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CLOSING THE NUCLEAR FUEL CYCLE WITH SALT

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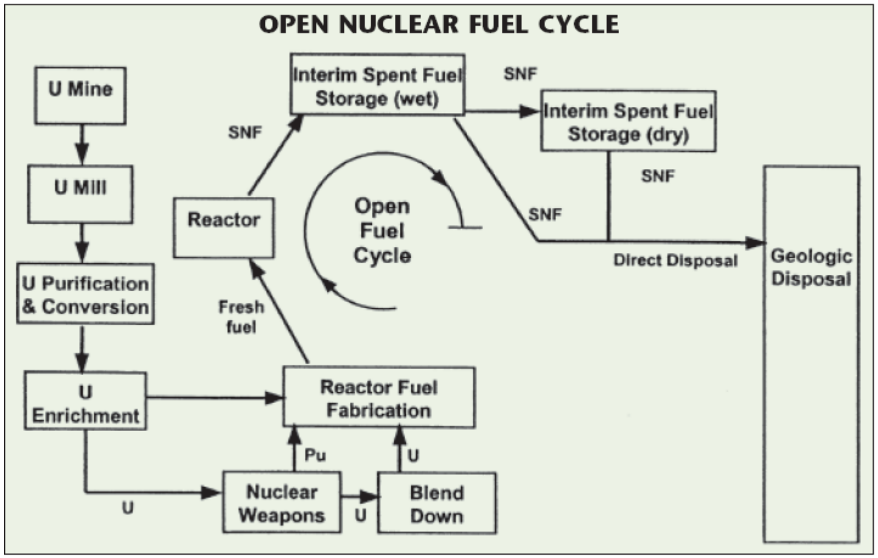
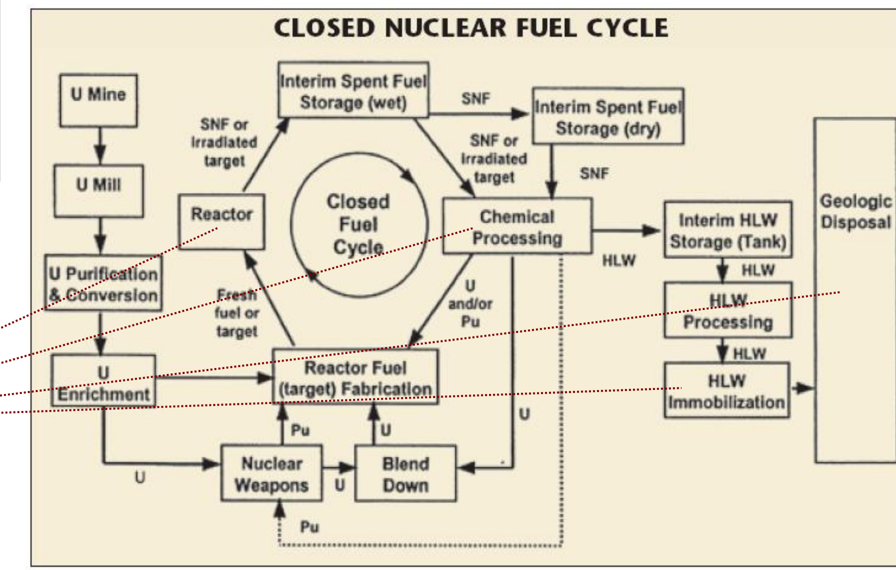
From Once-through Open to Closed Fuel Cycle

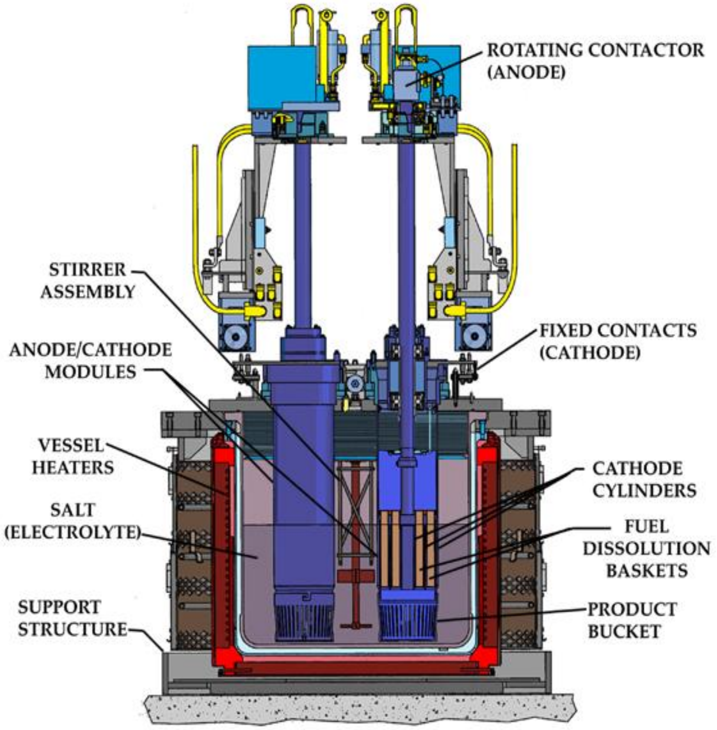




Ewing, 2006

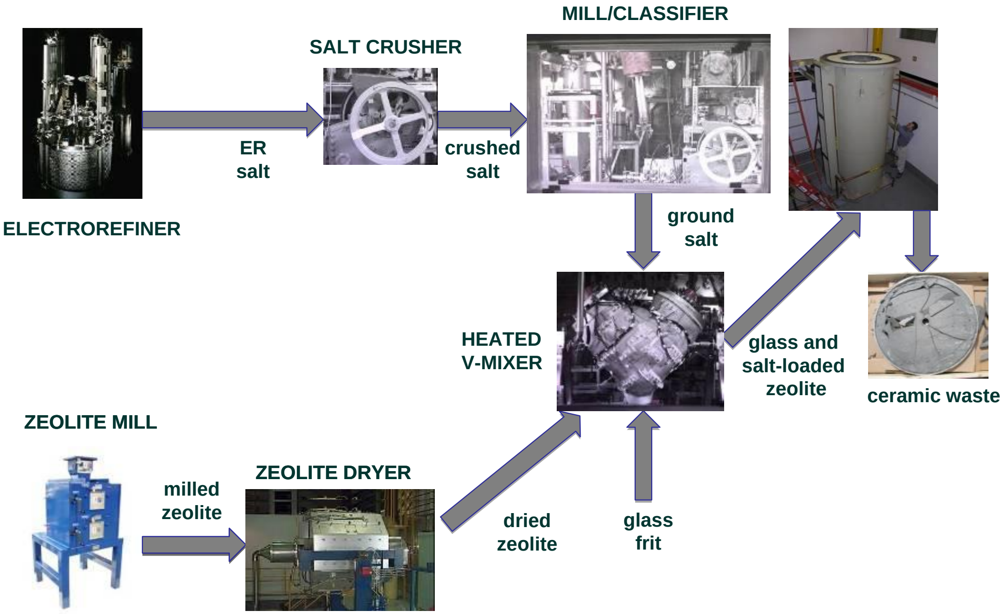
Salt As Waste Separation Media: Electrochemical Refinery (ER)

- Advantages of ER processes over aqueous processes
  - No involvement of complex aqueous chemistry
  - Compacted
  - Collocated with faster reactor
  - Proliferation-resistant: Plutonium is always co-deposited with other actinides.
  - Generating metallic fuel
  - Minimal process waste streams
  - Significant financial benefit



Electrochemical Refinery Salt Waste

Salt	Mark-IV ER	Mark-V ER
LiCl	0.199	0.290
KCl	0.253	0.365
NaCl	0.240	0.156
RbCl	5.02E-03	0.000
$SrCl_2$	1.37E-02	1.80E-04
YCl_3	1.03E-02	1.80E-04
CsCl	3.54E-02	1.02E-03
$BaCl_2$	1.98E-02	7.36E-04
$LaCl_3$	1.80E-02	5.17E-04
$CeCl_3$	3.41E-02	9.59E-04
$PrCl_3$	1.69E-02	4.83E-04
$NdCl_3$	5.78E-02	1.60E-03
$PmCl_3$	3.46E-04	5.21E-06
$SmCl_3$	1.12E-02	4.33E-04
$EuCl_3$	6.93E-04	5.30E-05
$GdCl_3$	3.00E-04	3.92E-05
$NpCl_3$	1.61E-03	1.22E-04
UCl_3	4.68E-02	5.60E-02
$PuCl_3$	3.50E-02	0.126
$AmCl_3$	4.69E-05	4.76E-05



Large equipment

Significant space

Shielded, inert-atmospheric hot cell

Expensive

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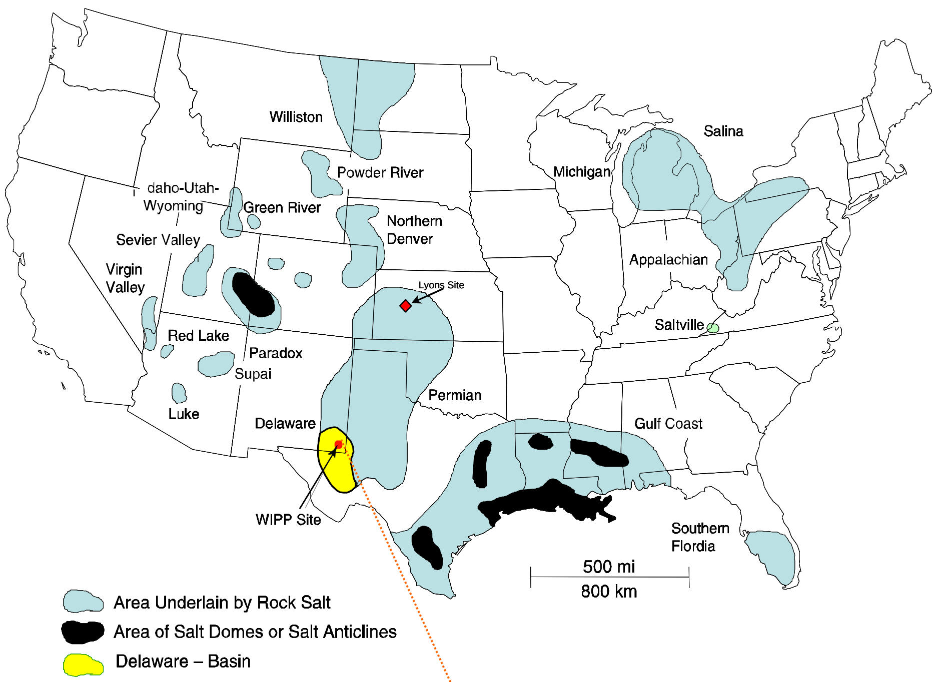
Salt As Disposal Media



- Wide geographic distribution (many potential sites)
- Salt can be mined easily
- Salt has a relatively high thermal conductivity
- Salt is plastic *
- Salt is essentially impermeable *
- Fractures in salt are self healing *
- Salt has existed underground for millions of years *

* Attributes of Natural Barrier

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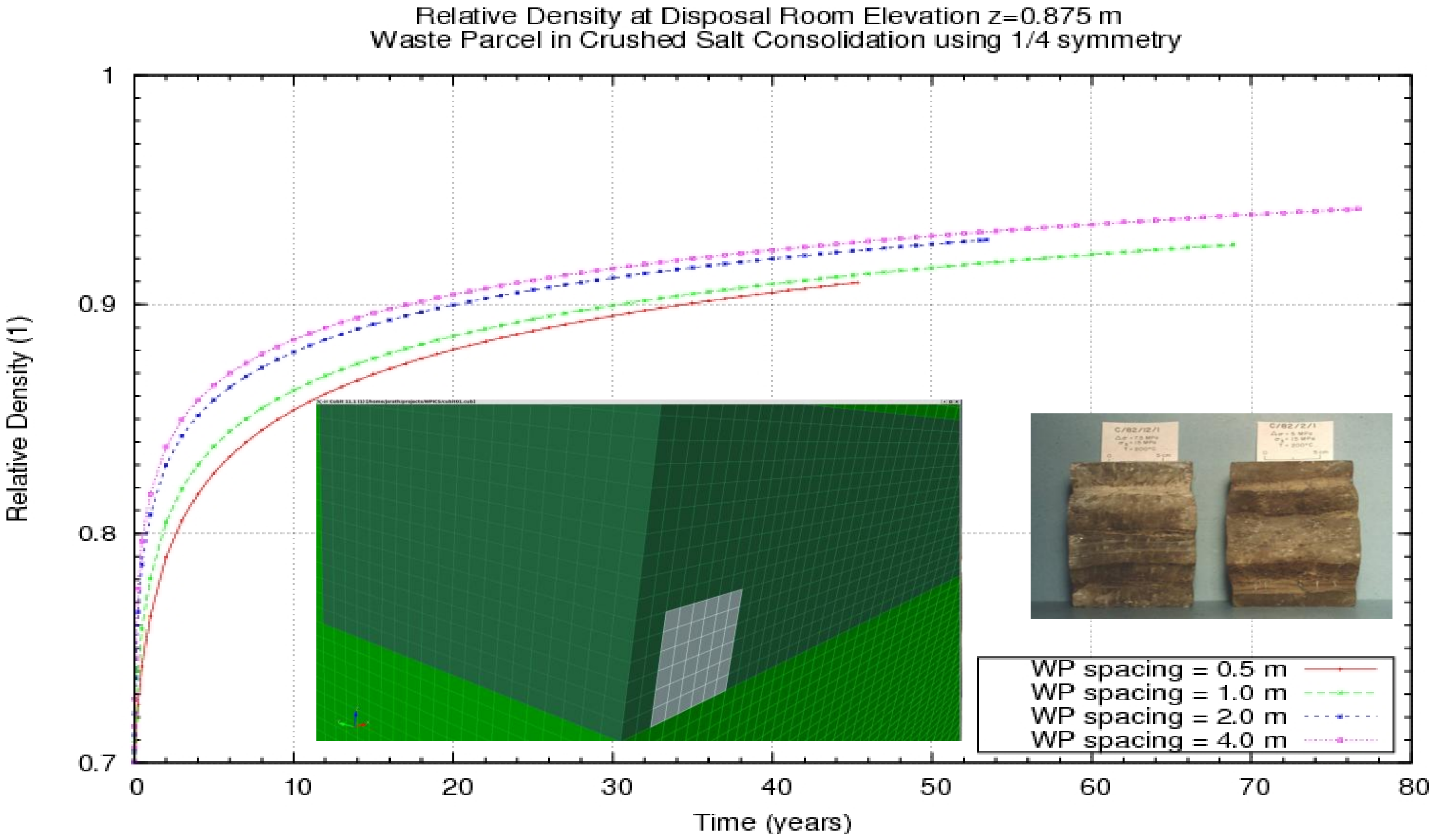
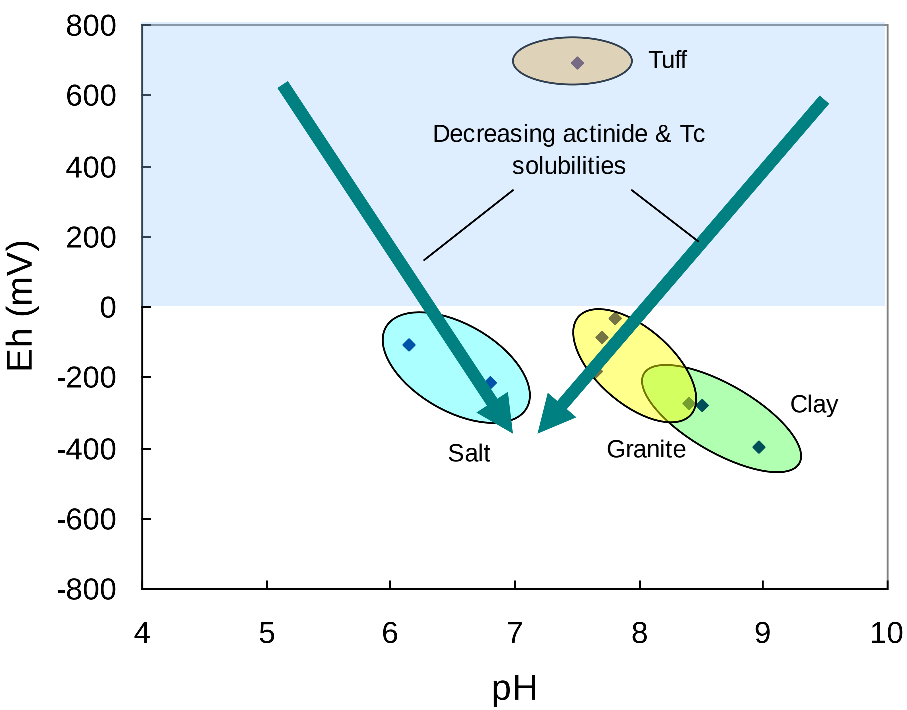
Salt As Disposal Media: Macro-Scale Encapsulation



- Damaged WIPP rock salt heals within 25 hours under hydrostatic stress of 14.48 MPa.
- Beyond a critical waste package spacing (~2 m), individual packages will be effectively isolated from each other.

Salt As Disposal Media: Other Key Characteristics

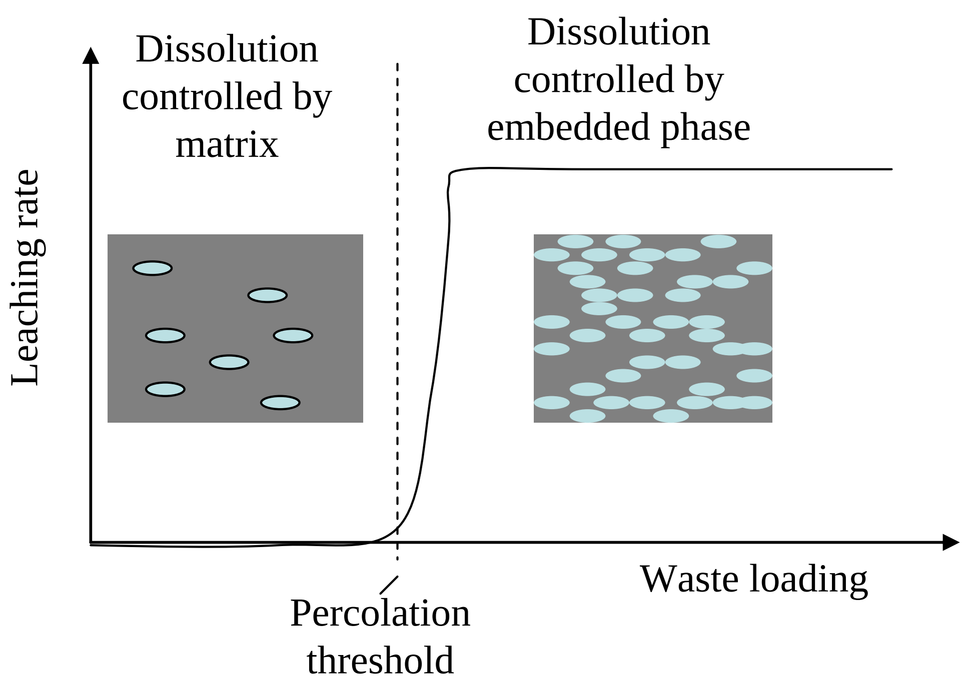


WIPP brineC	G-Seep	ERDA-6
B^{3+} (mM)	20	63
Br^- (mM)	10	11
Ca^{2+} (mM)	20	12
Cl^- (M)	5.35	4.8
K^+ (mM)	770	97
Mg^{2+} (M)	1.44	0.019
Na+ (M)	1.83	4.87
SO_4^{2-} (mM)	40	170
TIC (mM)	10	16
pH	6.5	6.17
Eh (mV)		-152

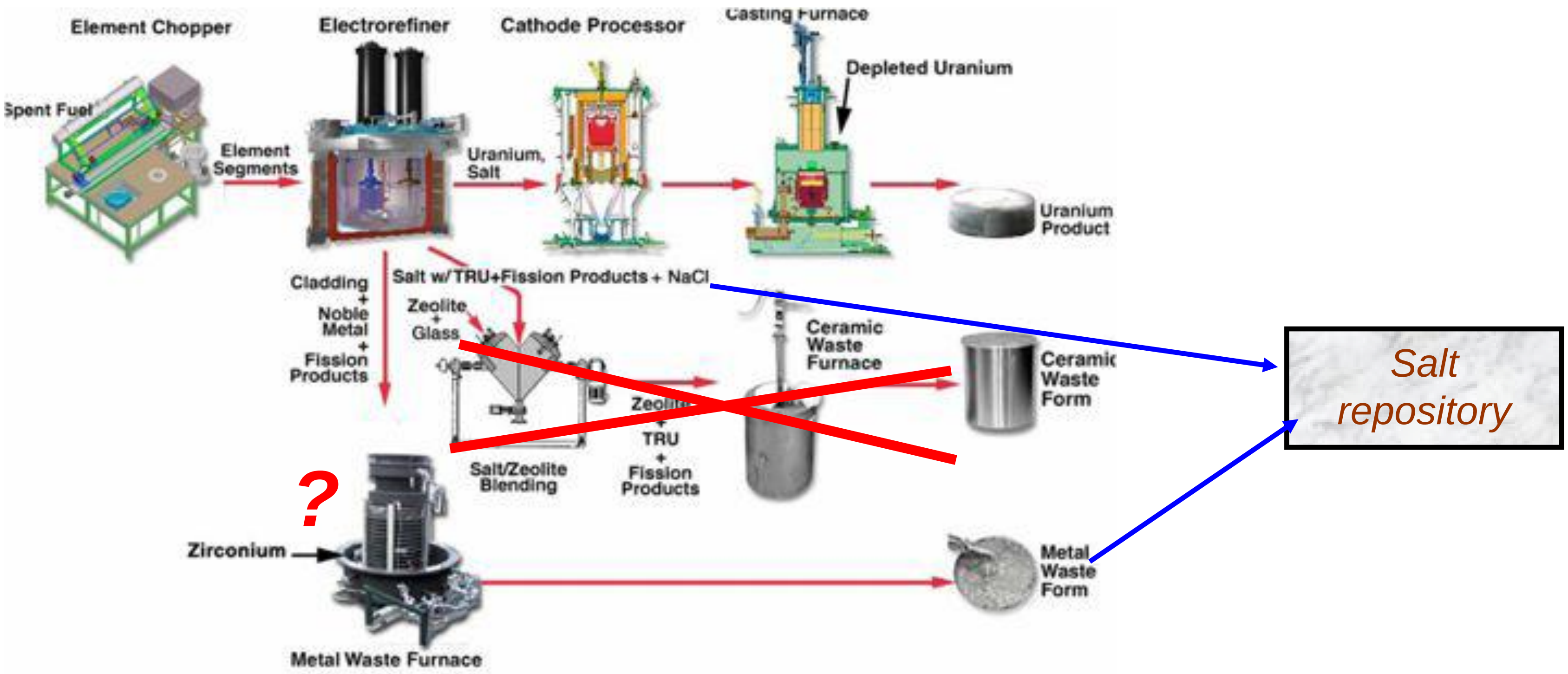
- Porosity: ~1%
- Permeability: <10-21 m2
- Diffusivity: ~10-16m2/s
- Eh: ~ -150 mV
- High ionic strength: colloid suspension unstable

Salt As a Stable Waste Form: Micro-Scale Encapsulation

- Stable waste forms:
  - Fluids in a salt repository already in equilibrium with:
    - halite (NaCl),
    - sylvite (KCl),
    - glaserite [$NaK_3(SO_4)_2$],
    - anhydrite ($CaSO_4$),
    - calcite ($CaCO_3$).
- Enough NaCl+KCl for effective encapsulation?
  - Percolation theory: NaCl+KCl > 70% in volume
  - Typical ER salt waste contains more than 50% of NaCl and KCl in mass fractions.
  - LiCl recycling may be needed.
  - Or add additional NaCl



Simplifying Waste Treatment & Waste Form Development



- The direct disposal concept will practically eliminate all process steps currently proposed for ER salt waste treatment and immobilization.
- The volume of waste for disposal will be significantly reduced.
- No robust waste packages are needed.
- Potentially lead to cost savings.

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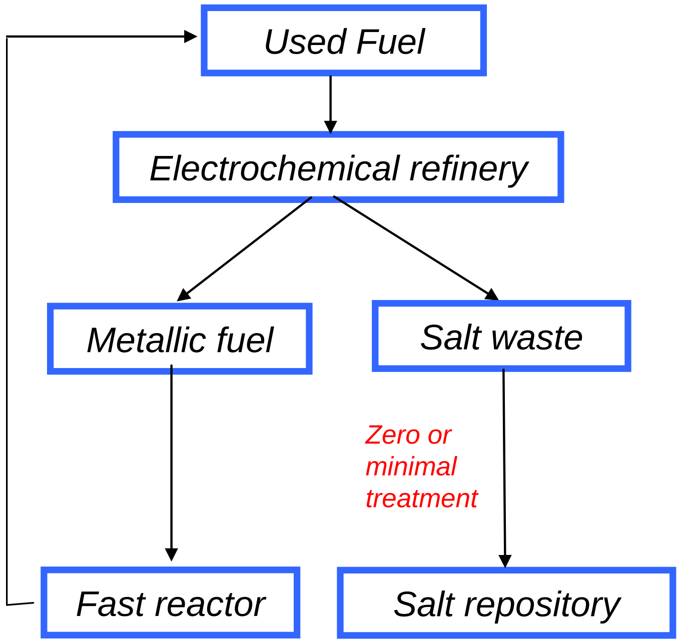
Closing the Fuel Cycle

- Integral Fast Reactor (IFR)
  - The IFR can potentially increase the use efficiency of uranium by a hundred fold.
  - Metallic fuel and liquid-metal sodium coolant are two key features of the IFR concept.
  - ER processes are completely compatible with the IFR.
- Closing the backend of an IFR and ER-based fuel cycle
  - Used fuel wouldl be reprocessed with an ER process.
  - During processing, some of the LiCl in the ER salt would be recycled back to the system.
  - The resulting salt waste would be directly disposed in a salt repository with zero or minimal treatment.
  - Uranium and transuranics would be recovered in a metallic form and then be supplied to metallic fuelled fast reactors for further use.



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Concluding remarks

- The direct disposal concept would essentially eliminate all process steps currently proposed for ER salt waste treatment and waste form development.
- The volume of waste for final disposal would be significantly reduced.
- The direct disposal concept could integrate fast reactor technology, the ER process, and the salt repository into a coherent and efficient fuel cycle.

Acknowledgments

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