% U-234



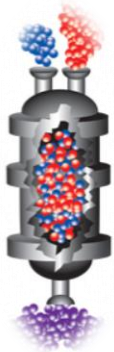
Low Enriched Uranium (LEU)

- 95.46% U-238
- **4.5% U-235**
- 0.04% U-234



High Assay Low Enriched Uranium (HALEU)

- 80.09% U-238
- **19.75% U-235**
- 0.16% U-234



Downblending

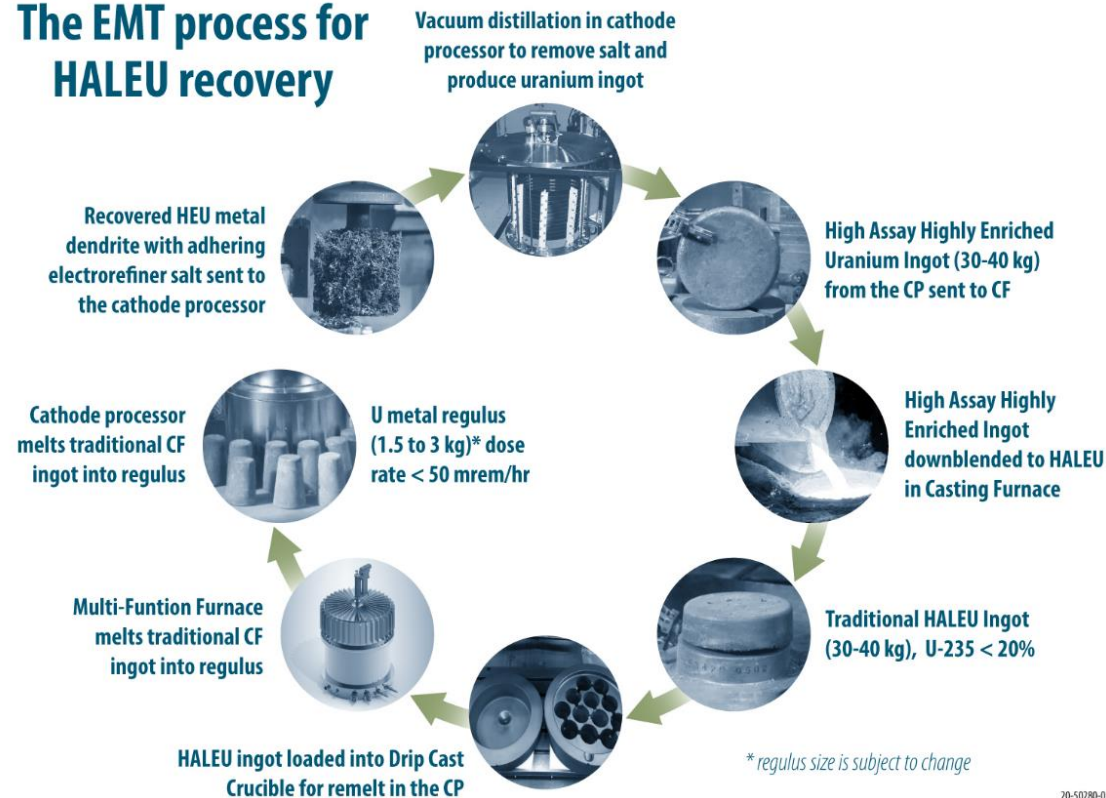
- Existing HEU stocks
- Recovered HEU stocks

- Very limited quantities may be available from U.S. government HEU reserves from past enrichment activities
- Downblending of materials recovered from HEU fueled research reactors offer potential solutions to meeting a portion of the near-term demand

Addressing HALEU needs

INL works with DOE and Industry to ensure the availability of HALEU

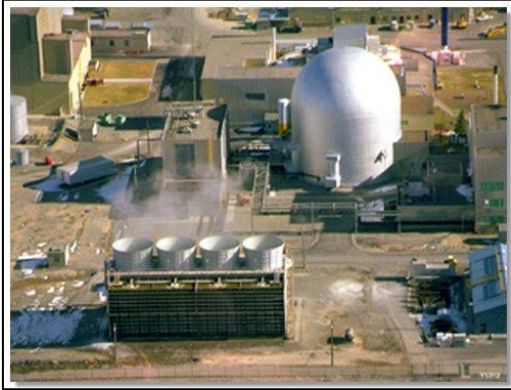
The EMT process for HALEU recovery



Recovery of HALEU from irradiated EBR-II HEU fuel

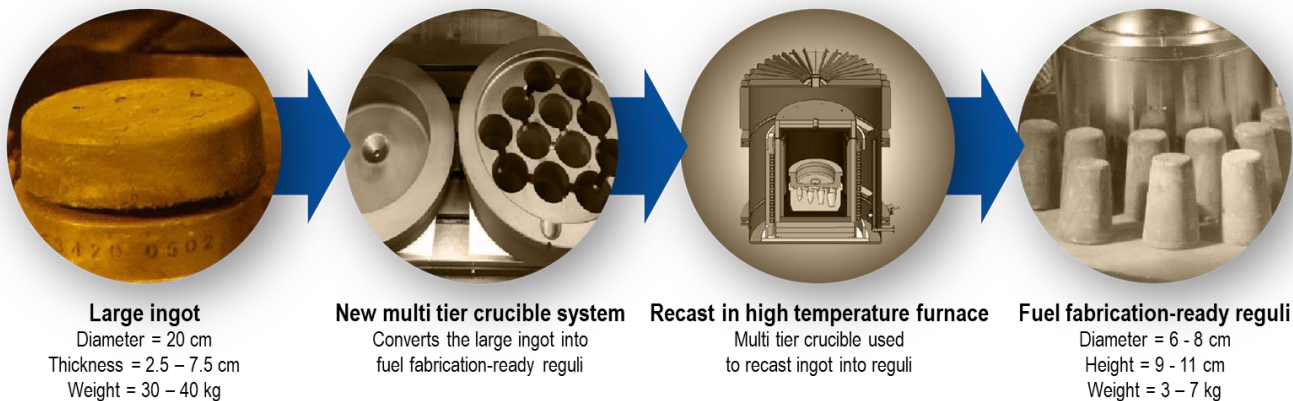
- Electrometallurgical treatment (EMT) process to condition the EBR-II HEU fuels.
- Process facilitates separation of uranium metal from fission products, transuranics and bond sodium
- To date, treatment of 1.78 MT of SNF resulting in 4.9MT of HALEU
- By 2028, approximately 10MT of HALEU as metal available

Process Enhancements to Expand Feedstock Opportunities



- Uranium recovered from treatment process originally intended for recycle in fast spectrum reactors as metal fuel, using remote fuel fabrication equipment
- Expanding re-use applications for advanced reactors, led to process treatment innovations

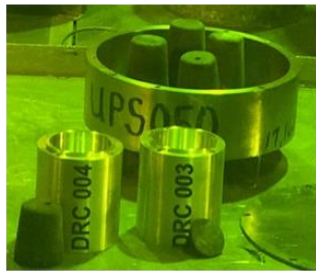
- Uranium casting revision resulted in reduced radiological dose and smaller physical size
- HALEU metal regulus suitable for glovebox fuel fabrication for some advanced reactors



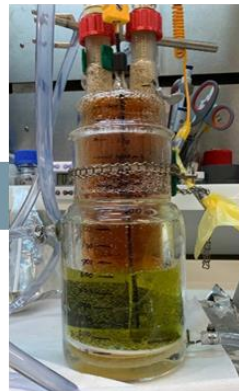
Expanding Options

Additional purification (“polishing”) is being demonstrated at a pilot-scale to further expand usability of HALEU

- Aqueous chemistry process converts HALEU metal to HALEU Oxide
- Removes additional contaminations (i.e., significantly reduces dose and transuranic content)
- Material can be suitable for additional advanced reactors (thermal spectrum applications)



*Low dose rate, small size
HALEU metal regulus*



U metal dissolution



U purification



This HALEU, once recovered and polished, is useable for thermal spectrum applications

- The “polished” oxide has been independently evaluated and found to meet some vendor’s facility acceptance requirements for TRISO fuel fabrication
- Additional contamination removal is an option when moving from our pilot-scale to engineering-scale

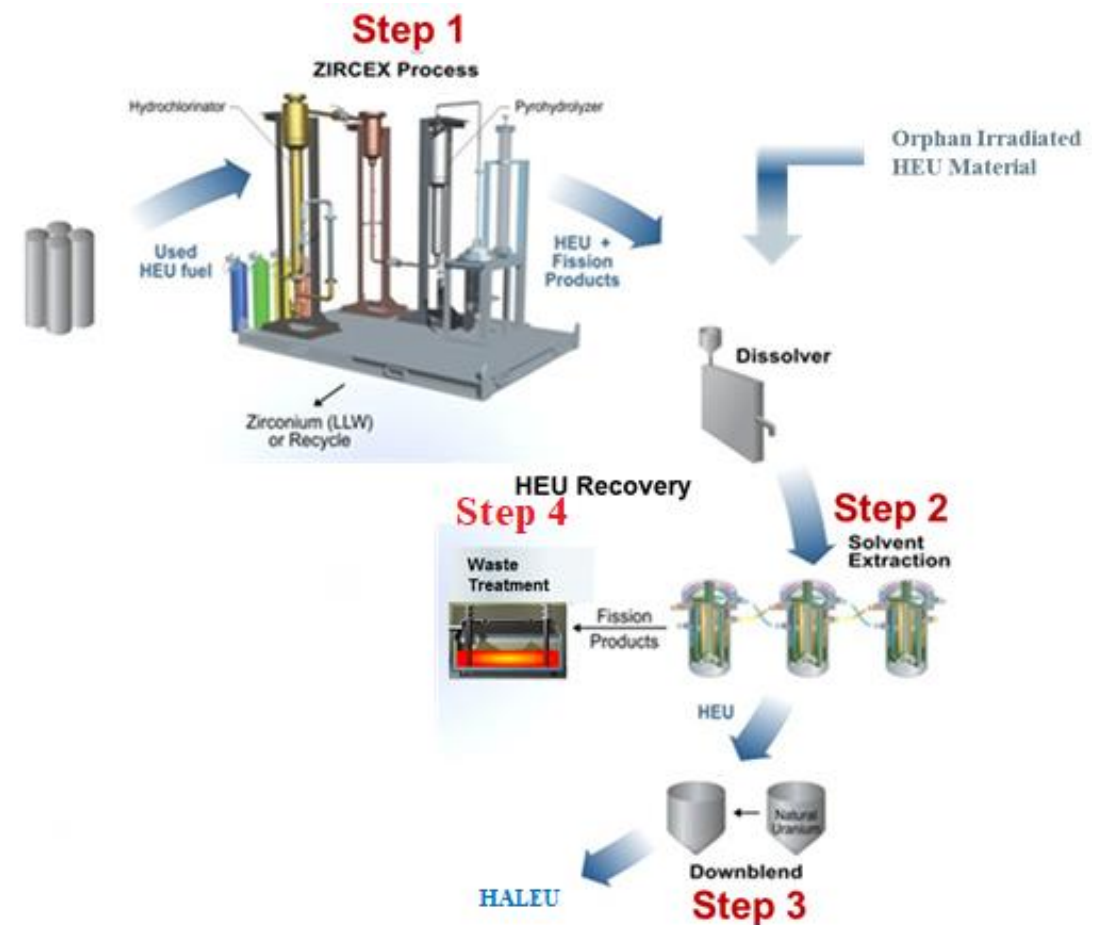
Average	
Analyte	Units
U-232	1.03E-03 ug/g U-235
U-234	1.76E+03 ug/gU
U-236	5.56E+03 ug/gU
Pu-239/240	7.02E+01 Bq/g U-235
Pu-238	1.67E+02 Bq/g U-235
Pu-241	4.60E+03 Bq/g U-235
Am-241	6.63E+01 Bq/g U-235
Cm-244	4.15E+01 Bq/g U-235
Np-237	9.29E+01 Bq/g U-235
Th-228	8.38E+02 Bq/g U-235
Th-230	8.53E+01 Bq/g U-235
Sr-90	8.00E-07 ug/g U-235
Tc-99	1.04E-02 ug/g U-235
Cs-137	1.15E-06 ug/g U-235
Cs-137	2.19E+00 MevBq/g U-235
Co-57	7.72E-08 ug/gU
Co-60	1.23E-08 ug/gU
Eu-154	1.31E-07 ug/gU
Total Fission Prod	7.20E-07 mCi/gU

Average	
Analyte	Concentration Units
Lithium	2.42E+00 ug/gU
Boron	6.73E+00 ug/gU
Sodium	1.43E+01 ug/gU
Magnesium	3.33E+00 ug/gU
Aluminum	2.42E+00 ug/gU
Silicon	2.42E+02 ug/gU
Phosphorus	2.42E+00 ug/gU
Calcium	1.29E+02 ug/gU
Vanadium	2.42E+00 ug/gU
Chromium	2.42E+00 ug/gU
Manganese	2.42E+00 ug/gU
Iron	2.42E+01 ug/gU
Cobalt	2.42E+00 ug/gU
Nickel	2.15E+00 ug/gU
Copper	2.42E+00 ug/gU
Zinc	5.74E+00 ug/gU
Zirconium	2.42E+00 ug/gU
Cadmium	2.42E+00 ug/gU
Tin	1.24E+02 ug/gU
Tungsten	2.42E+00 ug/gU
Lead	2.42E+00 ug/gU
Thorium	2.42E+00 ug/gU
Total	5.83E+02 ug/gU

Innovative Recycling Concepts Under Development at INL

The Hybrid ZIRCEX Process

- Dry head-end decladding process enables economic recovery of HEU or other SNM by minimizing secondary liquid waste
- HEU from fuel inventories such as Advanced Test Reactor (ATR) supports HALEU needs
- Four step process to recycle uranium from used nuclear fuel and treat the waste
 - Step 1, Gas-hydrochlorination (ZIRCEX) to remove fuel cladding
 - Step 2, Purification of uranium using solvent extraction
 - Step 3, Down blending of uranium to less than 20% U235
 - Step 4, Vitrification of fission products to immobilize the waste





Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

WWW.INL.GOV