INL/CON-24-77763-Revision-0

High Assay Low Enriched Uranium (HALEU) Production at the Fuel Conditioning Facility

May 2024

Changing the World's Energy Future

Guy L Fredrickson

Idaho National Laboratory

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Idaho Falls, Idaho 83415

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

May 16, 2024

Guy Fredrickson, Ph.D.

HALEU Production in FCF

(Electrochemical Separations)

Actinide Separations Conference

Petaluma, CA

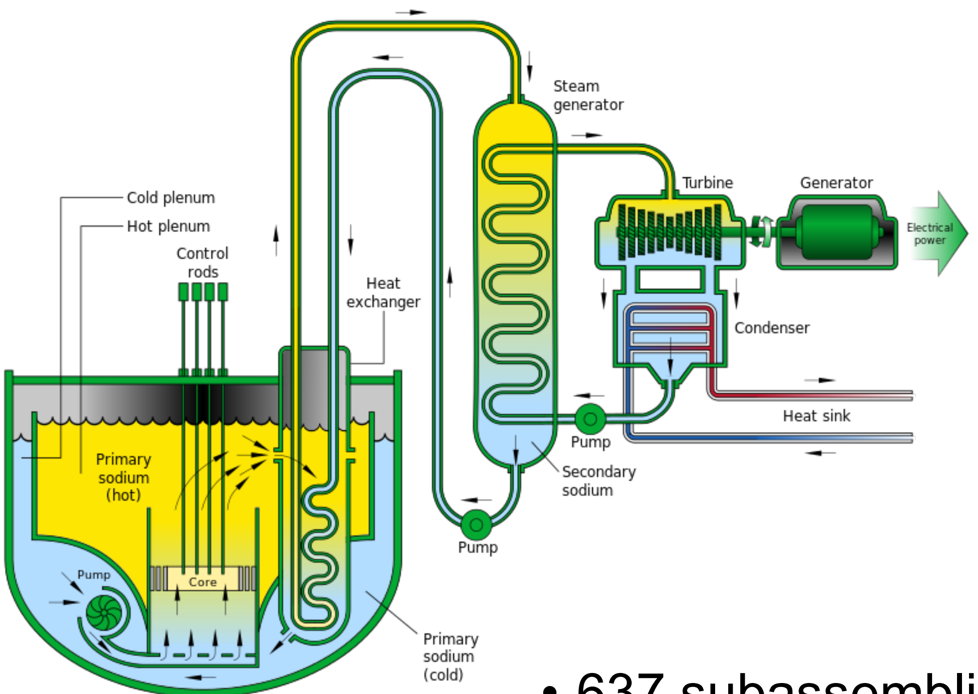
Export Control Review: INL/CON-24-77763

Outline

- Experimental Breeder Reactor II
- Fission Yield
- Uranium Electrorefining

Experimental Breeder Reactor II

Experimental Breeder Reactor II



- 637 subassemblies in the core
- 47 to 59 driver fuel subassemblies
- 3 kg enriched uranium per driver fuel subassembly
- 47 kg depleted uranium per blanket subassembly

Fuel Conditioning Facility (FCF)

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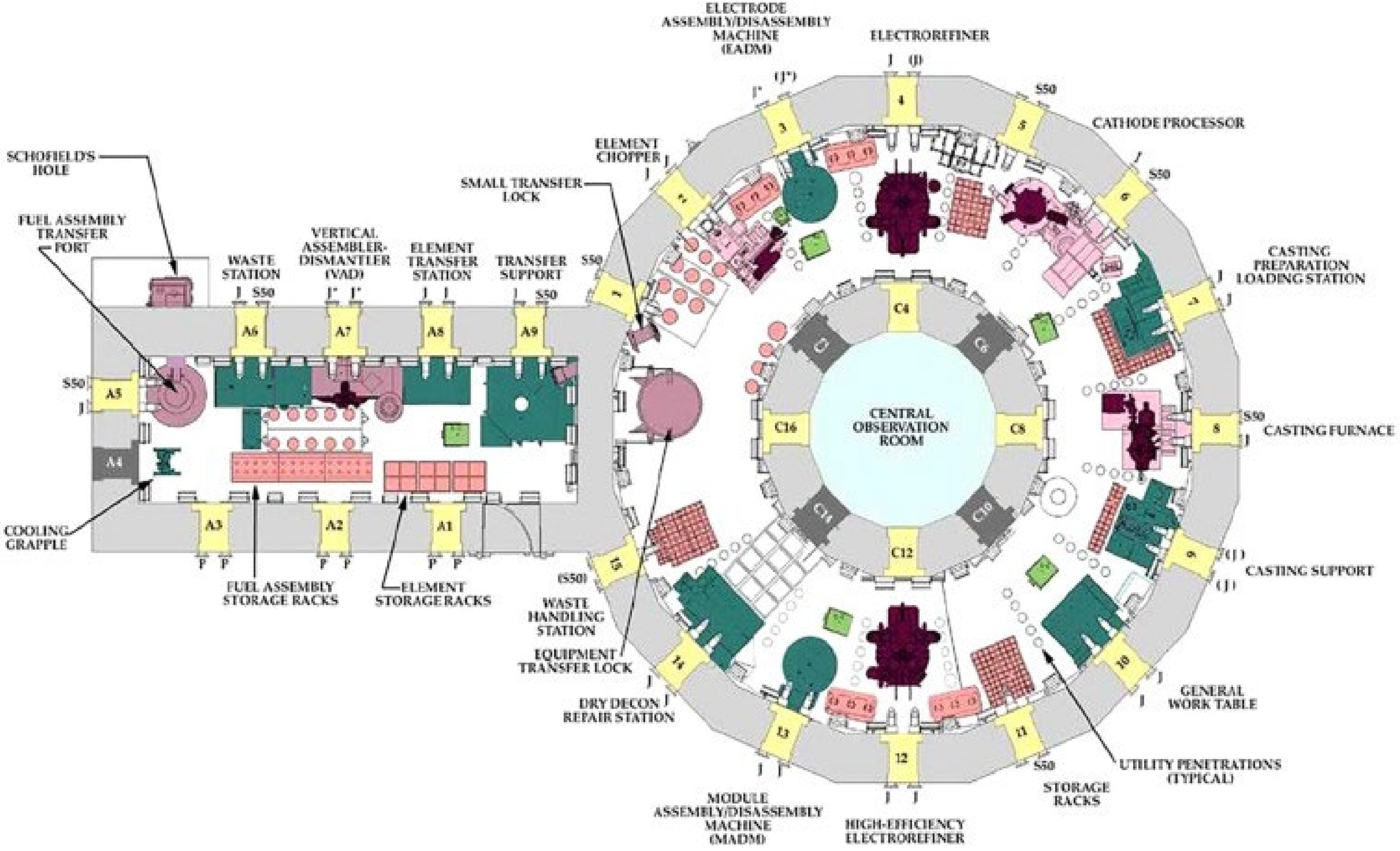
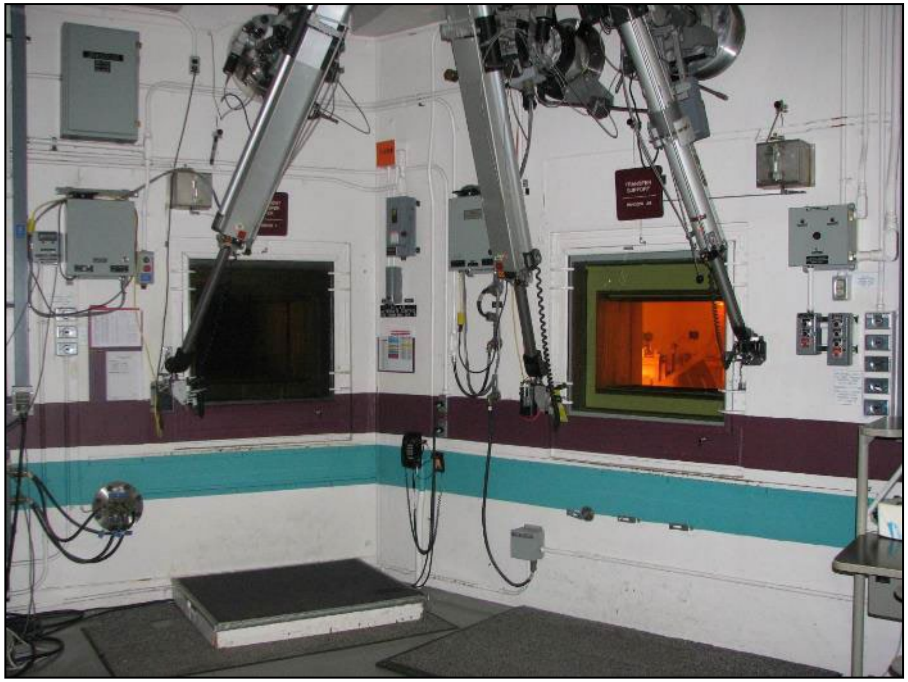


Fuel Conditioning Facility (FCF)



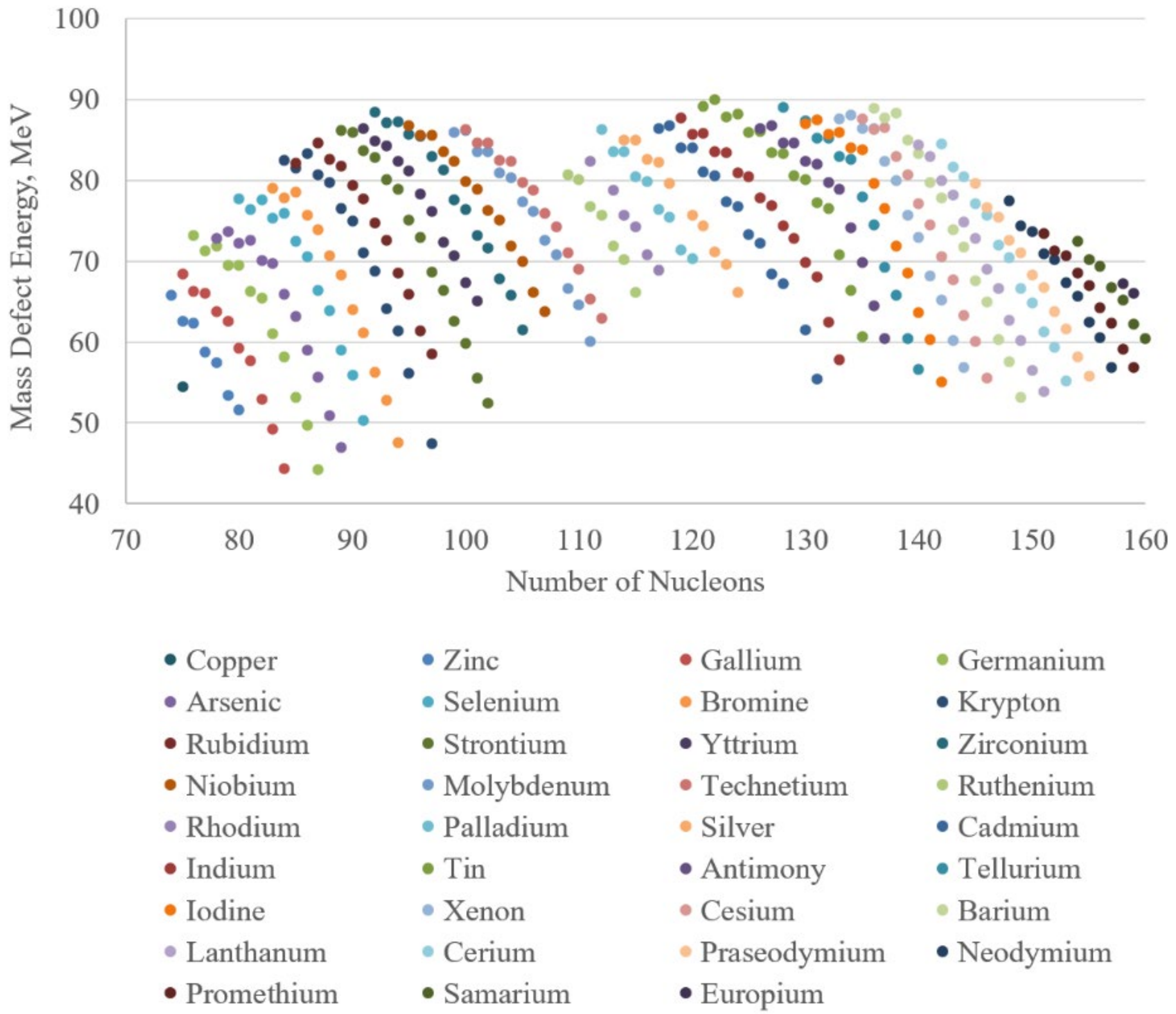
Fission Yield: Uranium Primary Daughters

Daughter A	Z	Daughter B	Z
Copper	29	Europium	63
Zinc	30	Samarium	62
Gallium	31	Promethium	61
Germanium	32	Neodymium	60
Arsenic	33	Praseodymium	59
Selenium	34	Cerium	58
Bromine	35	Lanthanum	57
Krypton	36	Barium	56
Rubidium	37	Cesium	55
Strontium	38	Xenon	54
Yttrium	39	Iodine	53
Zirconium	40	Tellurium	52
Niobium	41	Antimony	51
Molybdenum	42	Tin	50
Technetium	43	Indium	49
Ruthenium	44	Cadmium	48
Rhodium	45	Silver	47
Palladium	46	Palladium	46

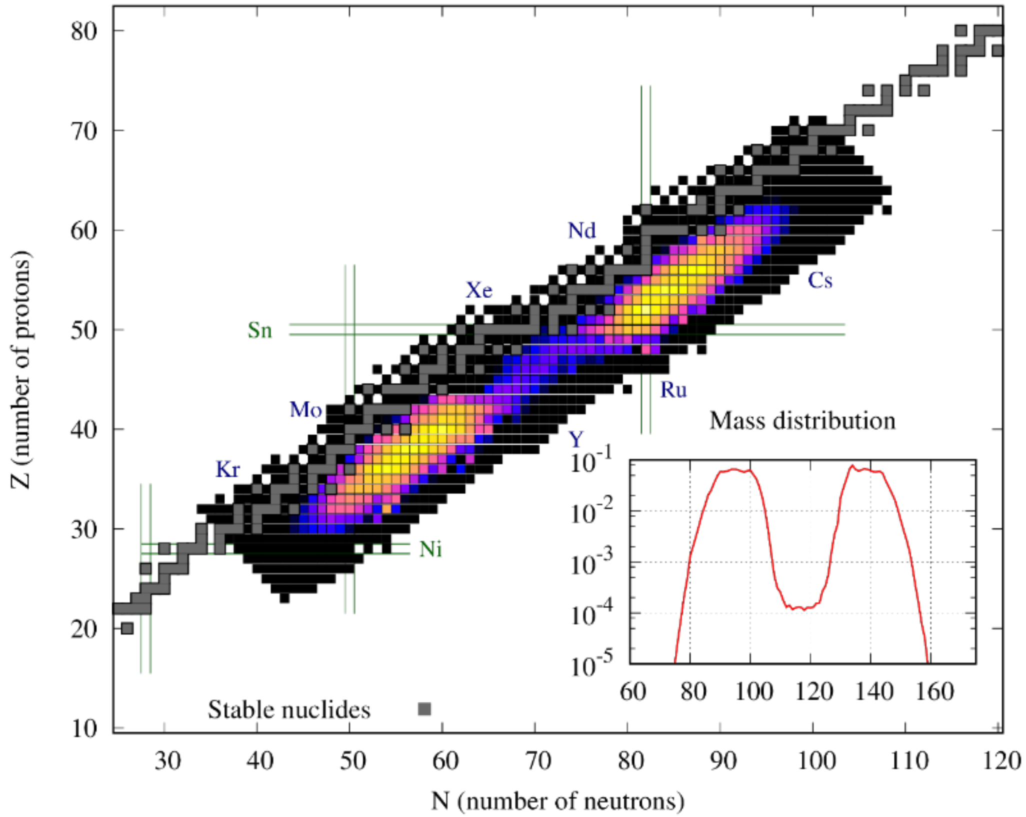
Primary Daughter Isotopes

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															
			Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
			Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Primary Daughter Isotopes

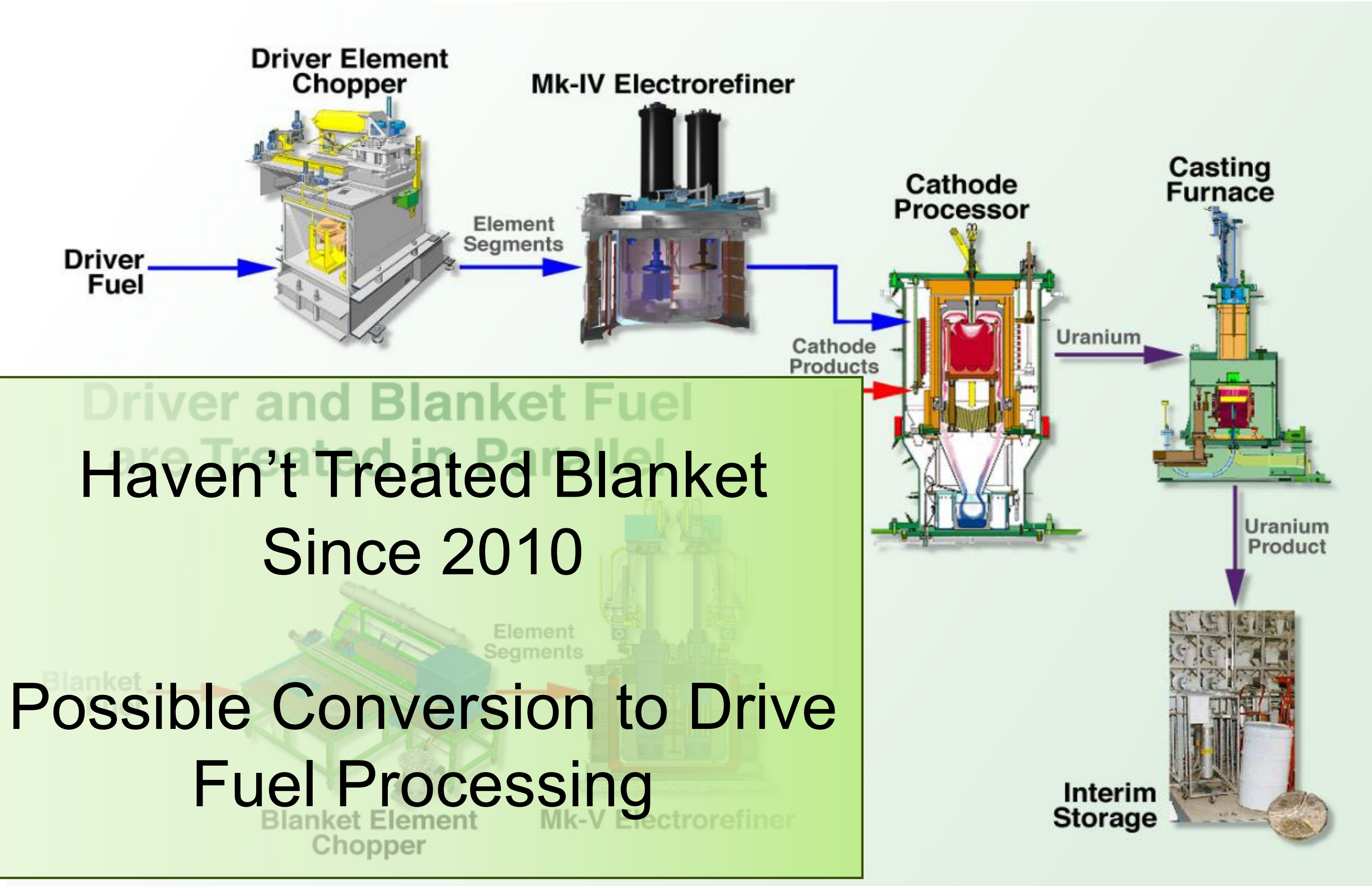


Fission Yield



1 kg d^{-1} fission is approximately 1000 MWt or 400 MWe.

Spent Fuel Treatment at FCF

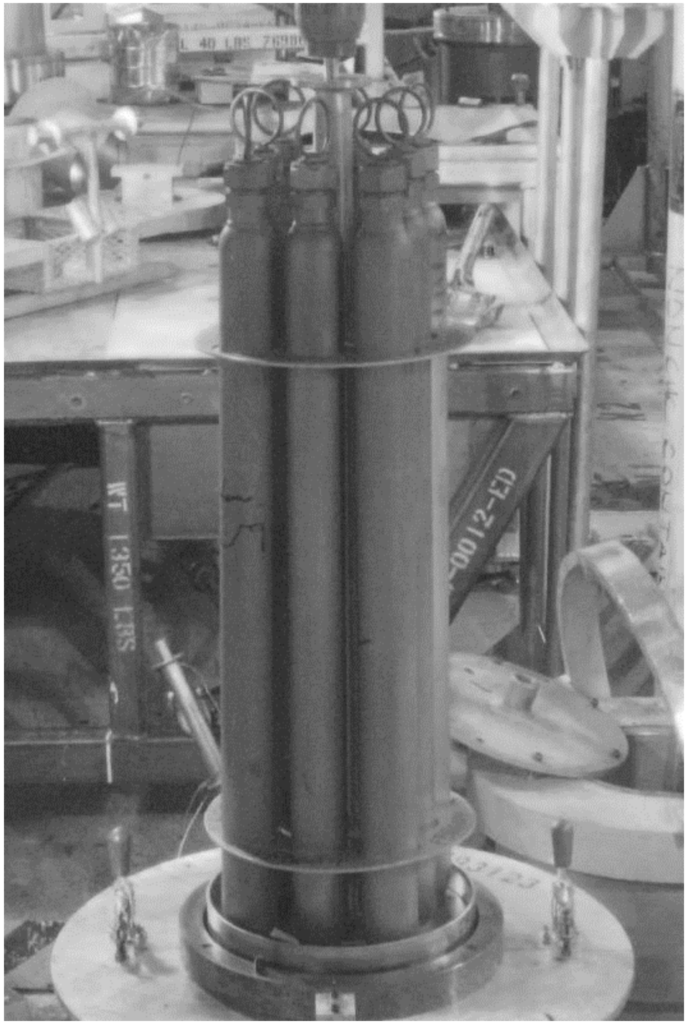


Haven't Treated Blanket Since 2010

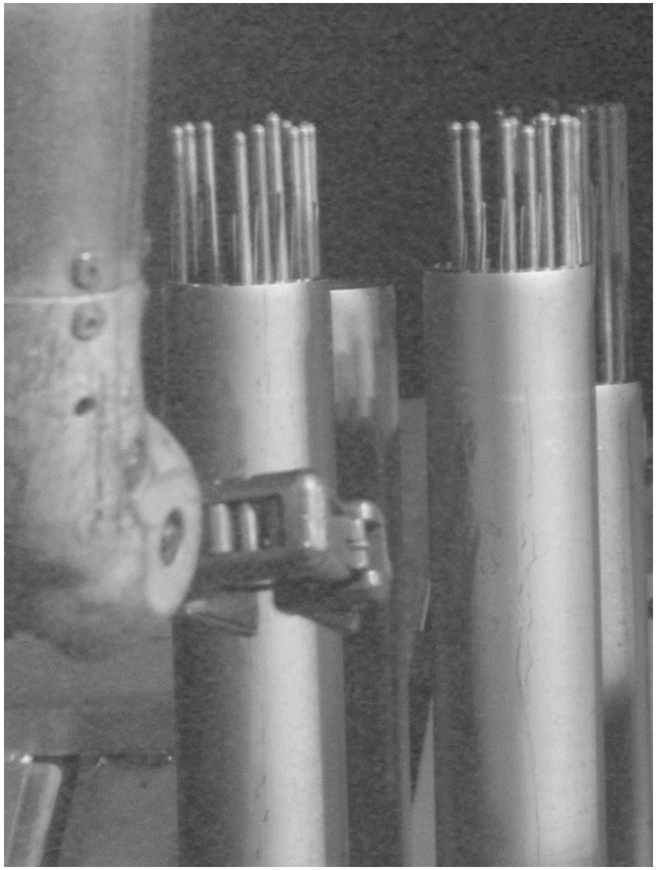
Possible Conversion to Drive Fuel Processing

Mk-IV Electrorefiner

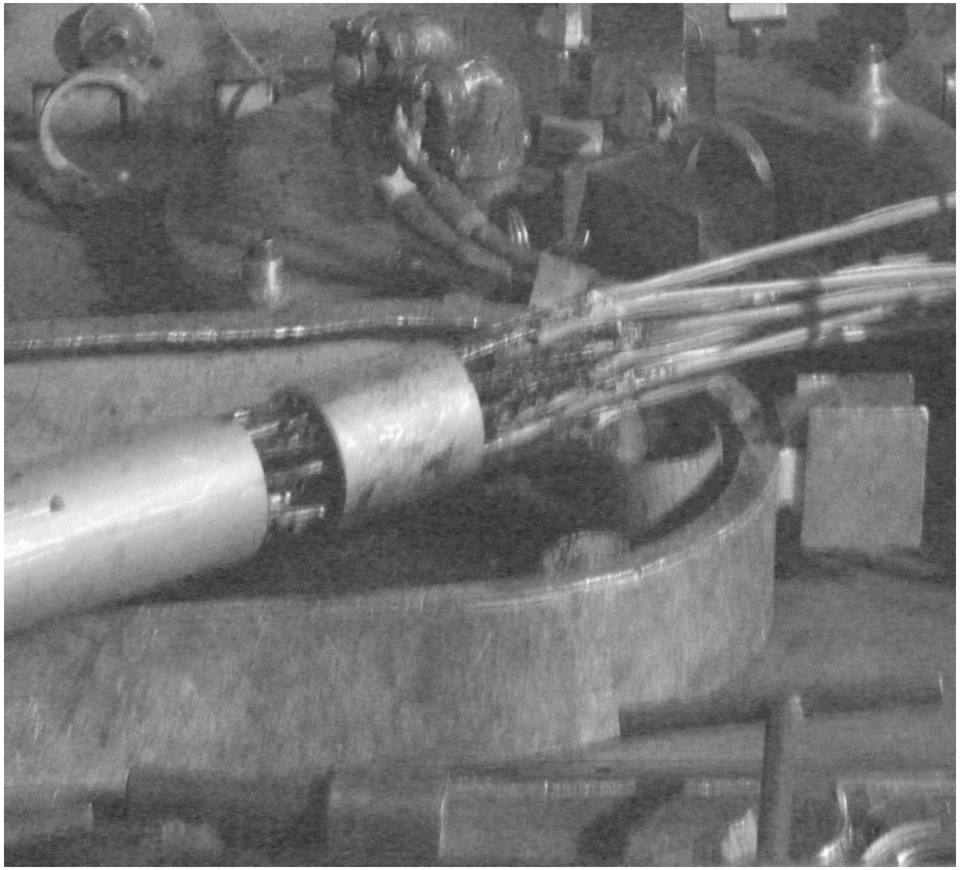
- Shipped 1978 to 1991
- CPP-666 Water Pool
- 3644 Bottles Remained
- Some Corroded Fuel



Mk-IV Electrorefiner

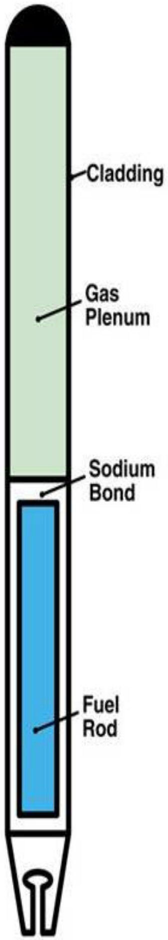


Pristine Fuel



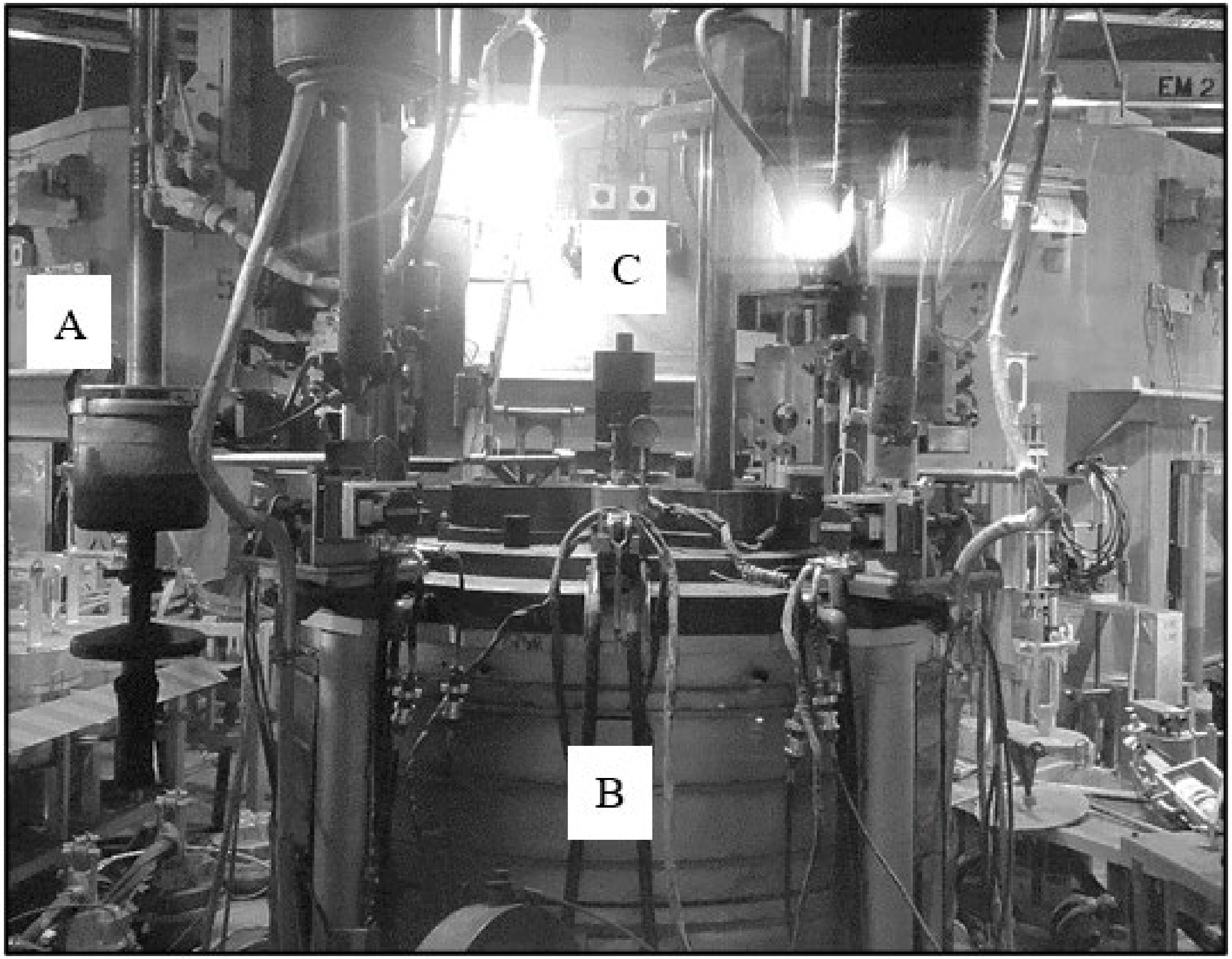
Corroded Fuel

Mk-IV Electrorefiner

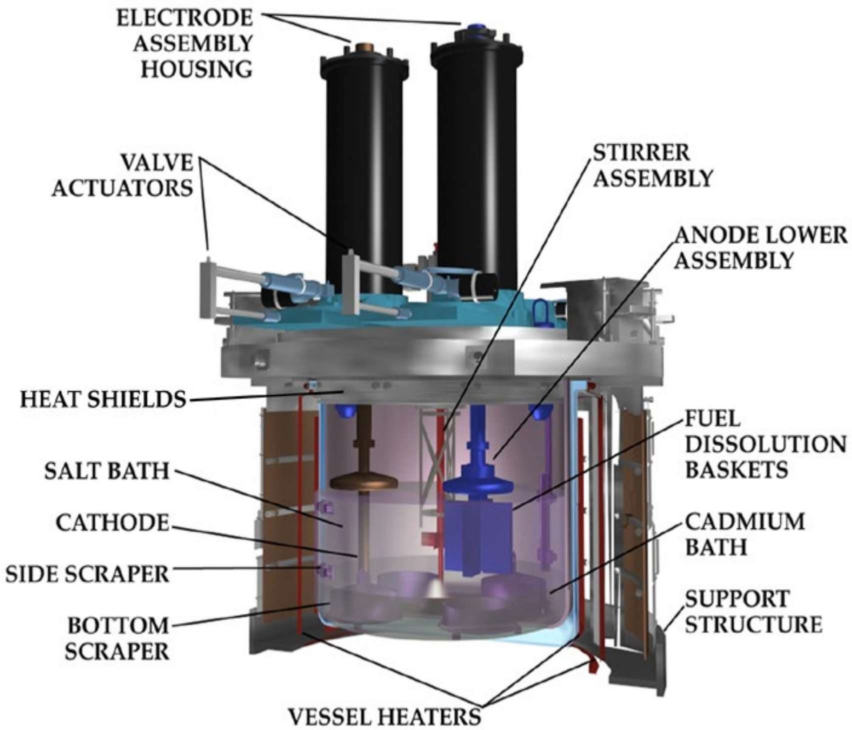


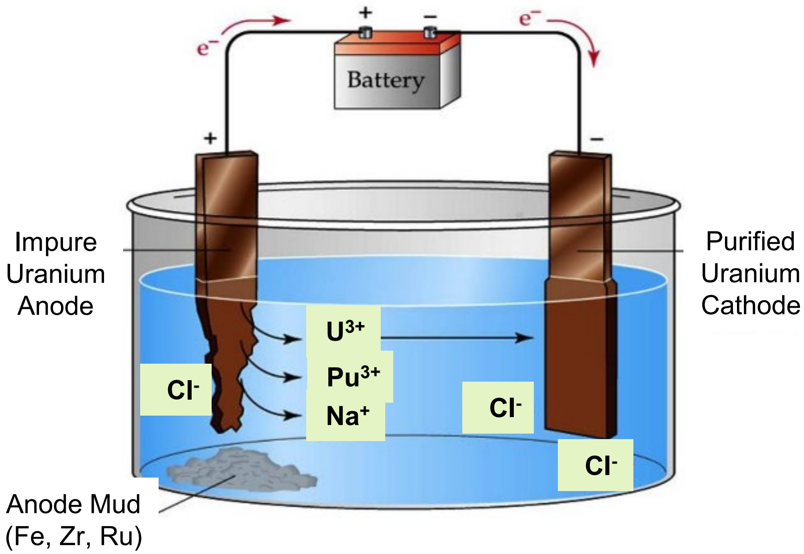
Mk-IV Electrorefiner

Mk-IV Electrorefiner



Electrorefining Comparison



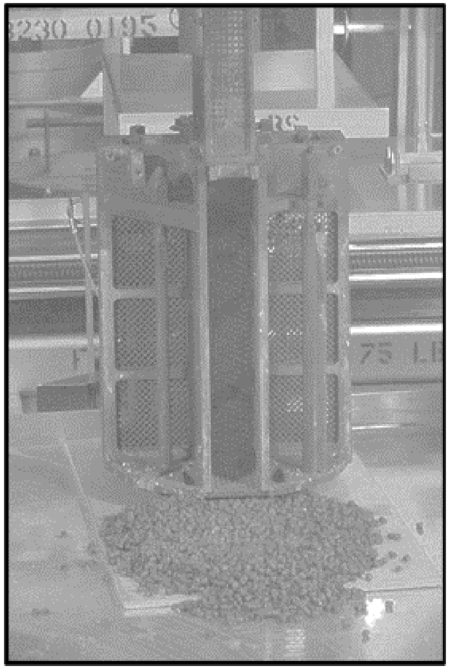


80-90% U → 99.99% U

Media: LiCl-KCl Eutectic Salt
Temperature: 500°C
Density: 1.6 to 1.8 g cm^{-3}
Color: Clear
Dynamic Viscosity: 2.2 mPa·s

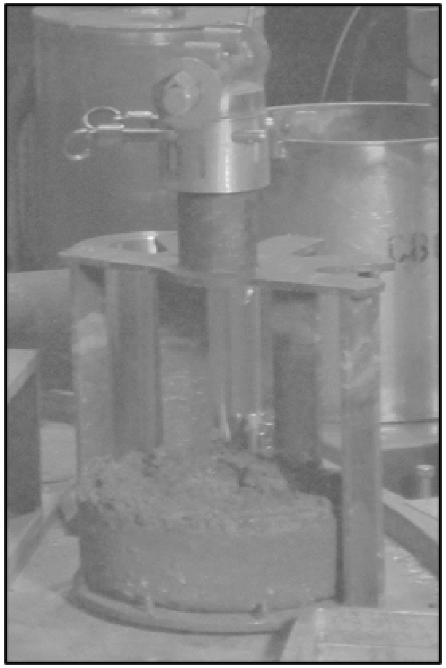
Mk-IV Electrorefiner

63% ^{235}U



Driver Anode Basket
(DAB)

0.2% ^{235}U

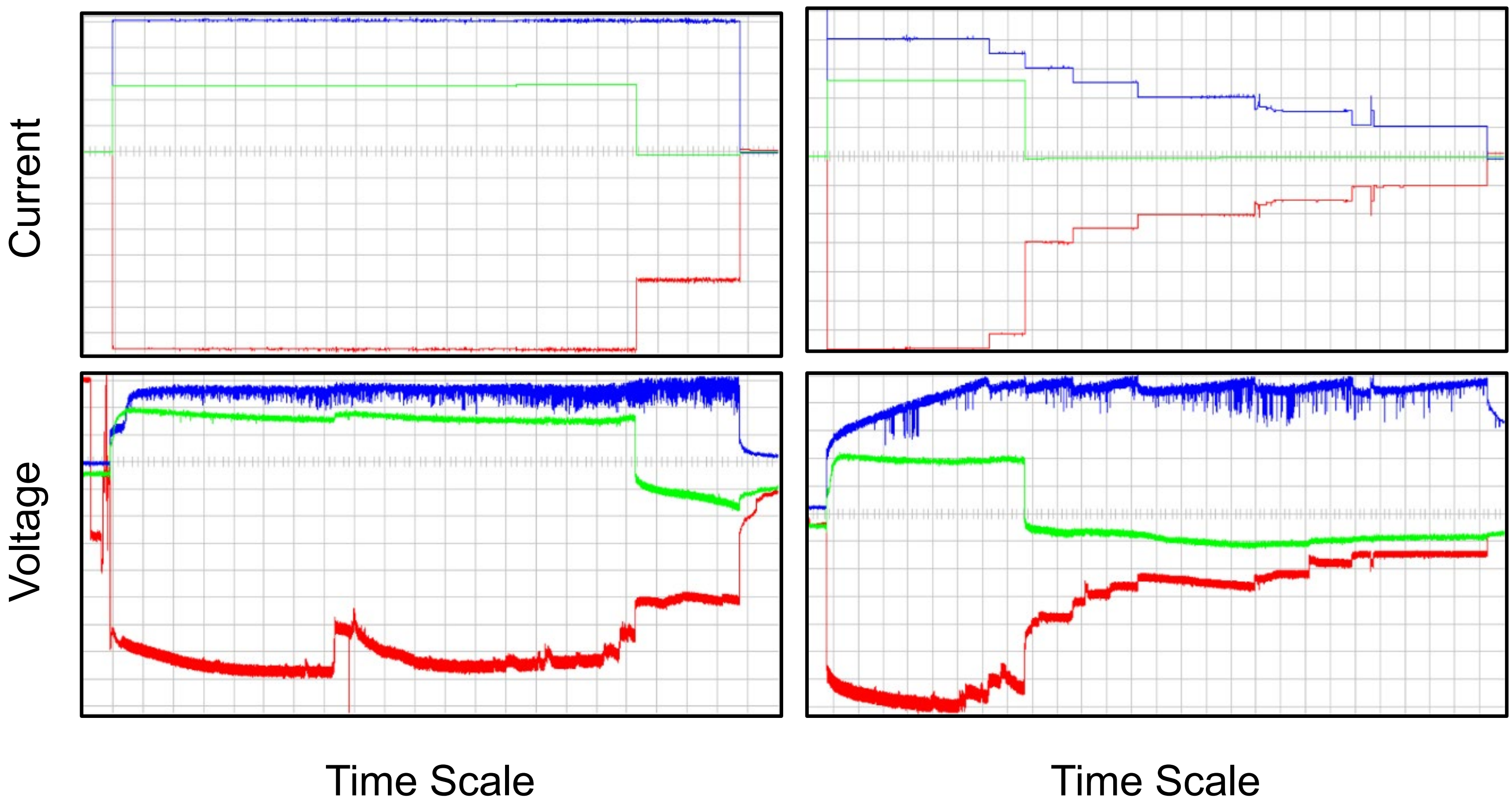


Ingot Dissolution Container
(IDC)

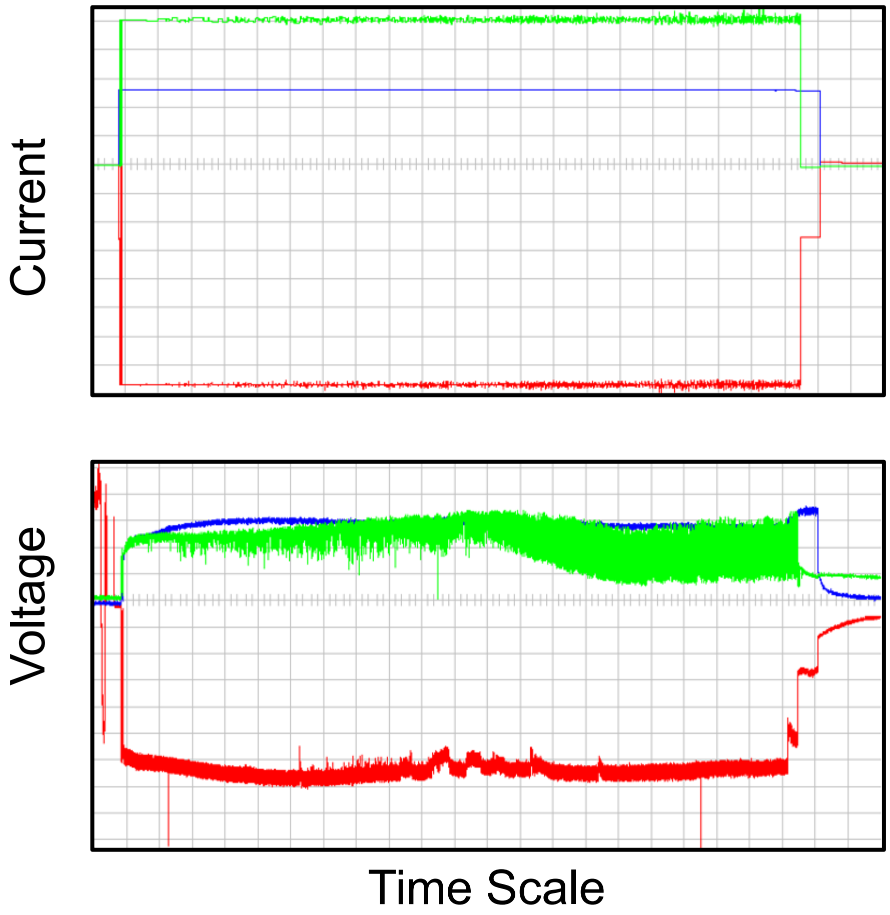
42% ^{235}U

Solid Cathode Mandrel
(SCM)

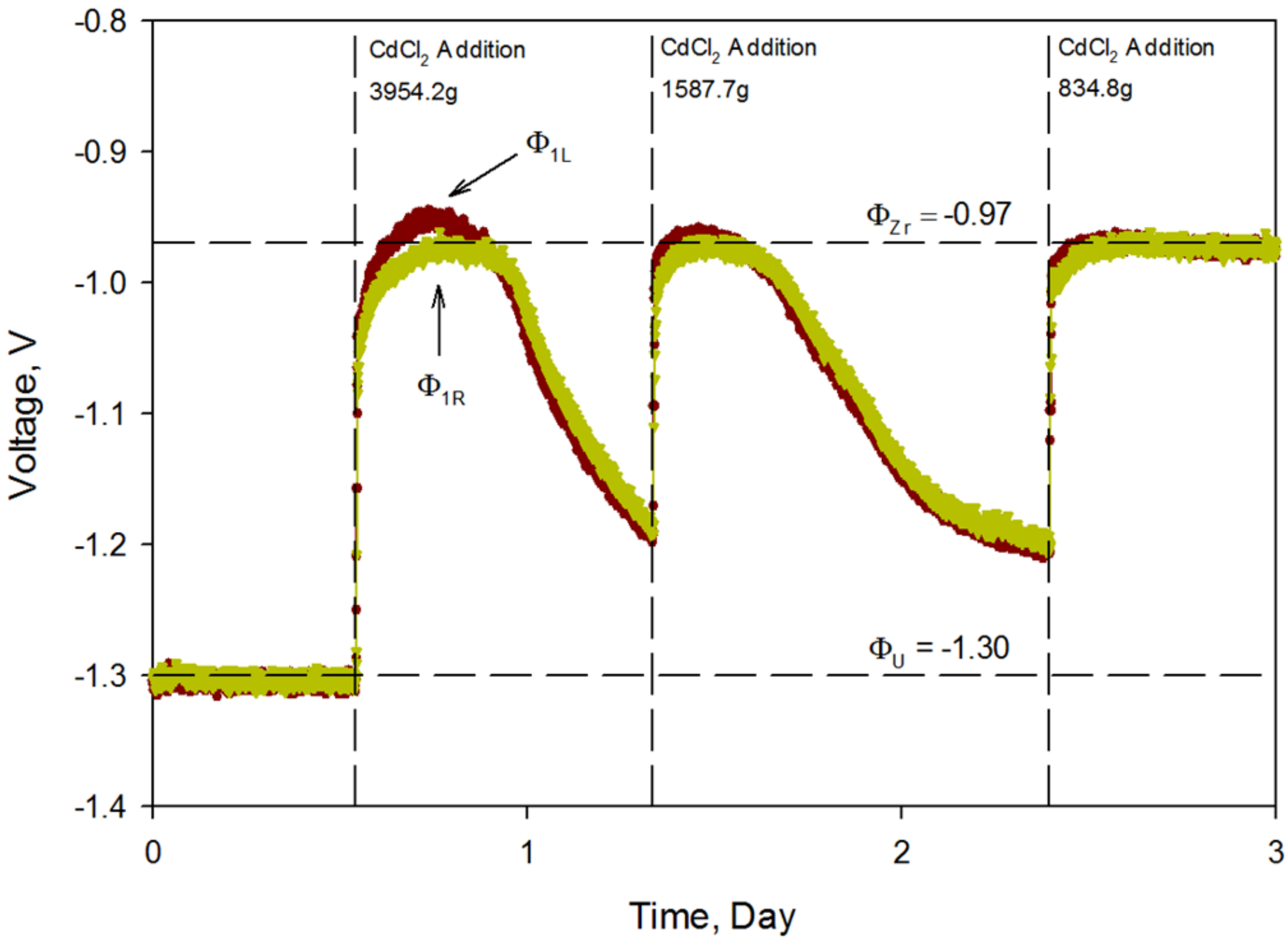
Mk-IV Electrorefiner: Direct Transport



Mk-IV Electrorefiner: Shorting During DT

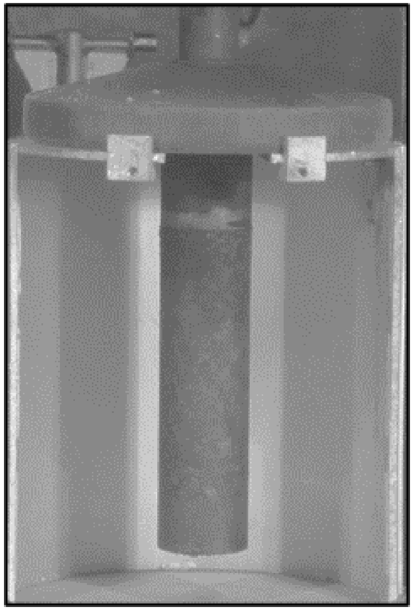


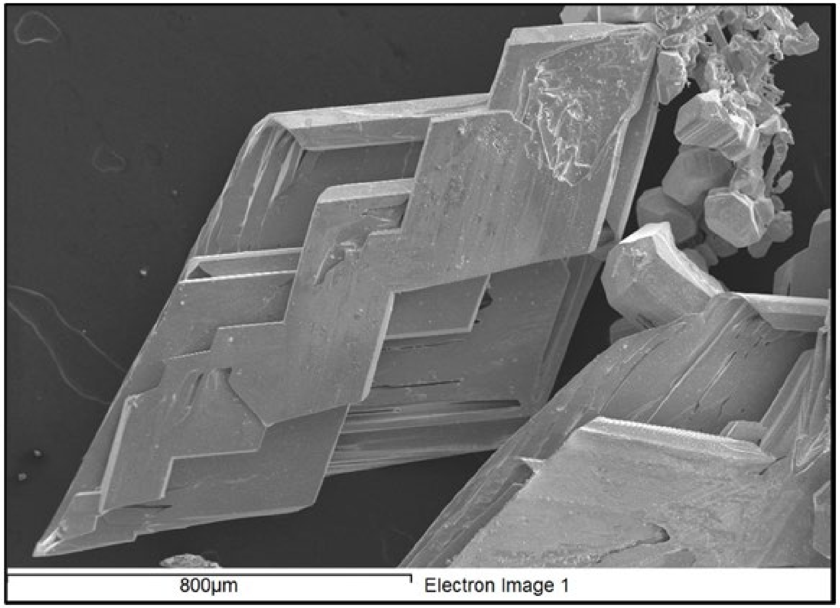
Mk-IV Electrorefiner: Ag/AgCl RE



Mk-IV Electrorefiner

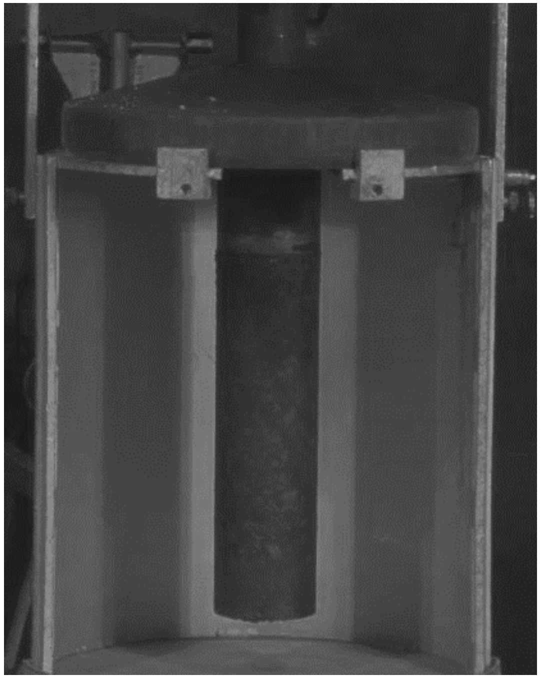
Mk-IV Cathode Deposit





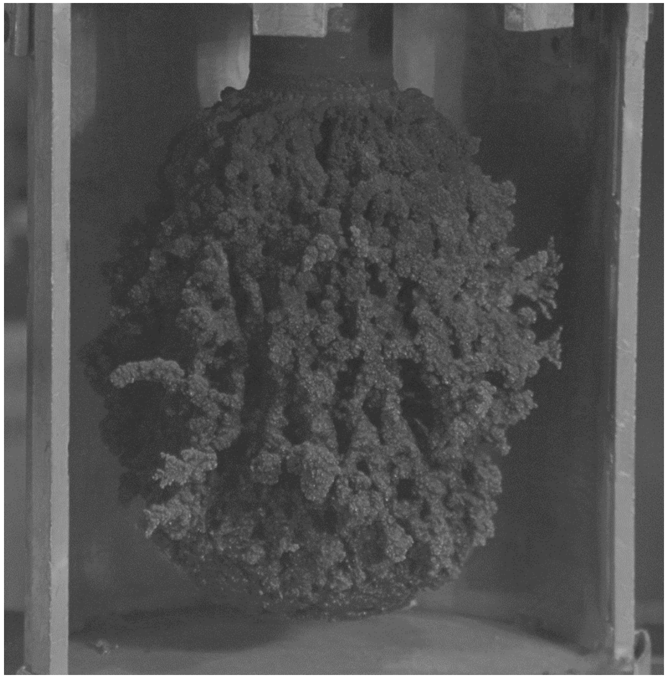
16% Salt

Mk-IV Electrorefiner



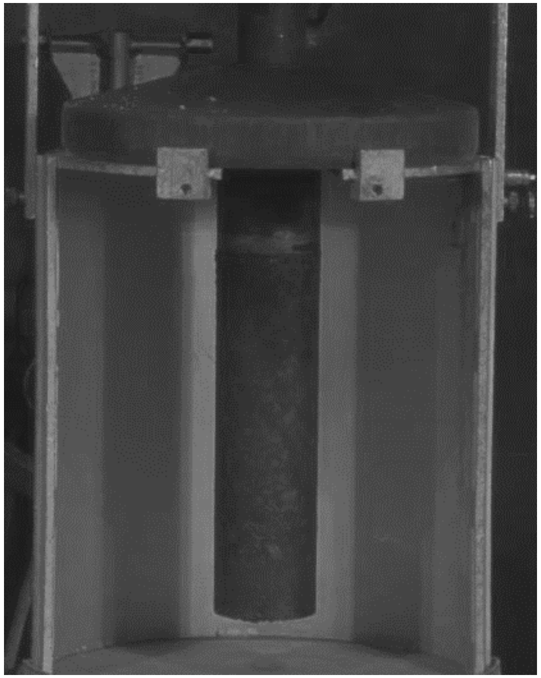
Bare SCM

Clean Uranium



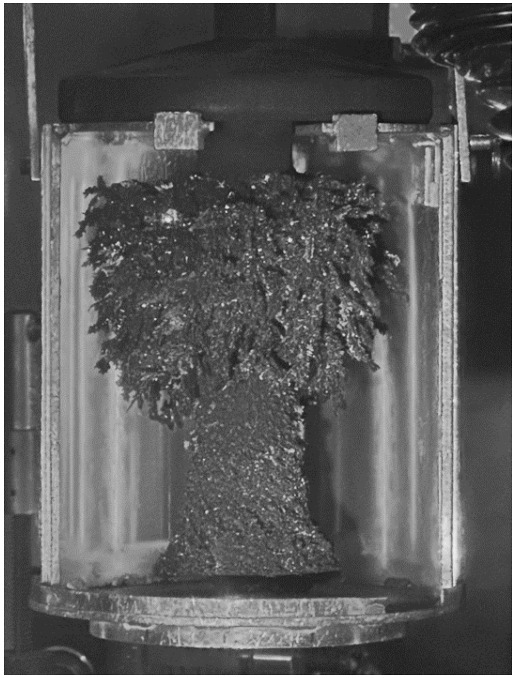
Codeposit of Uranium and Zirconium

Mk-IV Electrorefiner



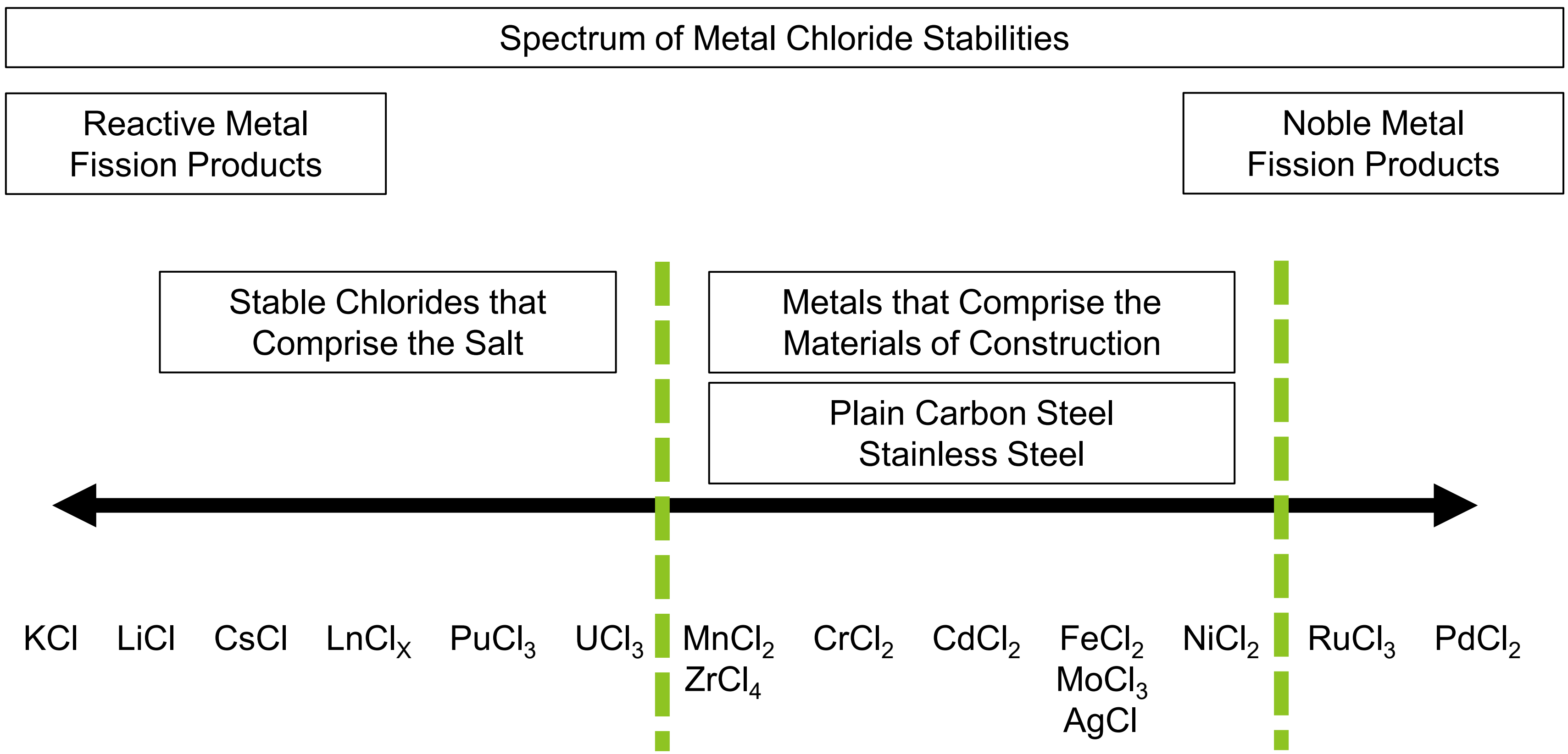
Bare SCM

Clean Uranium



“Sluffing”

Chemical Separations



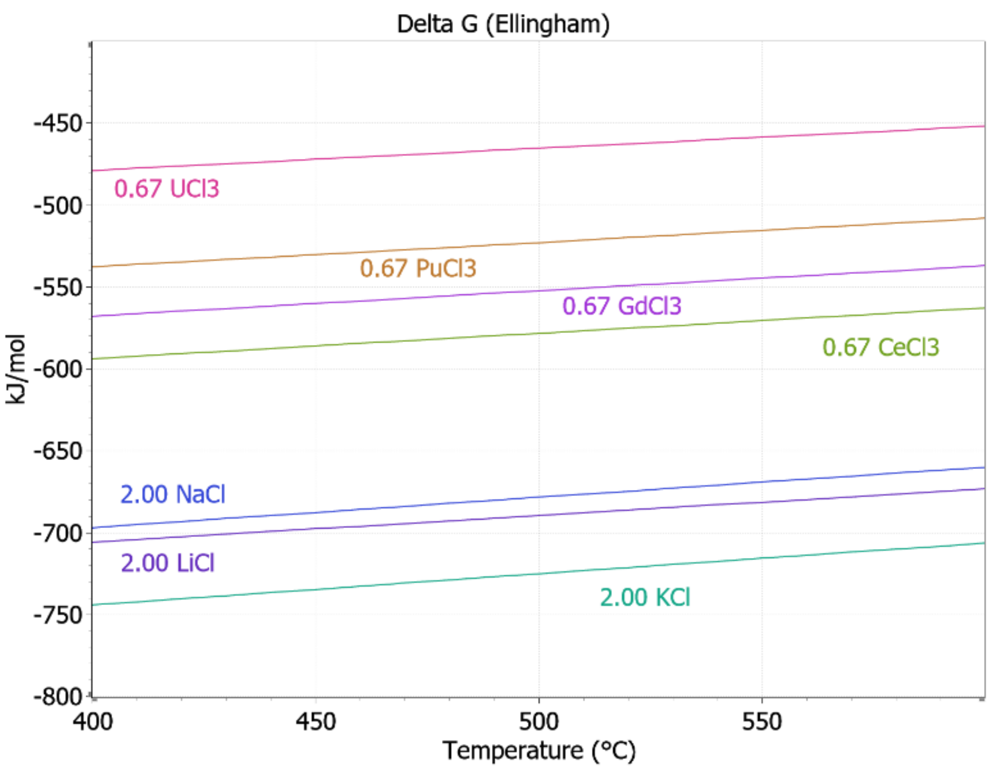
Chemical Separations

Exchange Reactions:

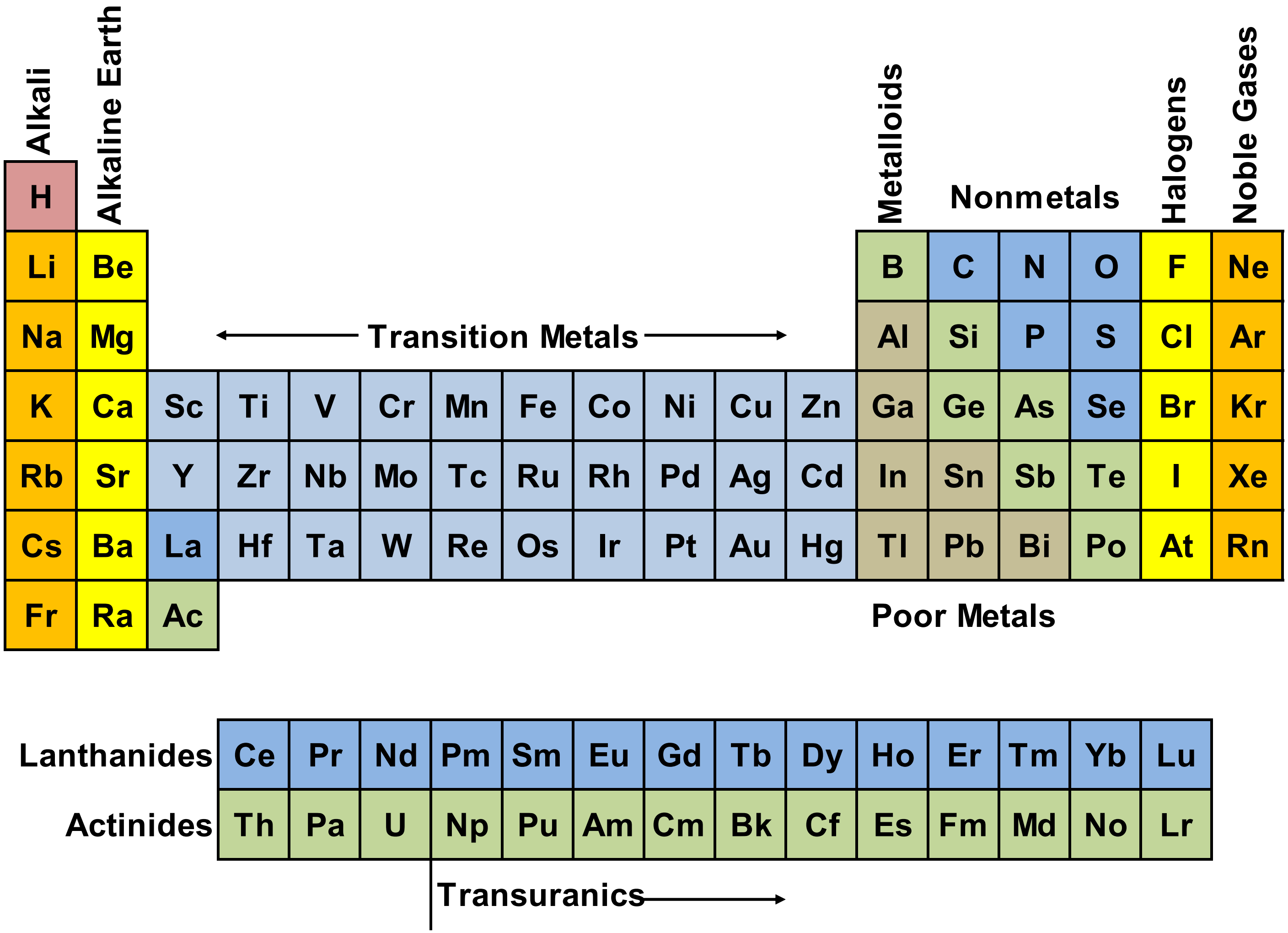
$3\ Na + UCl_3 = U + 3\ NaCl$

$Ln + UCl_3 = U + LnCl_3$

$Pu + UCl_3 = U + PuCl_3$

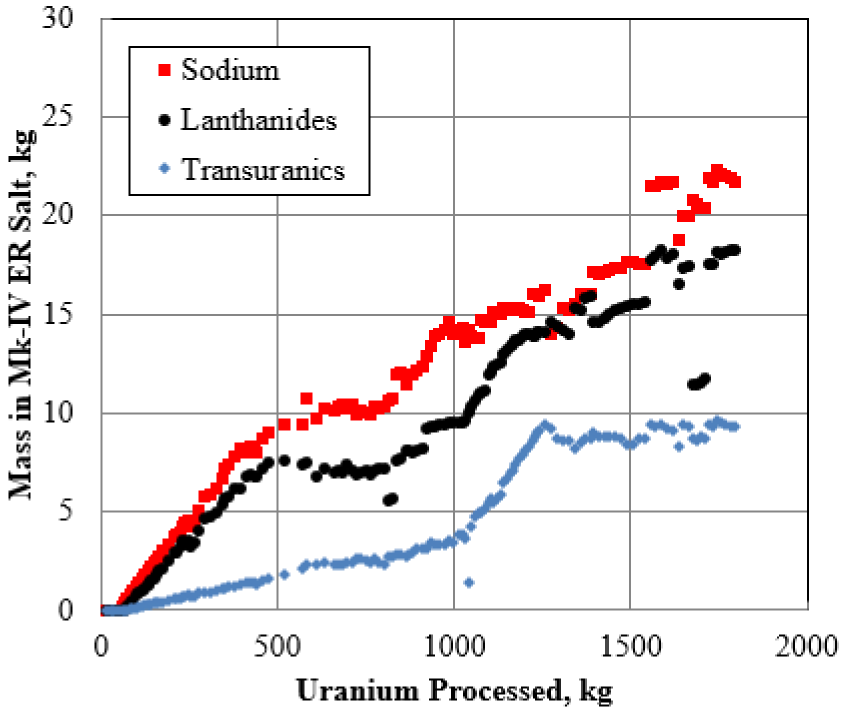


Chemical Separations

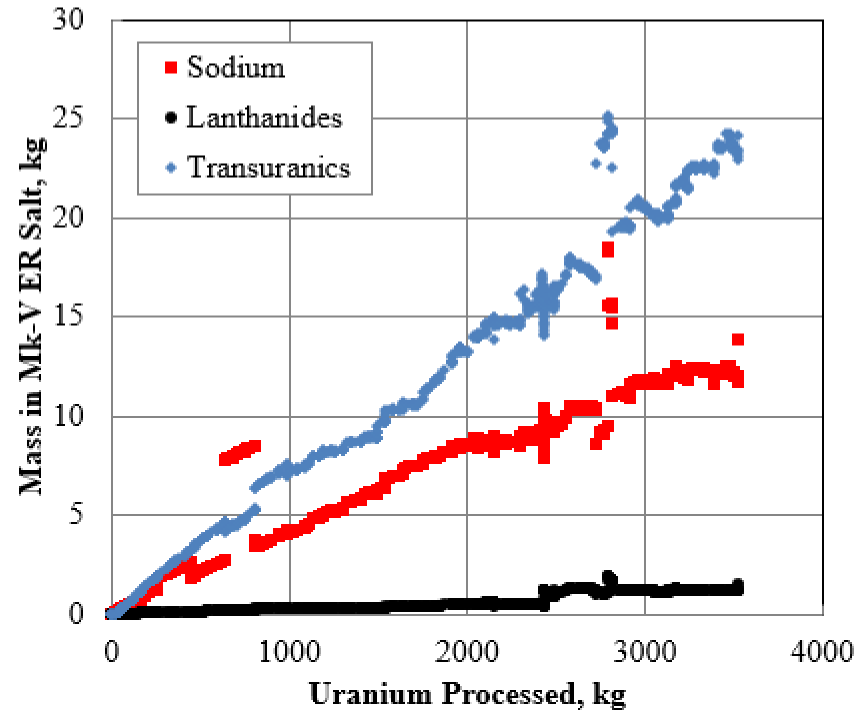


Accumulation in the Salt Phase

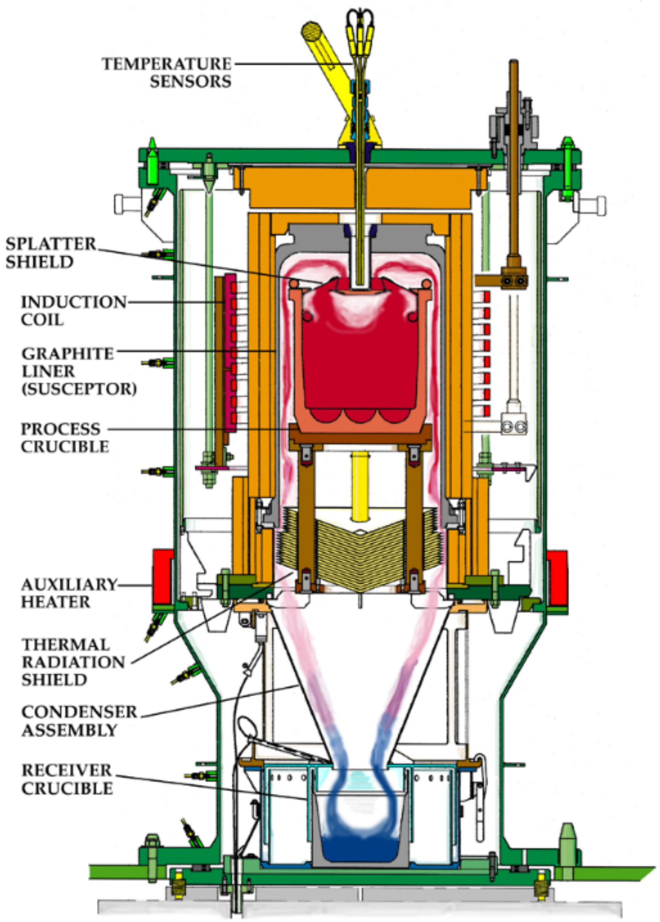
Driver Fuel (Mk-IV)

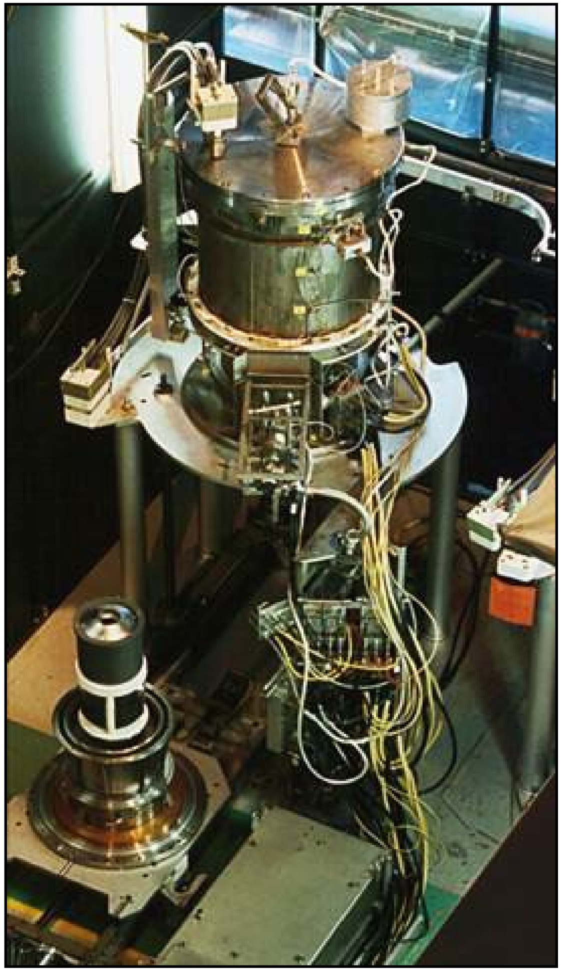


Blanket (Mk-V)

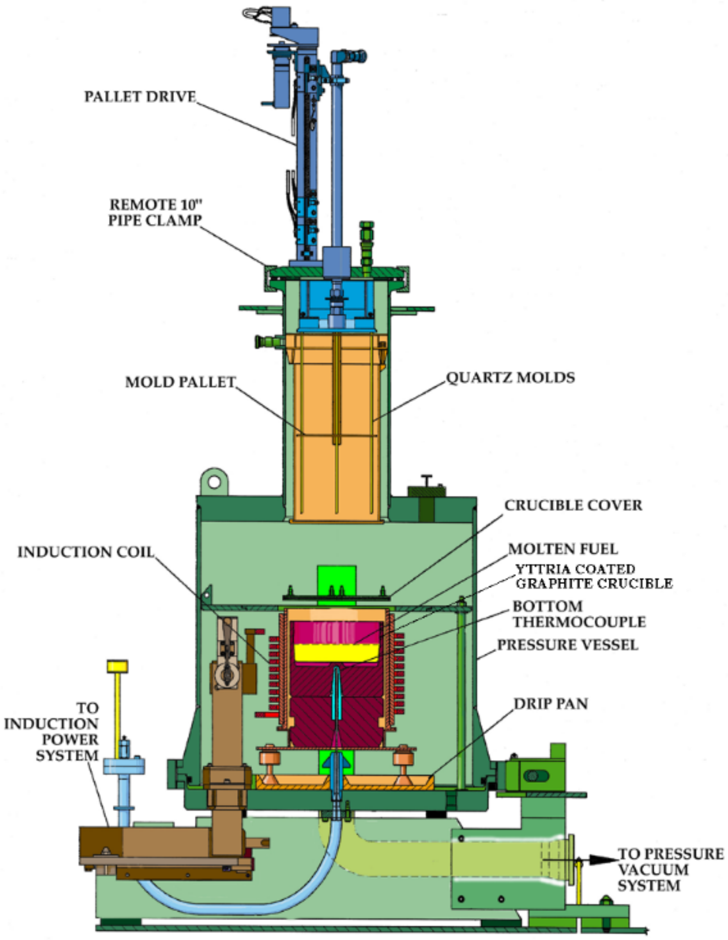


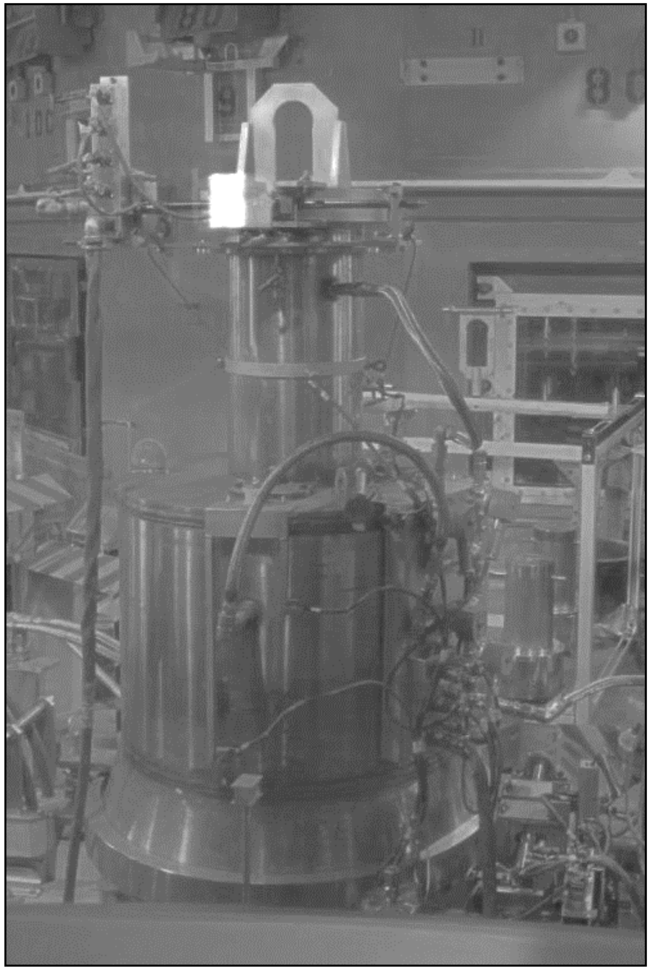
Cathode Processor



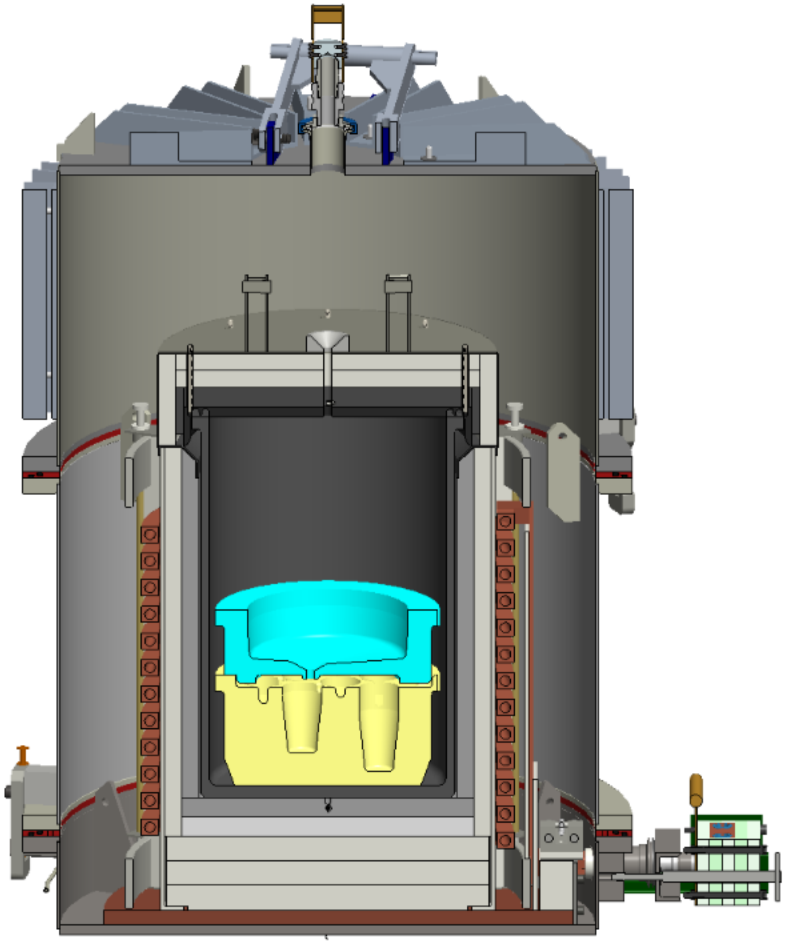


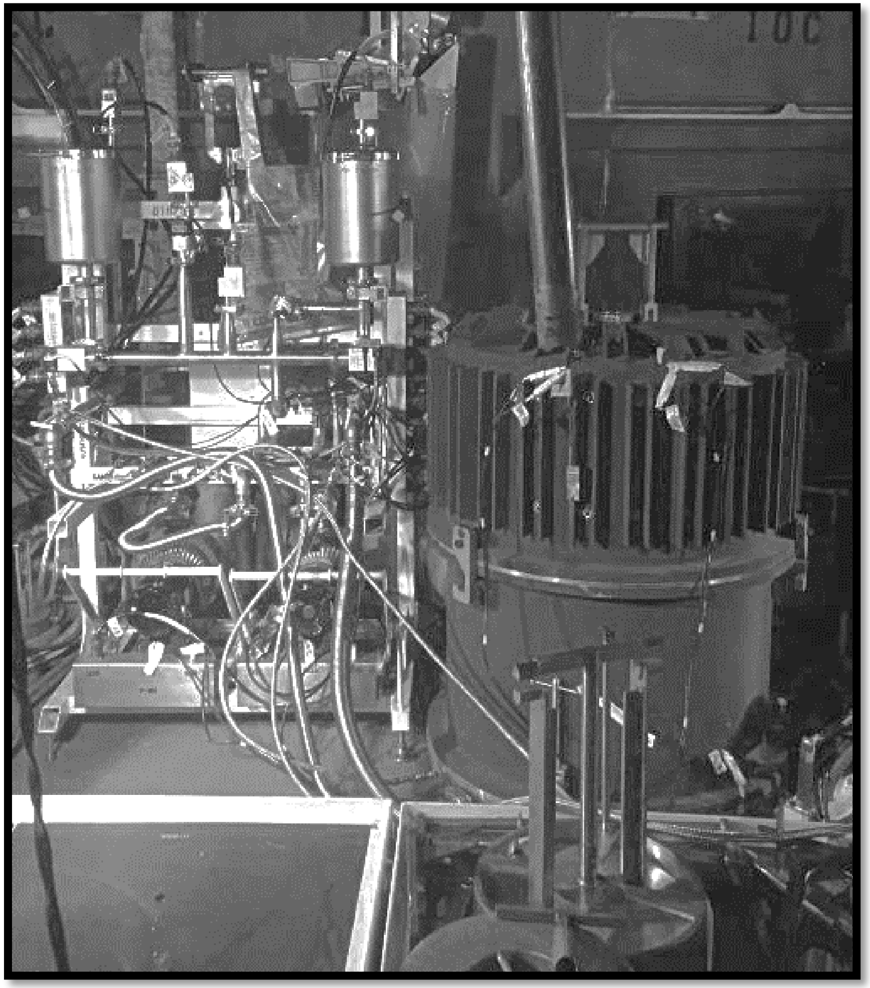
Casting Furnace





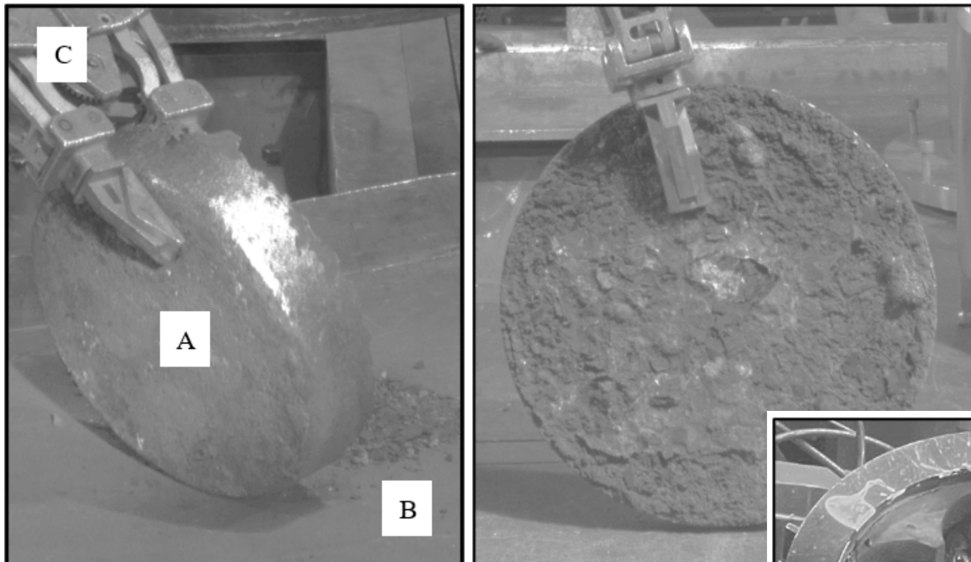
The "New" Multi-Function Furnace



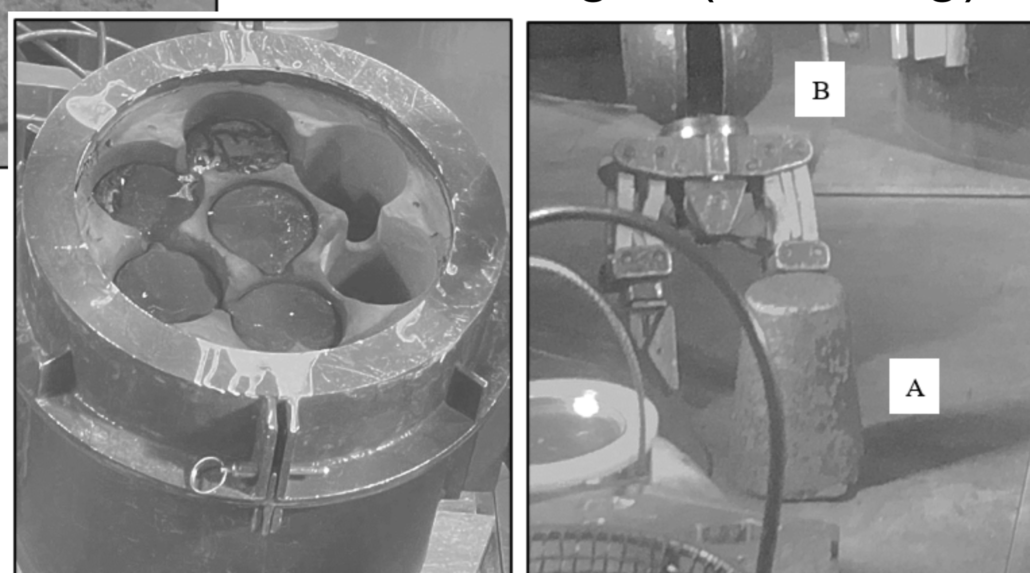


Cast Electrorefined Uranium

HALEU Ingots (25 to 50 kg)

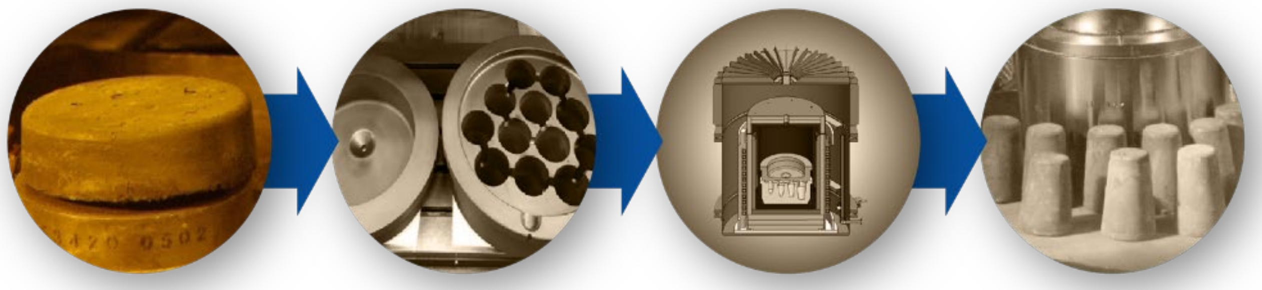


HALEU Reguli (3 to 7 kg)



HALEU "Pyro Polishing"

- "Polishing" to reduce radiological dose.
- Allow for glovebox fuel fabrication.
- IFR Program anticipated remote fuel fabrication.



Large ingot
Diameter = 20 cm
Thickness = 2.5 – 7.5 cm
Weight = 30 – 40 kg

New multi tier crucible system
Converts the large ingot into fuel fabrication-ready reguli

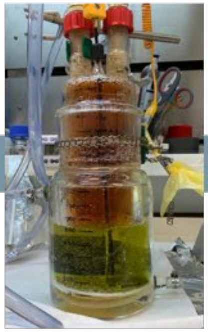
Recast in high temperature furnace
Multi tier crucible used to recast ingot into reguli

Fuel fabrication-ready reguli
Diameter = 6 - 8 cm
Height = 9 - 11 cm
Weight = 3 – 7 kg

HALEU "Aqueous Polishing"

- Aqueous chemistry process produces HALEU oxide.
- Significantly reduces dose and transuranic content.
- Material is suitable for oxide-fuel fabrication or further conversion.

Low dose rate, small size HALEU metal regulus



U metal dissolution

U purification

References

- G.L. Fredrickson, T.S. Yoo, “Engineering Scale Pyroprocessing Activities in the United States”, U.S. Nuclear Regulatory Commission, TLR-RES/DE/REB-2023-10

- G.L. Fredrickson, M.N. Patterson, D. Vaden, G.G. Galbreth, T.S. Yoo, J.C. Price, E.J. Flynn, R.N. Searle, “History and Status of Spent Fuel Treatment at the INL Fuel Conditioning Facility”, Progress in Nuclear Energy, 143 (2022) 104037

- G.L. Fredrickson, T.S. Yoo, “Review – Nuclear Fuels and Reprocessing Technologies: A U.S. Perspective”, Idaho National Laboratory, INL/EXT-20-59106, March 2021

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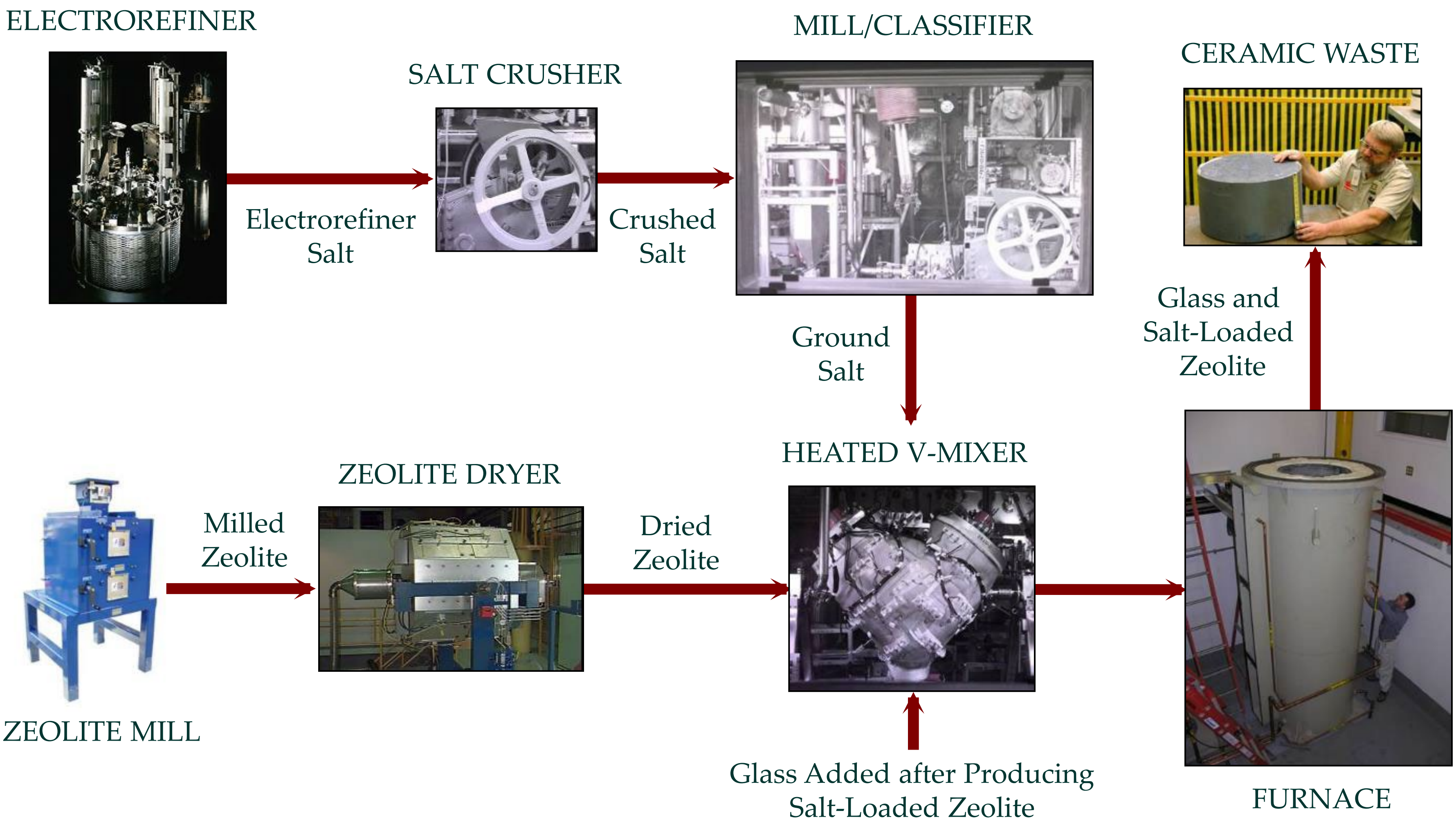
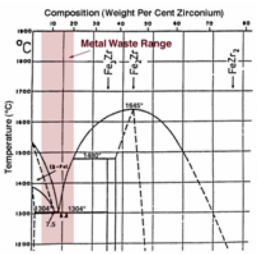
Salt Distillation from Cladding Hulls

Salt Waste Processing



Metal Waste Processing

Metal Waste Hardware



Zirconiu
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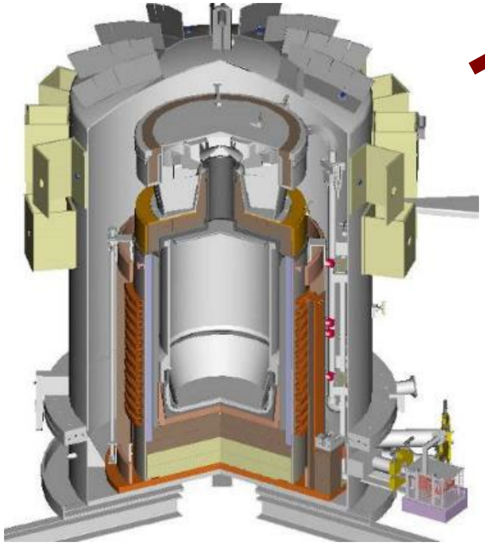

Salt

Metal Waste
Ingot

Yucca Mountain Nuclear Waste Repository