ARPA-E Converting UNF Radioisotopes into Energy Workshop

July 27-28, 2021
WebEx Virtual Event

Guy Fredrickson

Overview of Pyroprocessing

for reprocessing and spent fuel treatment

INL/MIS-21-63449
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Idaho National Laboratory

Historical Background of Reprocessing

INL/EXT-20-59106


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Review – Nuclear Fuels and Reprocessing Technologies: A U.S. Perspective

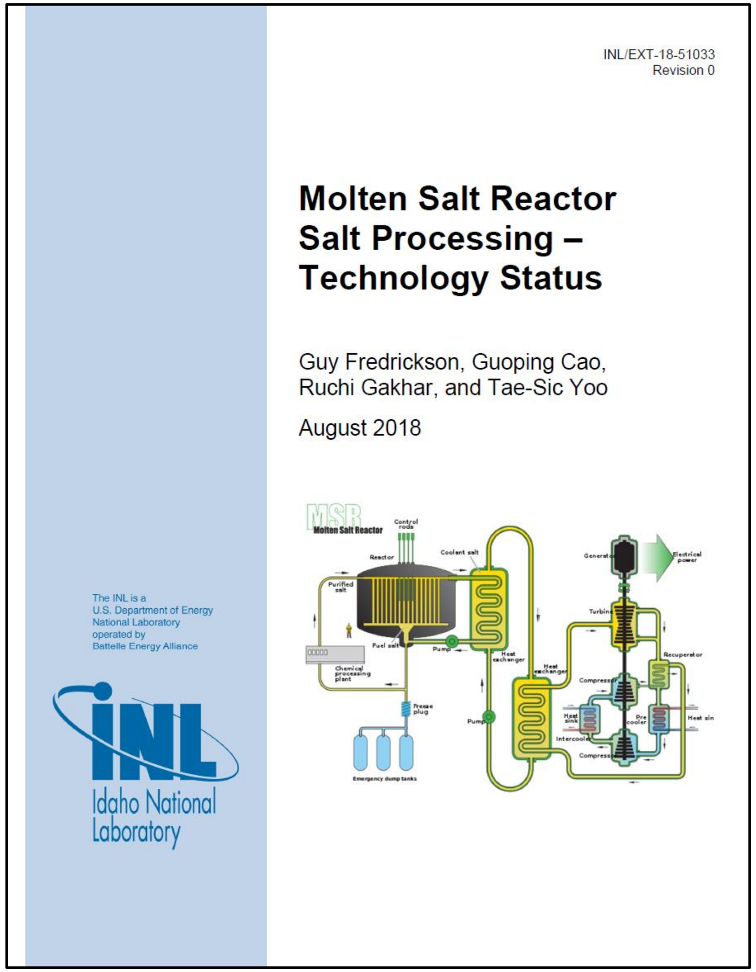
March 2021

Guy Fredrickson
Tae-Sic Yoo

Idaho National Laboratory

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

INL/EXT-18-51033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Revision 0

Molten Salt Reactor Salt Processing – Technology Status

Guy Fredrickson, Guoping Cao, Ruchi Gakhar, and Tae-Sic Yoo

August 2018

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

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Historical Background of Aqueous Reprocessing

Hanford Site (1944 to 1993)

- Plutonium Production Reactors: B, D, F, H, DR, C, KW, KE, and N
- Plants: T, B, U, S, A, UO_2

Savannah River Site (1954 to Present)

- Plutonium Production Reactors: R, P, L, K, and C
- Canyons: F and H
- Lines: A and B
- MOX Fuel Fabrication Facility (now Pu-pit production)

Idaho Chemical Processing Plant (1953 to 1993)

- HEU Fuel Reprocessing

Historical Background of Aqueous Reprocessing

US Commercial Reprocessing Ventures (1966 to 1976)

- Nuclear Fuel Services Company, West Valley, NY (only plant to operate)
- Midwest Fuel Recovery Plant, Morris, IL
- Barnwell Nuclear Fuel Plant, Barnwell, SC
- Exxon Nuclear Fuel Recovery and Recycling Center, Oak Ridge, TN
- Presidents Ford and Carter steered the US away from reprocessing.

Generalities

	Aqueous	Non-Aqueous
Scale	Industrial	Engineering
Flowsheet	Semi-Continuous	Batch
Media	Aqueous and Organic	Molten Salts and Metals
Temperatures	Less than 100°C	500°C to 1500°C
Input/Output	Oxide to Oxide	Oxide to Oxide
	Metal to Oxide	Oxide to Metal
		Metal to Metal

Historical Background of Non-Aqueous Reprocessing

- MOX Fuel Salt Cycle Process (1960s)
- Molten Salt Reactor $^{232}Th/^{233}U$ Fuel Cycle Process (1960s)
- Metallic Fast Reactor Fuel Melt Refining Process (1960s)
- Metallic Fast Reactor Fuel Electrometallurgical Process (1980s to present)

Pyroprocessing of Mixed Oxide (MOX) Fuels

MOX Fuel → Molten Salt Cell → Purified UO_2 and PuO_2 → Washing, Grinding, Blending → MOX Fuel Powder → MOX Fuel Fabrication

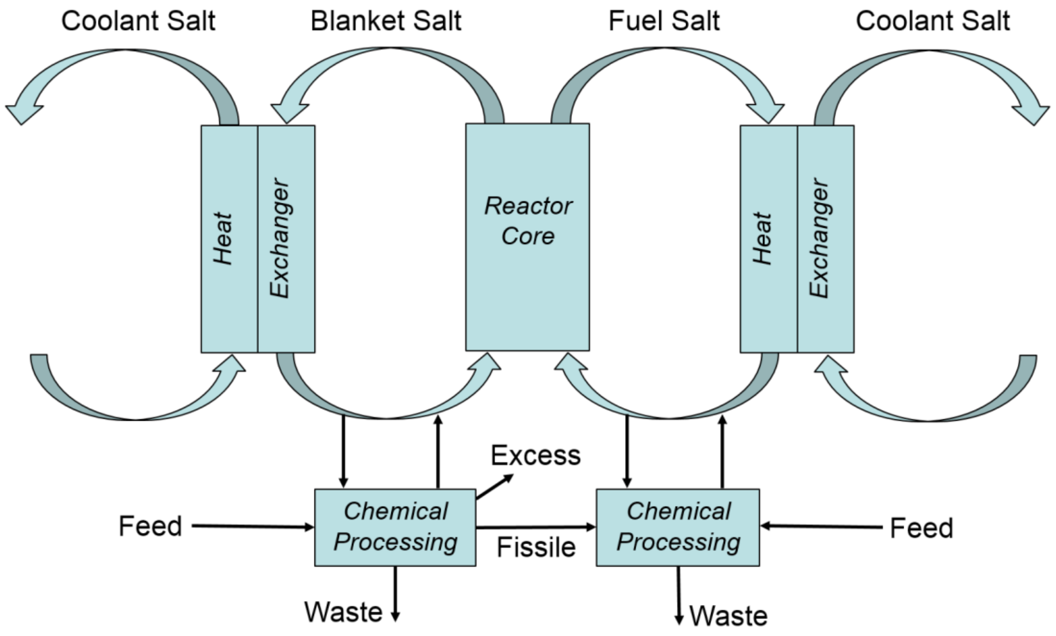
Molten Salt Cell

- Chlorination
- Partitioning
- Codeposition
- Scavenging
- Precipitation
- Purification

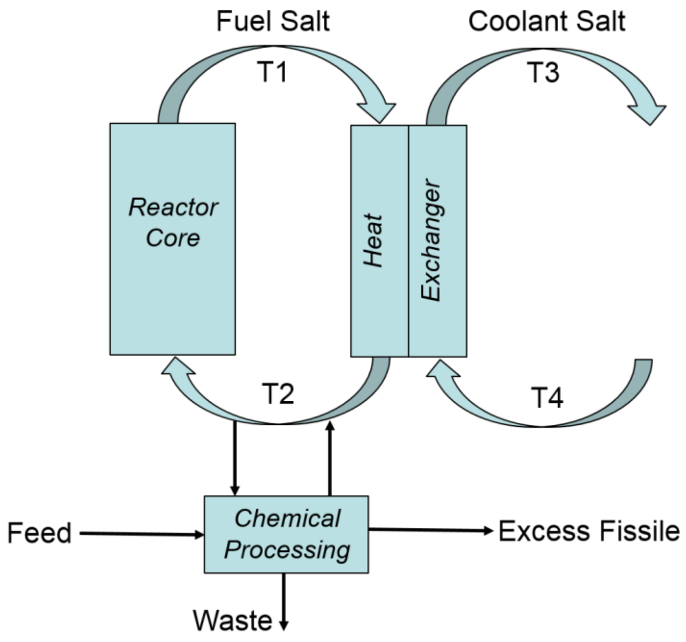
- Hanford Salt Cycle Process (ca 1959)
- Dimitrovgrad Dry Process
- RIAR Dry Process

"Pyroprocessing" to support a $^{232}Th/^{233}U$ MSBR

Two-Fluid MSBR

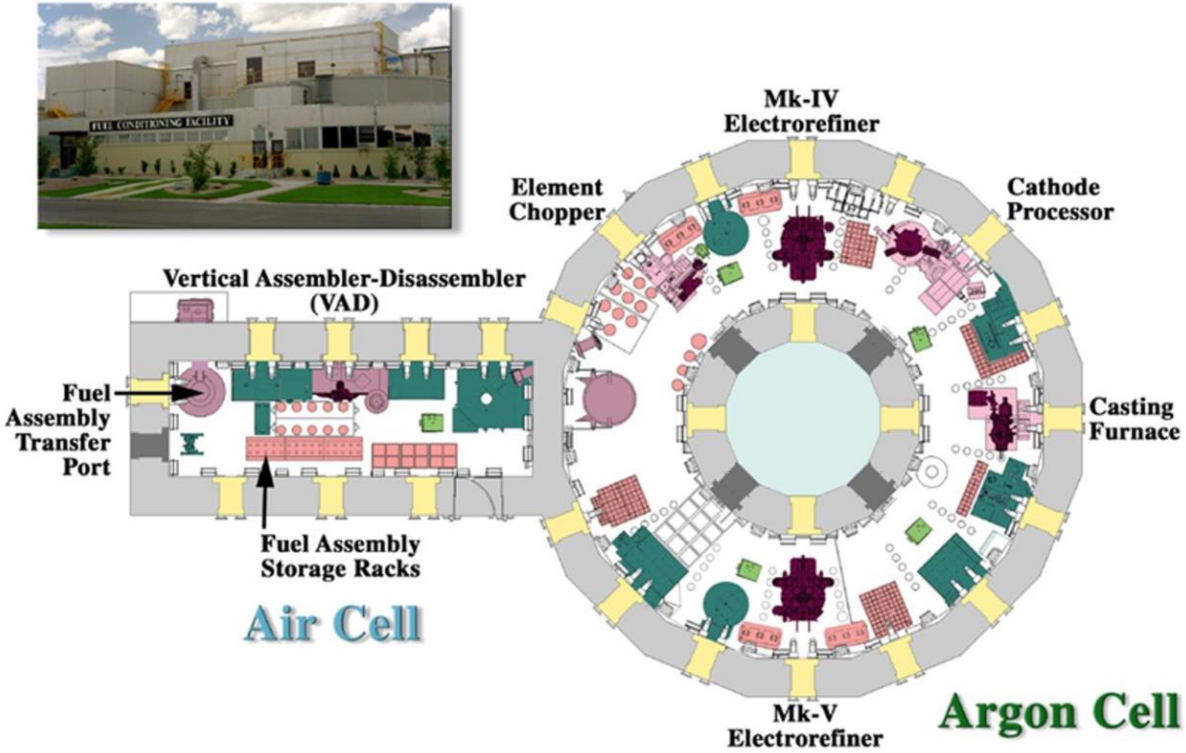


Single-Fluid MSBR



Takeaway: Fuel salt processing is directly connected to reactor operations.
Primary function is Pa management.

Experimental Breeder Reactor - II



Experimental Breeder Reactor - II

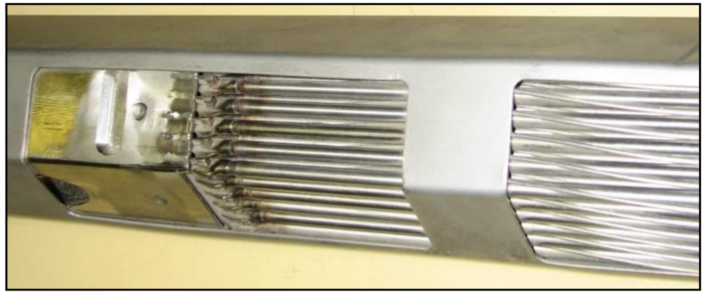
Driver Fuel Subassemblies:

- 91 and 61 pins per SA
- 3 kg HM per SA

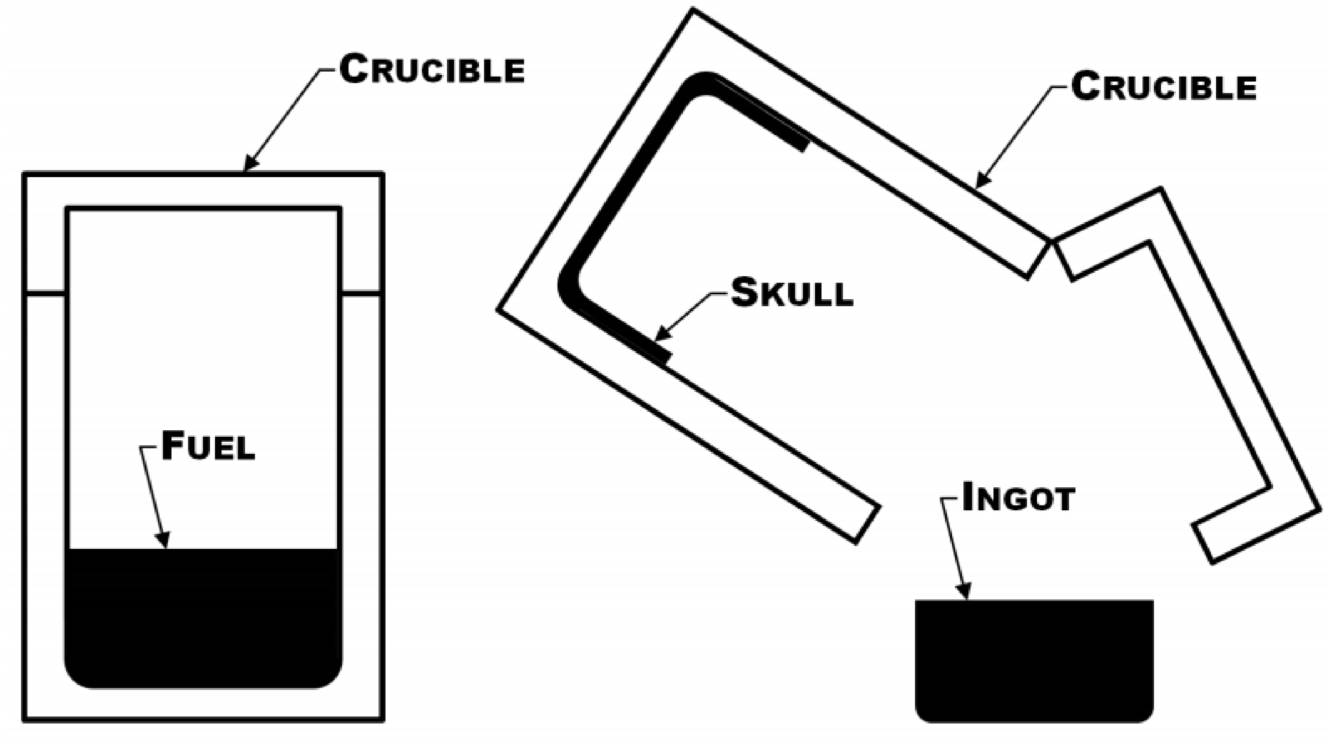
Blanket Subassemblies:

- 19 pins per SA
- 47 kg HM per SA

Total:	637
Outer Blanket:	510
Inner Core:	127
Driver:	47 to 59



Melt Refining/Skull Reclamation Process (1963 – 1968)

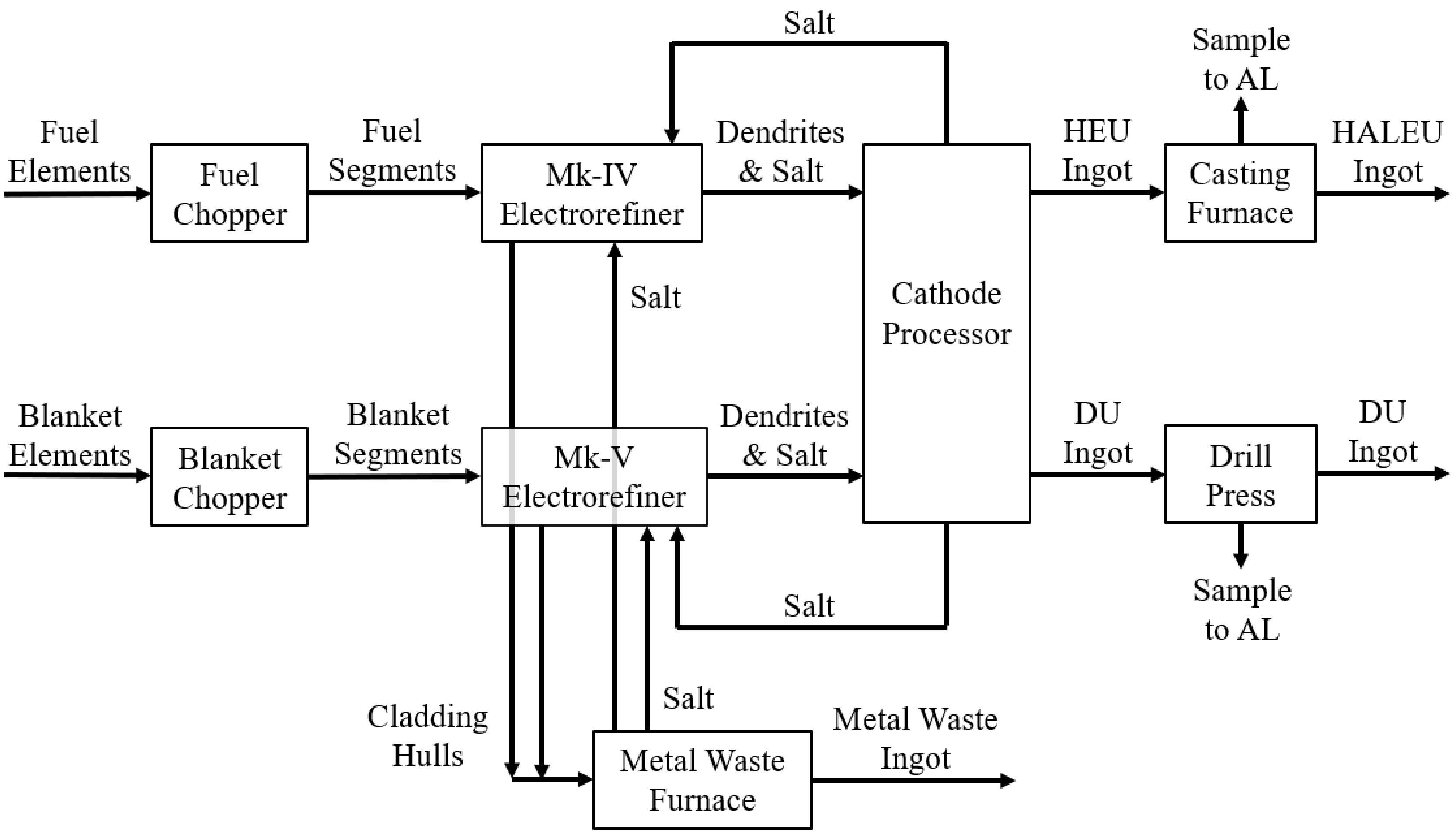


34,000 Fuel Elements

Fissium Alloy, wt%:

- 2.50 Mo
- 2.00 Ru
- 0.26 Rh
- 0.19 Pd
- 0.10 Zr
- 0.04 Si
- 0.01 Nb

Electrometallurgical Process (1996 to present)



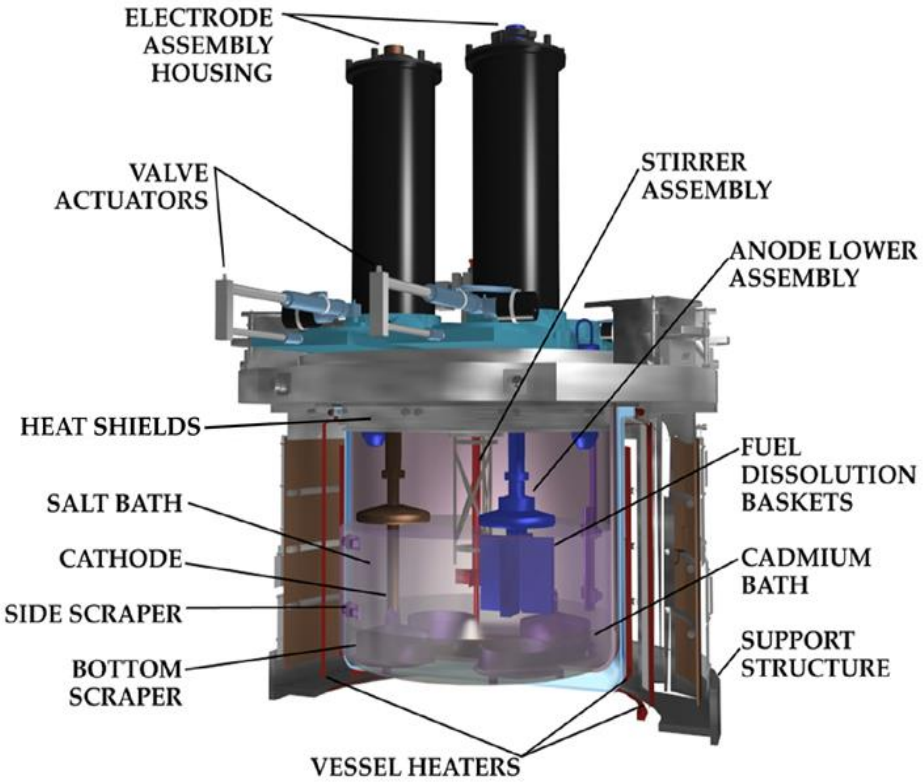
Electrometallurgical Process

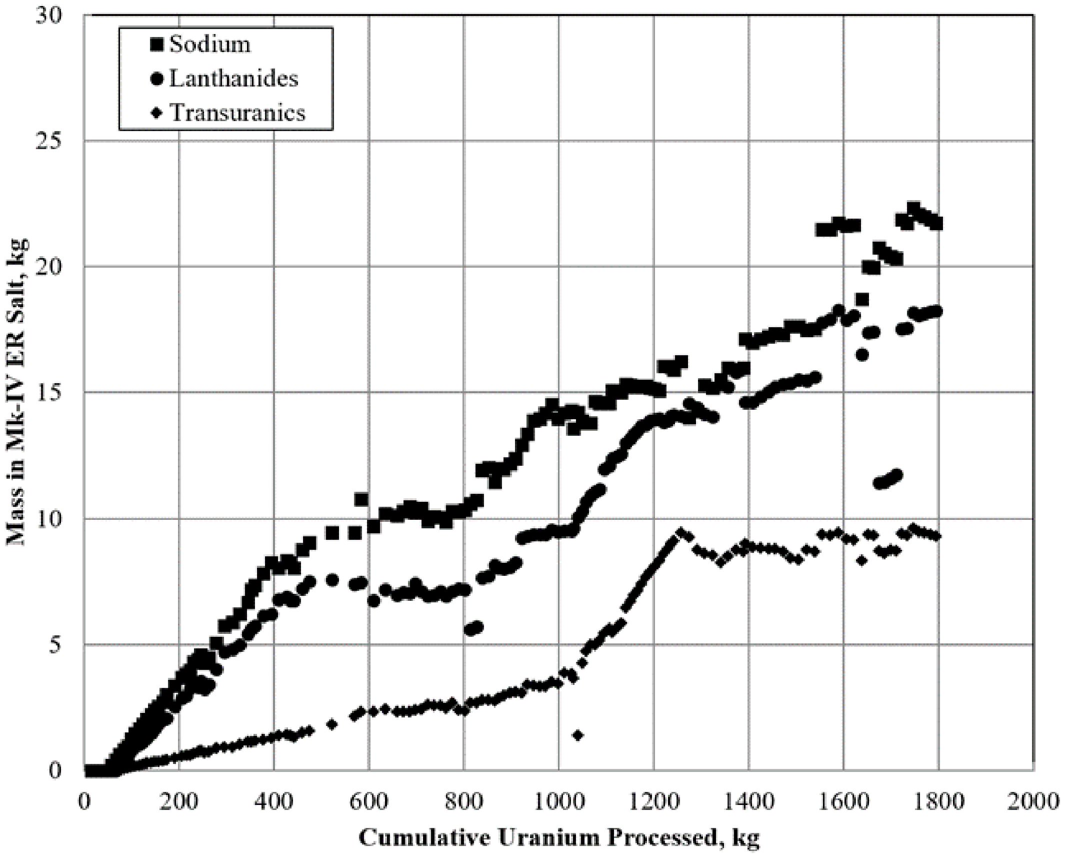
- Ceramic Waste Form
  - Salt is occluded into zeolite 4A, mixed with powdered glass, and heated and converted into a sodalite waste form.

- Metal Waste Form
  - Anode residue is mixed with zirconium and converted into a stainless steel/zirconium eutectic waste form.

- Off Gas
  - Off gas from the process is vented into the hot cell, which periodically vents to the atmosphere via HEPA filters. O_2 and H_2O are constantly scrubbed to levels < 50 ppm.

Electrometallurgical Process

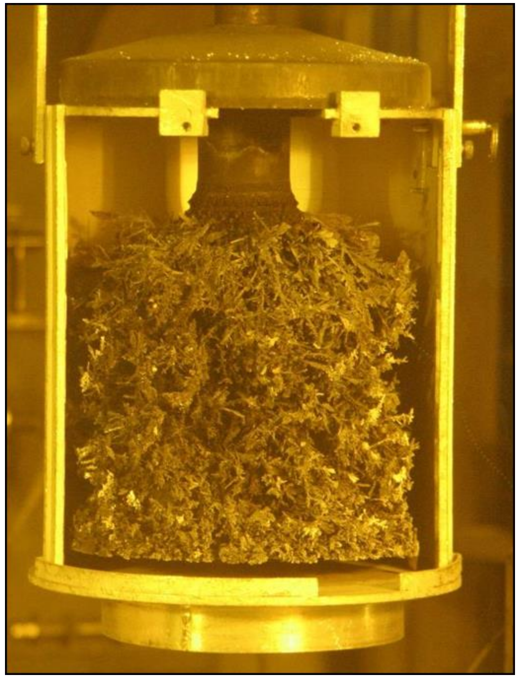




Mk-IV ER for Driver Fuels

Electrometallurgical Process

Bare Cathode
Mandrel

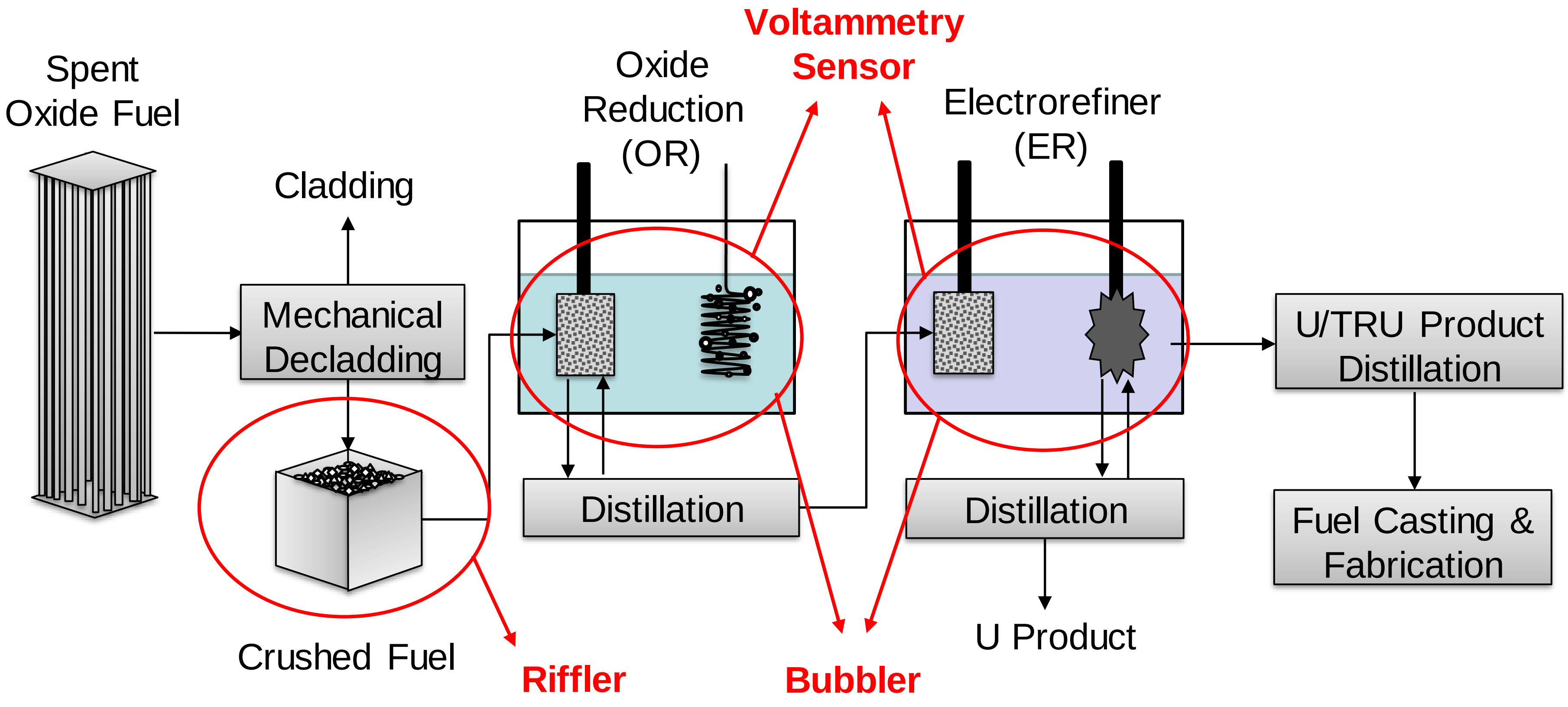


Electrorefined
Uranium

Consolidated
Uranium Ingot

Recast
Uranium Reguli

Generalized Flowsheet



Rotary Riffler

- Oxide fuels are declad and sized to powders.
- Collects small representative samples from bulk heterogeneous granular materials.
- Serves as a form of input accountancy.

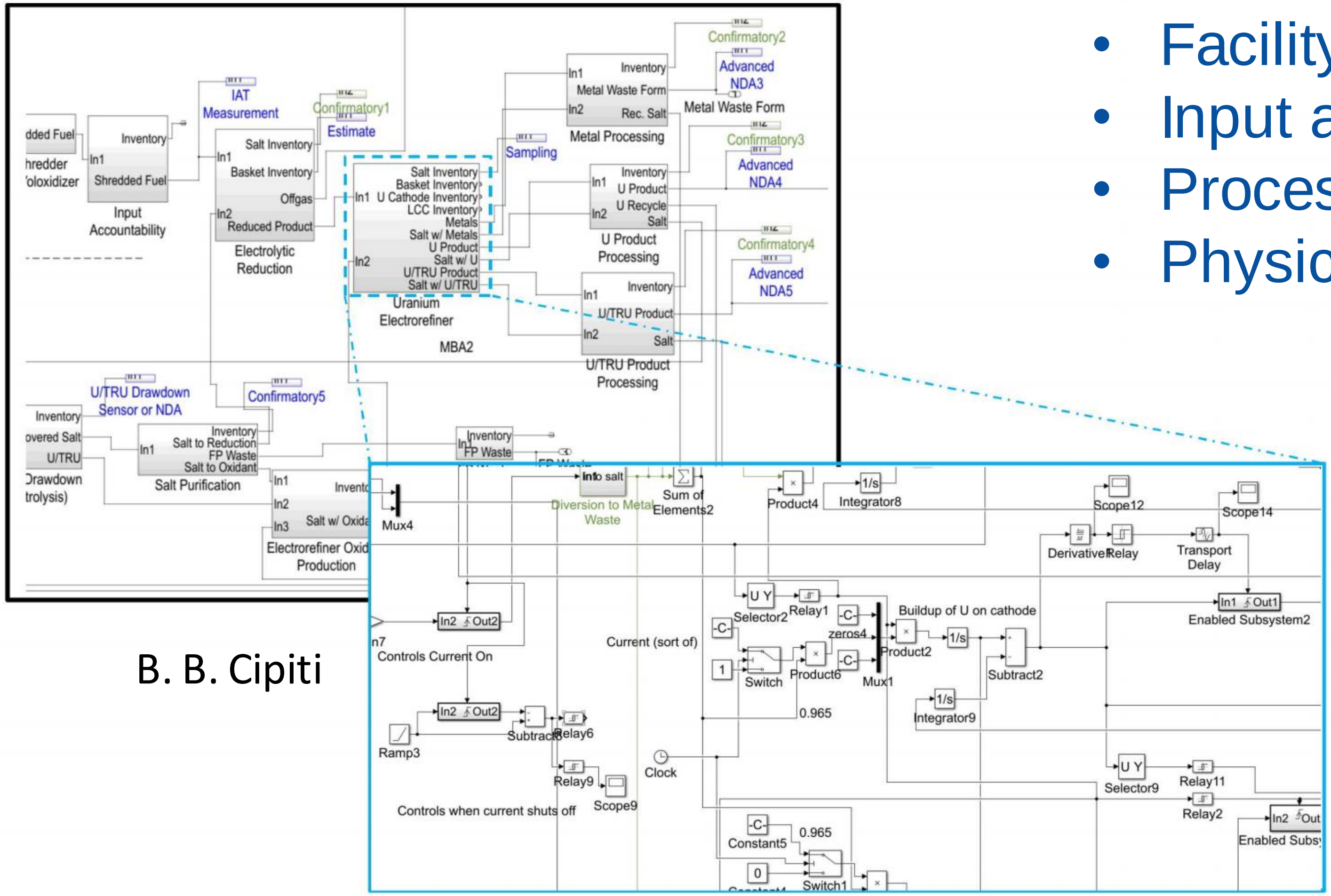
Bubbler Probe

- Probe is inserted into OR or ER salt.
- Measures salt density, surface tension, level, and volume (from calibration curve).
- Serves as a form of inventory accountancy.

Voltammetry Probe

- Probe is inserted into the OR or ER salt.
- Electrochemical measurements are taken with a potentiostat.
- Serves to verify presence of Li_2O in OR.
- Serves to verify presence or absence of actinides in OR and ER.

Integration of Safeguards Technologies



B. B. Cipiti

- Facility design.
- Input accountancy.
- Process monitoring.
- Physical security.

Scaleup Issues

- Very application specific.
- Fuel type.
- Enrichment level.
- Plutonium level.
- Modular systems.
  - ➢ Current density limited.
  - ➢ Criticality mass limited.

Aluminum Production
Hall-Héroult Cells

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