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EMT Process Potential for Research Reactor Fuels Post H-Canyon

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NSNFP Strategy Meeting

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Outline for Presentation

- Background on EBR-II and the spent fuel inventory
- Description of electrometallurgical treatment (EMT) technology
- Processing history and current plan for completion
- Different research reactor (RR) fuel types
- Technology needed to adapt EMT to treating RR fuels
- Capacity to treat RR fuels in FCF
- Prospects for expansion of EMT technology to other facilities

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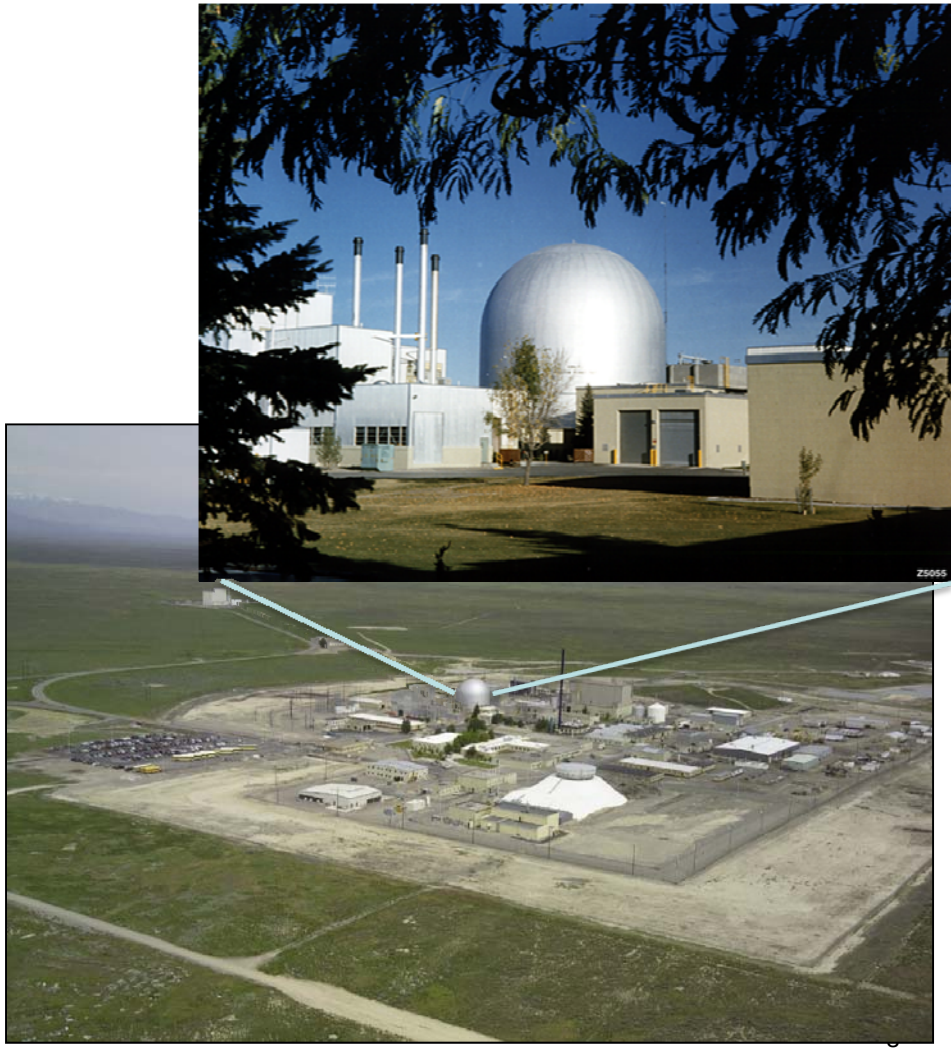
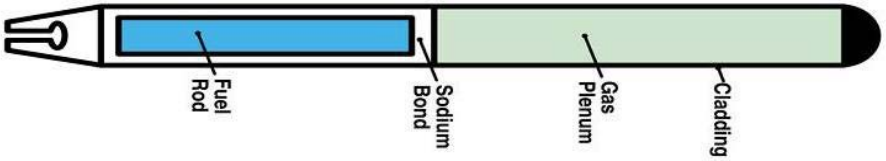
Experimental Breeder Reactor-II

- **Located on Materials and Fuels Complex of Idaho National Laboratory**
- **EBR-II was a metallic-fueled sodium-cooled, fast reactor.**
  - Operated from 1963 to 1995.
  - Uranium-10 wt % zirconium driver fuel.
  - High enrichment driver fuel (67-78%)
  - DU blanket (1% Pu--used for breeding)
  - High burnup (>30 atom %) achieved in some fuel pins.
  - All fuel sodium bonded
- **Demonstration test reactor for EMT-based Integral Fast Reactor System (1984 to 1995).**





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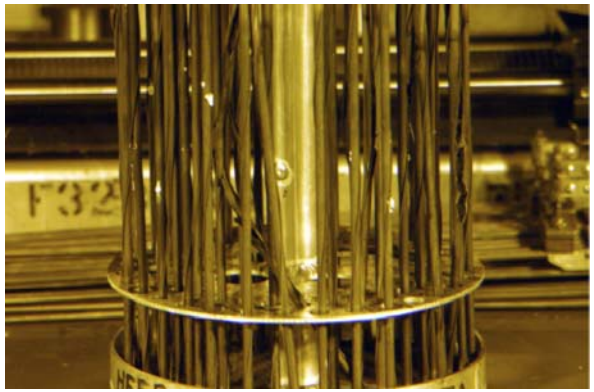
Spent Fuel from EBR-II and FFTF

- **Driver fuel**
  - High enriched U-Zr alloy
  - Sodium bonded
  - 3.1 MT initial quantity
- **Blanket fuel**
  - Depleted U
  - Sodium bonded
  - 22.4 MT initial quantity

Fuel Type	*EBR-II Driver (MTHM)*	*FFTF Driver (MTHM)*	*EBR-II Blanket (MTHM)*	*Total (MTHM)*
Initial Fuel June 1996	*3.1*	*0.25*	*22.4*	*25.75*
Fuel Treated as of October 2009	*0.8*	*0*	*3.2*	*4.0*
Remaining Untreated Fuel	*2.3*	*0.25*	*19.2*	*21.65*

- **Why not direct dispose with commercial fuel in a high level waste repository?**
  - Metallic sodium bonding is highly reactive with water
  - Image to the right shows breached fuel pins recovered from dry storage
  - Blanket fuel has high attractiveness level due to significant Pu concentrations and low fission product content



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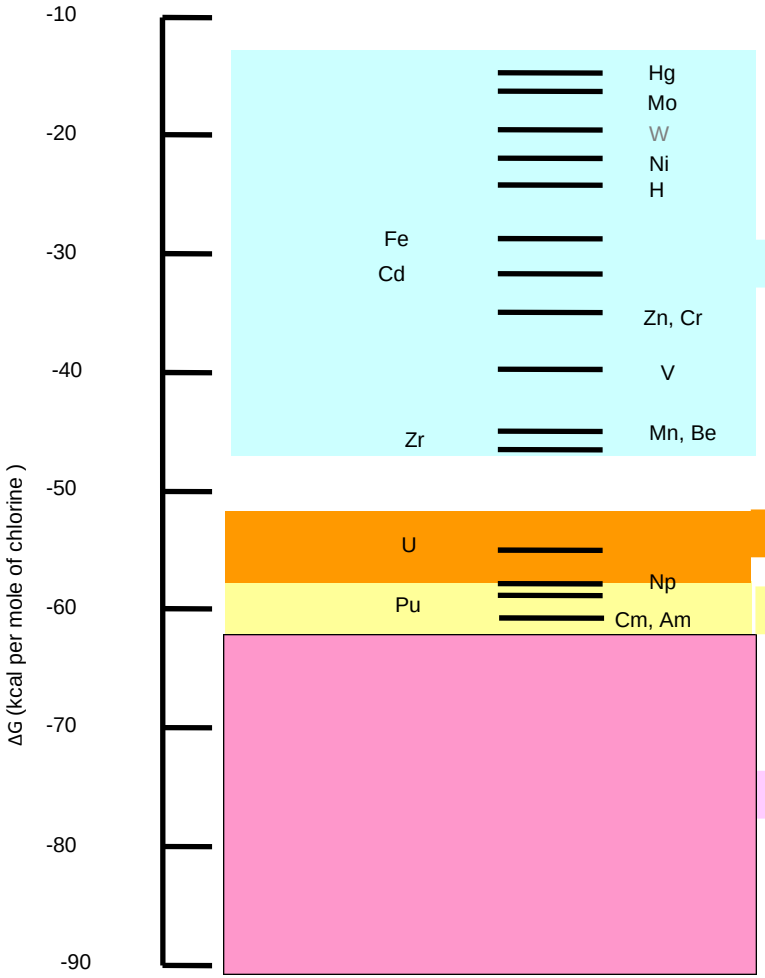
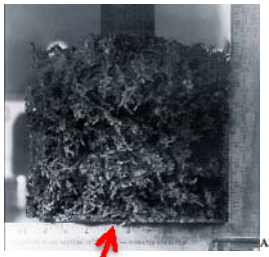
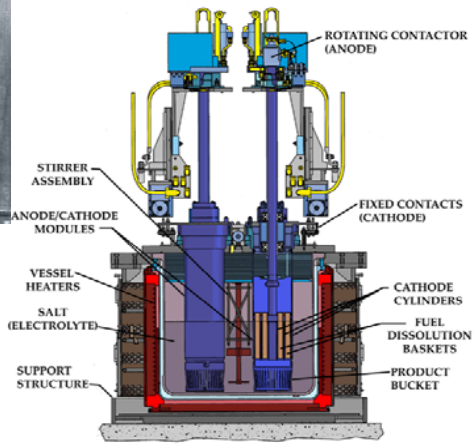
Scientific Basis of EMT Separations: Electrorefining



Retained with cladding materials in the anode basket → metal waste

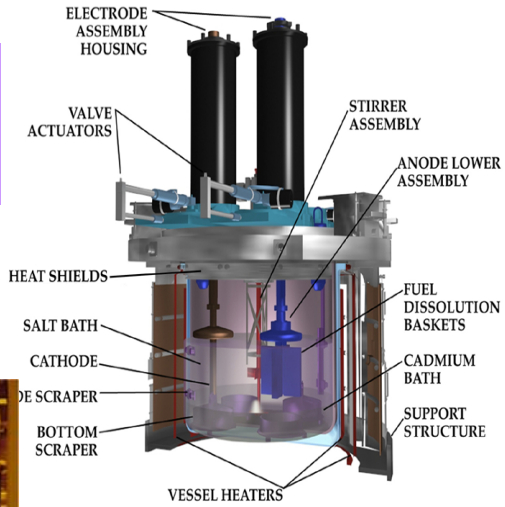




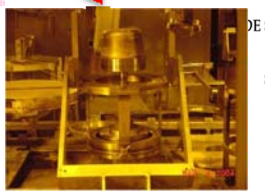
Recovered by a solid cathode as uranium product → fabrication of recycled fuel

Recovered by liquid cadmium cathode together with uranium → fabrication of recycled fuel

External electrical potential is needed



Accumulated in the molten salt → ceramic waste



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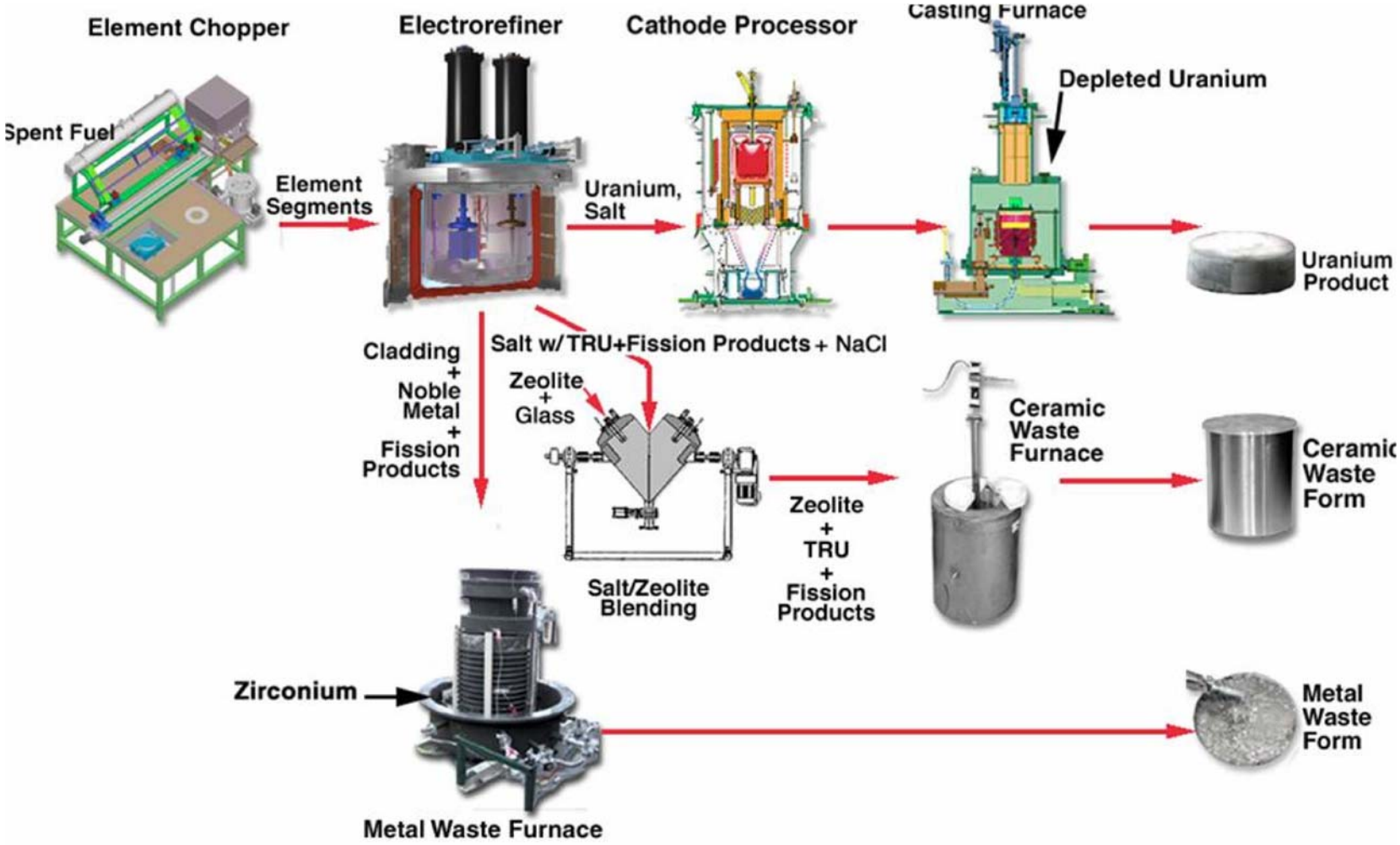
EMT Flowsheet for EBR-II Treatment



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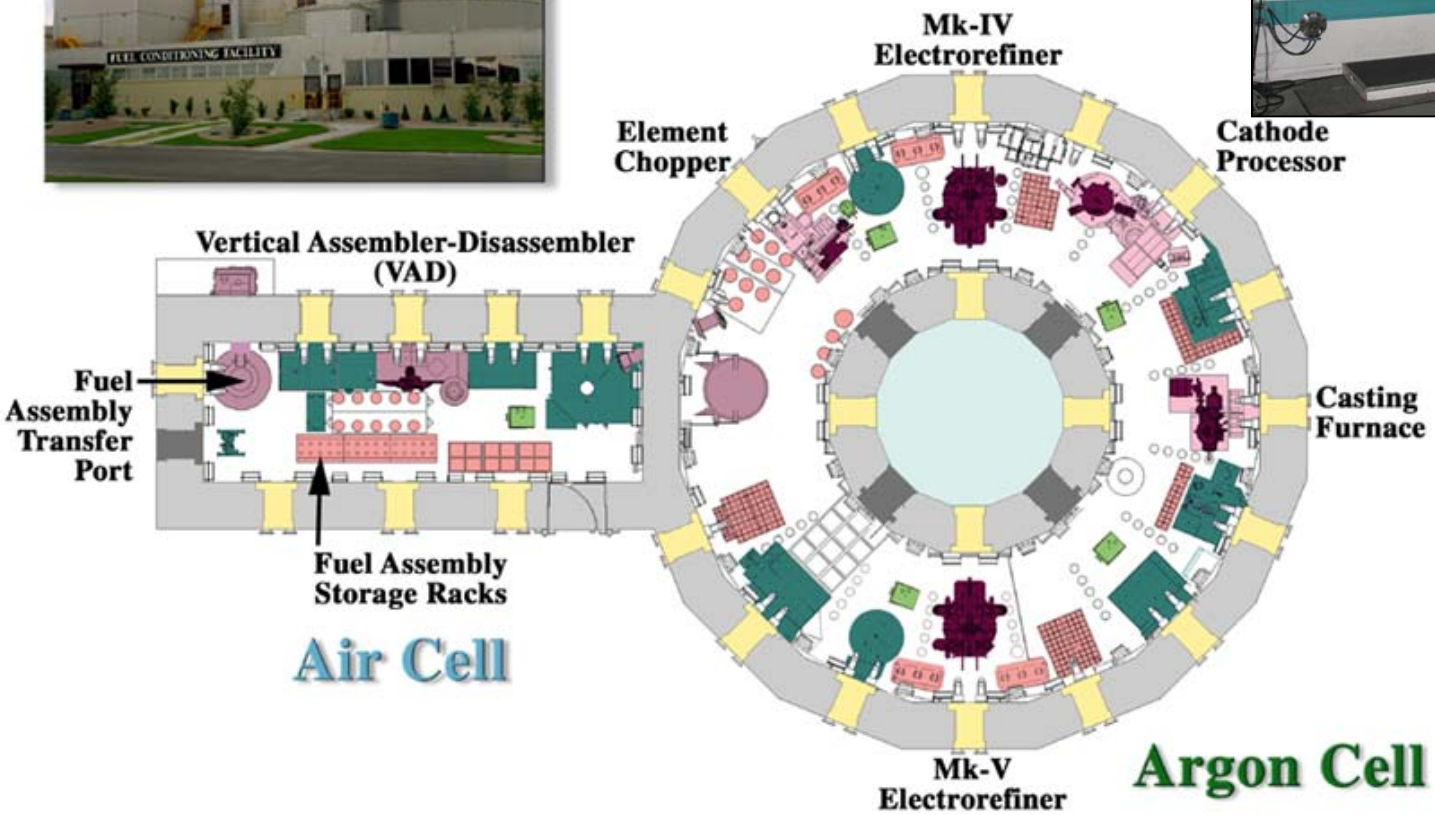
Fuel Conditioning Facility



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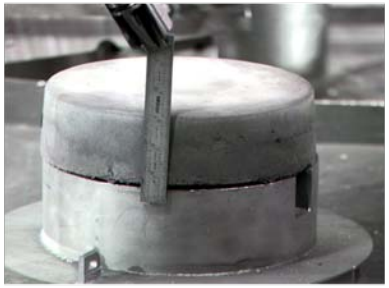
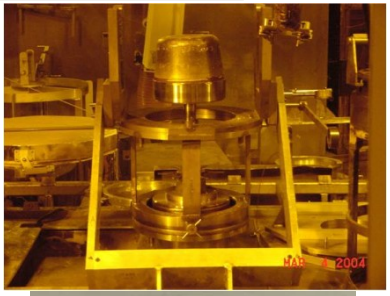
End Products from EMT

- **Uranium metal**
  - Currently downblended with DU and stored at Materials & Fuels Complex
  - May be converted into LWR fuel via oxidation and downblending
- **U/TRU metal**
  - Uses liquid cadmium cathode
  - Recovery testing only with U/TRU returned to ER
  - Disposition path uncertain
- **Ceramic waste**
  - Disposal in high level waste repository
- **Metal waste**
  - Disposal in high level waste repository



U metal



U/TRU metal

Ceramic waste

Metal waste

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Current Plan for Completing EBR-II & FFTF Fuel Treatment

fiscal year	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
FFTF driver		200	50												
EBR-II driver			270	400	400	400	400	400	120						
EBR-II blanket	400								2500	2500	3400	3400	3400	3400	286

- **2035 is deadline for DOE to remove spent fuel from State of Idaho**
- **Various scenarios being considered for when to initiate production operations for ceramic and metal waste**
- **Current plan assumes funding will be received starting next year for transfer of remaining driver fuel to MFC site**
- **Near maximum capacity with 7x24 hr operation**

Material	*Work Shift*	*Max Annual Throughput (kg)*
Blanket	*7-12's*	*1600*
	7-24's	*3400*
Driver	*7-12's*	*240*
	7-24's	*600*

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Domestic Research Reactor Fuels

Fuel Type	Current DRR Inventory (MTHM)	2035 DRR Inventory (MTHM)	Compatible with EMT?
U alloy (Al)	0.70	4.46	Pretreat
U_3Si_2	0.11	0.16	Pretreat
UO_2/UO_3	19.4	21.7	Pretreat
U metal	2.77	2.77	Yes
U-Zr hydride	0.47	0.50	Pretreat

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Pre-Treatment of Non-Metallic Fuels for Eventual Processing via EMT

- **Oxide fuels**
  - Oxide reduction

$$UO_2 \rightarrow U + O_{2(g)}$$

- **Aluminum alloy fuels**
  - Chlorination of aluminum

$$UAl + 3Cl_2 \rightarrow UCl_3 + AlCl_{3(g)}$$

- **Silicide fuels**
  - Chlorination of Si

$$U_3Si_2 + 8.5Cl_{2(g)} \rightarrow 3UCl_3 + 2SiCl_{4(g)}$$

- **Hydride fuels**
  - Oxidation
  - Oxide reduction

$$UH_3 + 1.5O_{2(g)} \rightarrow UO_2 + 1.5H_2O_{(g)}$$

$$UO_2 \rightarrow U + O_{2(g)}$$

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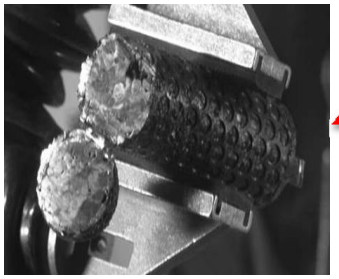
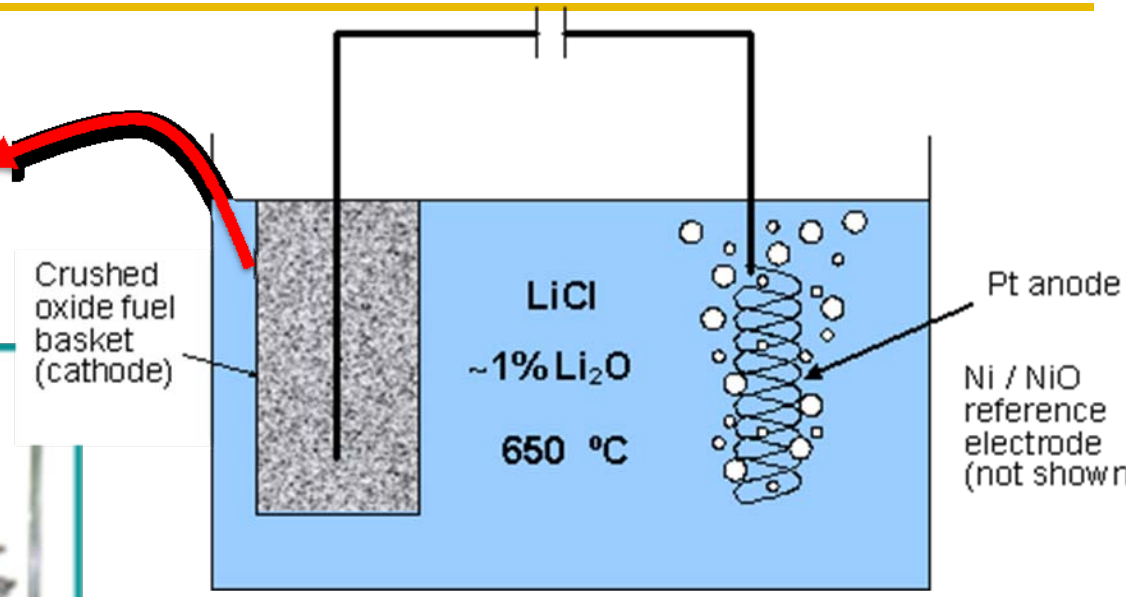
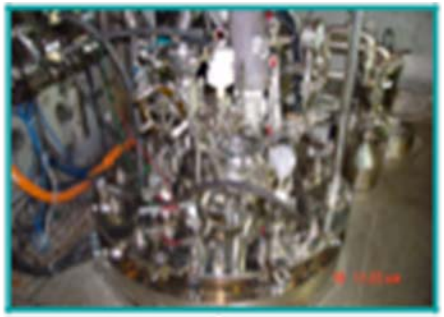
Electrolytic Oxide Reduction







Primary reactions

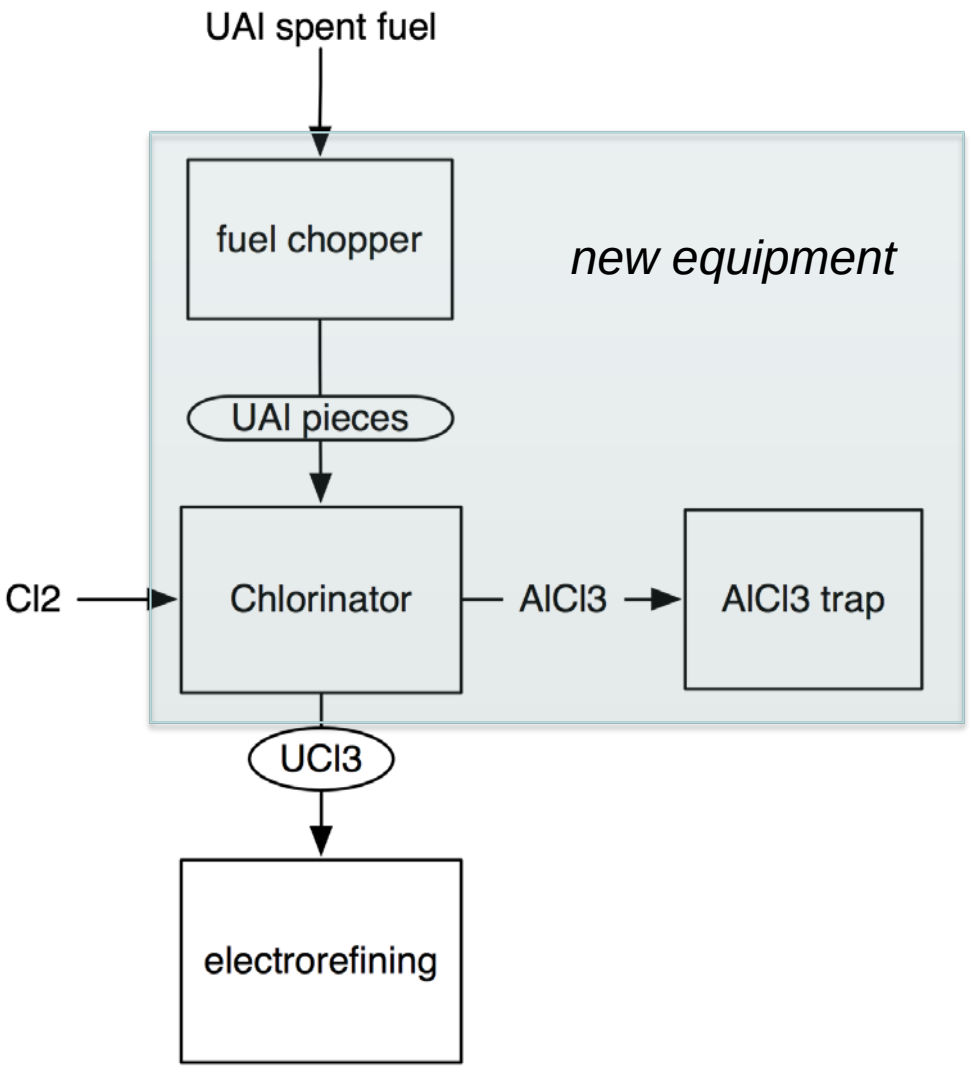
Cathode: $UO_2 + 4e^- \rightarrow U + 2\ O^{2-}$

Anode: $2\ O^{2-} \rightarrow O_2(g) + 4e^-$

Net: $UO_2 \rightarrow U + O_2(g)$

Chlorination of U-Al Alloy

- ATR fuel can hypothetically be treated with this process
- Reference Malmbeck et. al. (Global 2007)
- Chlorinate at 150 C to avoid formation of gaseous U chlorides
- Actinide chlorides can be directly added to the ER salt
- Similar process will likely work with silicide fuel



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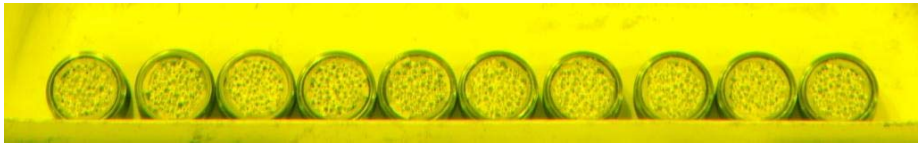
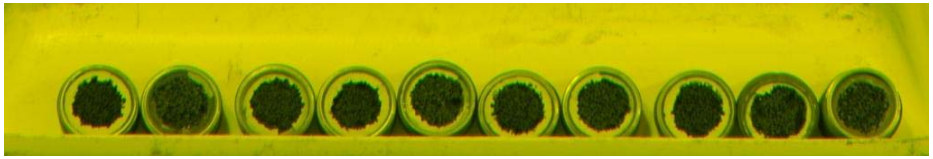
Oxidation Process

- Similar to voloxidation technology that has been developed for decladding UO_2 and reducing its particle size.
- Oxidation occurs at 600 C
- Off-gas from fuel includes Cs, I, Tc, Rb. Must be captured using series of traps.





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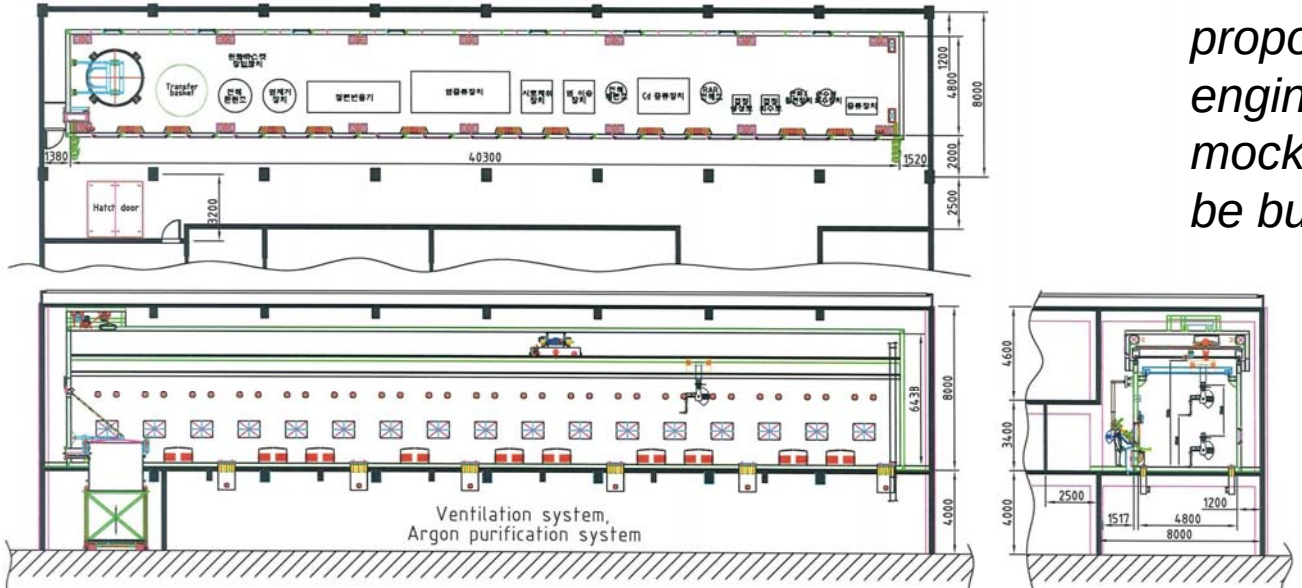
Additional Production Capacity in FCF

- **With its current commitments, FCF should be considered as**
  - Test bed for adaptation of EMT technology for research reactor fuels
  - Production facility for very limited quantities of RR fuel
  - May accommodate miscellaneous commercial oxide fuel samples and U-Al from ATR

Fuel Type	Current DRR Inventory (MTHM)	2035 DRR Inventory (MTHM)	Treat in FCF?
U alloy (Al)	0.70	4.46	Limited
U_3Si_2	0.11	0.16	Yes
UO_2/UO_3	19.4	21.7	Very Limited
U metal	2.77	2.77	Yes
U-Zr hydride	0.47	0.50	Yes

Expansion of EMT Process Technology Implementation

- General Electric-Hitachi has a high level of interest in using EMT to reprocess off-spec LWR oxide fuel at Wilmington, NC site. Technology development proposal was drafted.
- Republic of Korea intends to commercialize EMT for processing spent fuel from their commercial reactors. Potential exists to jointly develop a new EMT facility on U.S. soil with partial financial support from ROK. Diplomatic issues pending.
- Potential partnership between GE-H, ROK, and DOE?



proposed design for engineering-scale mock-up facility to be built in ROK