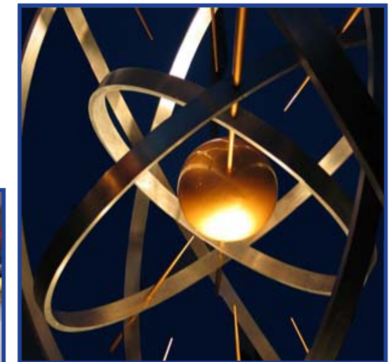
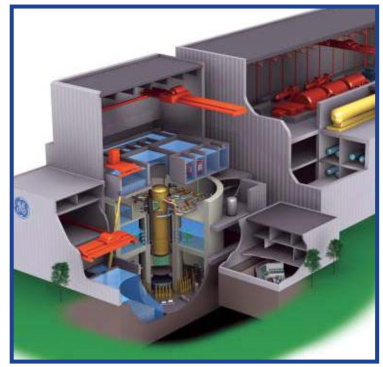
RECYCLE IN FAST REACTORS



U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD MEETING



SEPTEMBER 23, 2009
NATIONAL HARBOR, MARYLAND

Eric P. Loewen, Ph.D.
GE Hitachi Nuclear Energy Americas LLC

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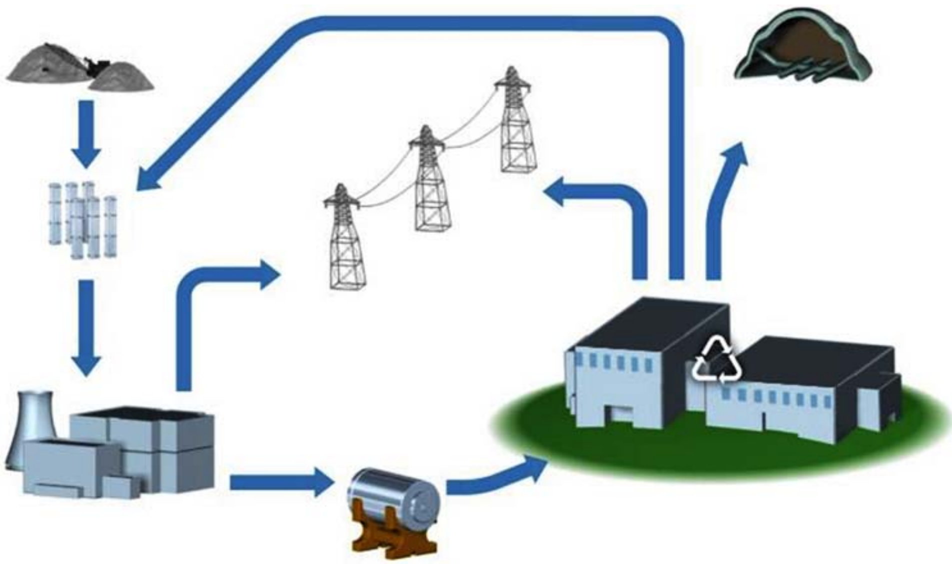
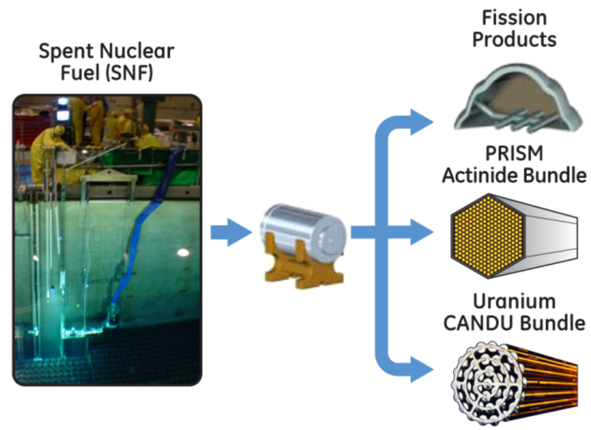
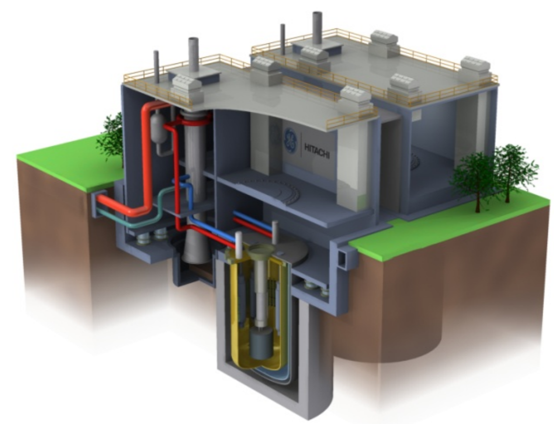
GEH's Advanced Recycling Center fully closes the nuclear fuel cycle





NFRC - Electrometallurgical



ARR - PRISM Power Block

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Recycling Separations: Electrometallurgical

✓ **NAS Committee Findings**

- No technical barriers for electrometallurgical processing of EBR-II fuel
- DOE should seriously consider continued development as an option to aqueous treatment of uranium oxide spent nuclear fuel

✓ **Prudent starting point**

- Domestic solution available today

1964-1969 Melt Refining
- **AEC Funded**
- Innovative design approaches

1984 IFR Program
- **DOE funded**
- Prove metal fuel performance

~ 1990 Japan
- **Japanese Support**
- Contributed $40M
- Committed $60M
- Contributed $6M for LWR oxide reduction

1989-1995 IFR Ends
- **Program Terminated**
- EBR-II shut down
- EBR-II 30 years of successful operation

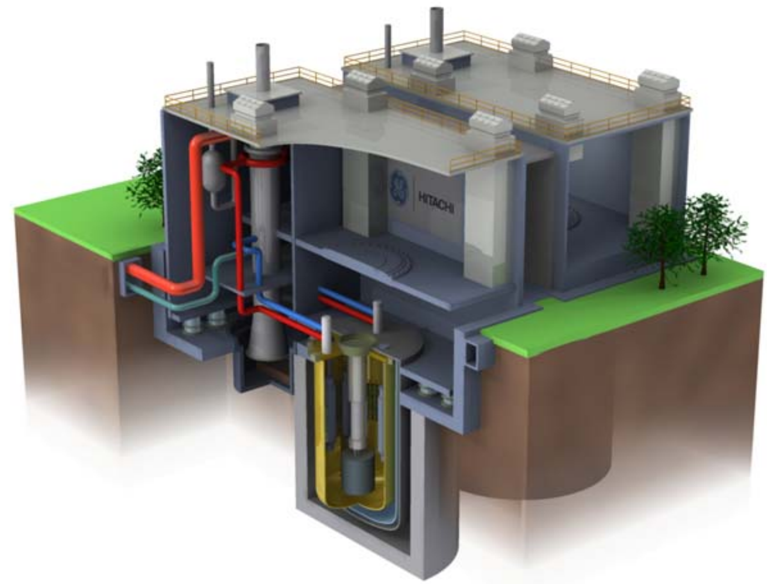
1995-1999 EBR-II Fuel
- **EBR-II Fuel Treatment**
- Requires treatment
  - Enrichment
  - Na bond
  - Pyrophoric
  - RCRA
- DOE ROD
- NAS review

2007-2009 GNEP
- EIS completed
- Processing EBR-II fuel currently
- 3T processed
- Best practices

Recycling Reactor: PRISM

✓ Advanced Conceptual Design
- Already paid for by US government
- Available today

✓ NRC "…no obvious impediments to licensing…"
- Prudent starting point



1981-1984 GE Program
- **GE funded**
- Innovative design approaches

1985-1987 PRISM
- **DOE funded $30M**
- Competitive LMR concepts

1988 PRDA
- **DOE funded $5M**
- Continuing trade studies

1989-1995 ALMR
- **DOE funded $42M**
- Preliminary design
- Regulatory review
- Economics
- Utility advisory board
- Commercialization
- Tech development ($107M additional)

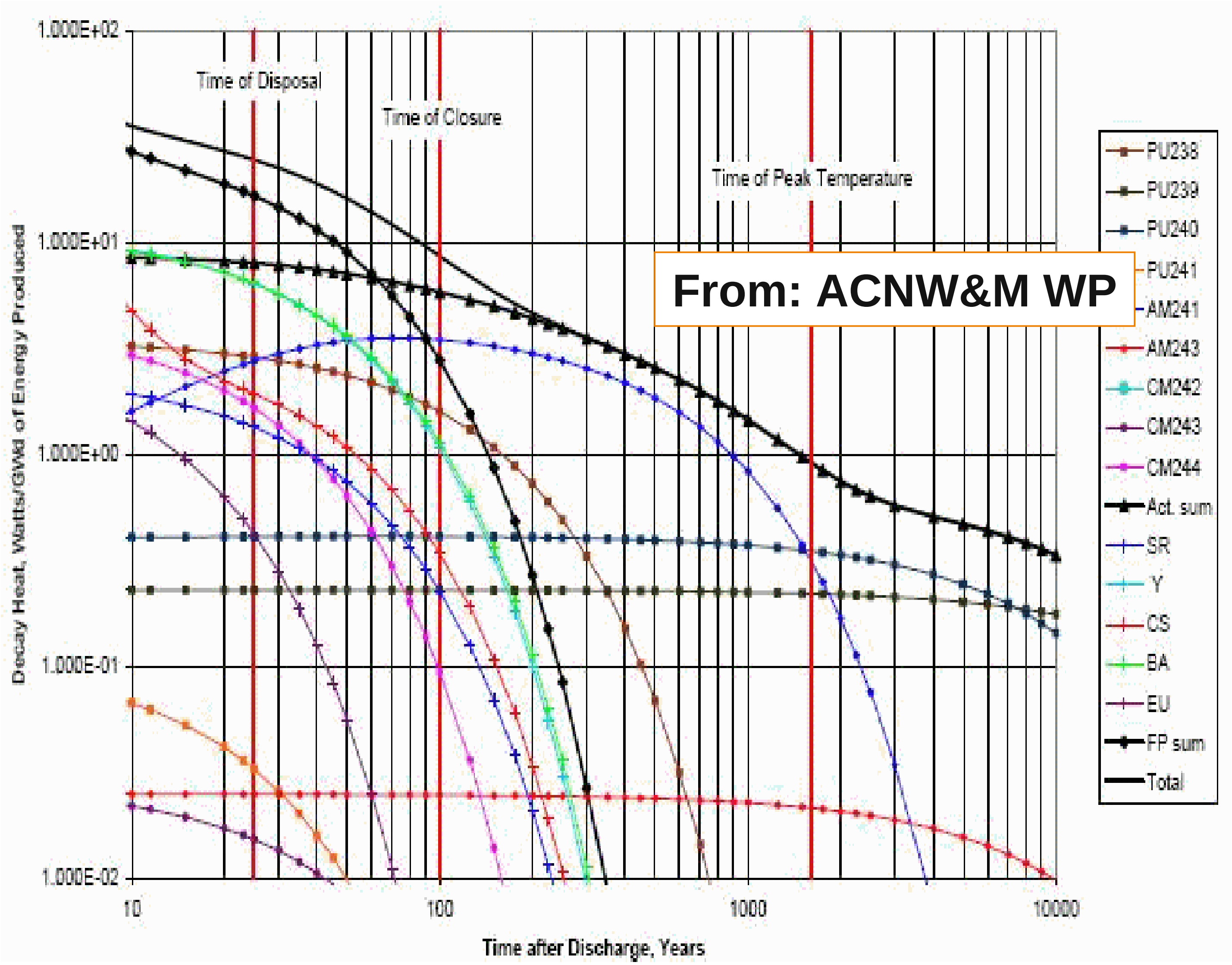
1995-2002 S-PRISM
- **GE Funded**
- Improved economics
- Actinide burning scenarios

2007-2009 GNEP
- Demo reactor
- Actinide burning
- Commercial
- Best practices
- Advanced power conversion cycle

Why is GEH pursuing electrometallurgical separations?

- ✓ Environment
- ✓ Economics
- ✓ Engineering Safeguards
- ✓ NAS Endorsement

Heat load is important … Environment



Why the dry process?

… Environment

Electrometallurgical Process

- ✓ Simple to build and operate
- ✓ U and TRU separation based on electro-chemical potential – no pure Pu
- ✓ Shorter half life and heat in waste
- ✓ Achieves economies of scale through modularity and duplication
- ✓ Nth of kind produces positive cash flow when combined with PRISM

Fuel Cycle Facility for 1,400 MWe Fast Reactor … Economics

	Pyroprocessing	Aqueous Processing
Size and Commodities		
building volume, ft^3	852,500	5,314,000
volume of process cells, ft^3	41,260	424,300
high density concrete, cy	133	3,000
normal density concrete, cy	7,970	35-40,000
Capital Cost, $million (1986$)		
facility and construction	62.6	178.6
equipment systems	29.8	298.6
Total	**92.4***	**477.2****

**ANL-AFR-25 report*
***ORNL/TM-9840*

Old reports but the ratio is important

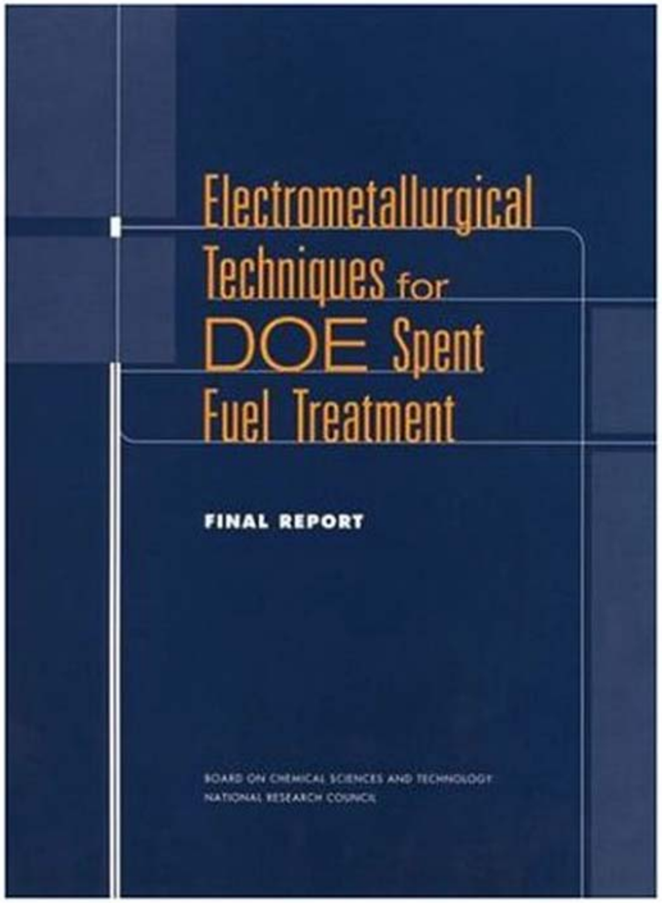
Weapons Usability Comparison
… Engineered Safeguards

	Weapon Grade Pu	Reactor Grade Pu	PRISM Grade Actinide
Production	Low burnup PUREX	High burnup PUREX	Fast reactor pyroprocess
Composition	Pure Pu 94% Pu-239	Pure Pu 65% Pu-fissile	Pu + MA + U 50% Pu-fissile
Thermal power W/kg	2 - 3	5 - 10	80 - 100
Spontaneous neutrons, n/s/g	60	200	300,000
Gamma radiation r/hr at ½ m	0.2	0.2	200

*Provided by ANL

National Academy of Science

Started in 1994 w/ 10 reports



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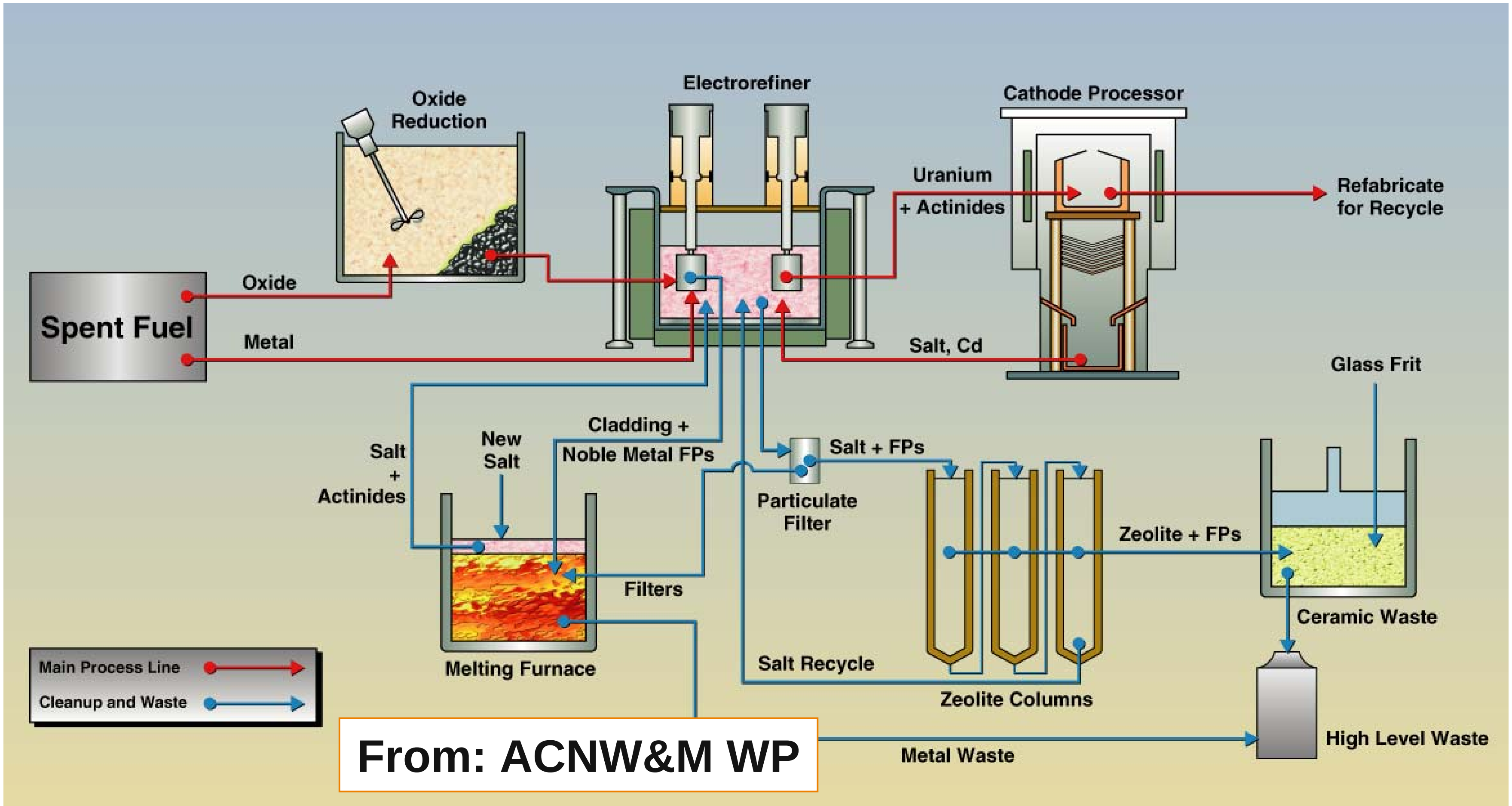
Finding: The committee finds that ANL has met all of the criteria developed for judging the success of its electrometallurgical demonstration project.

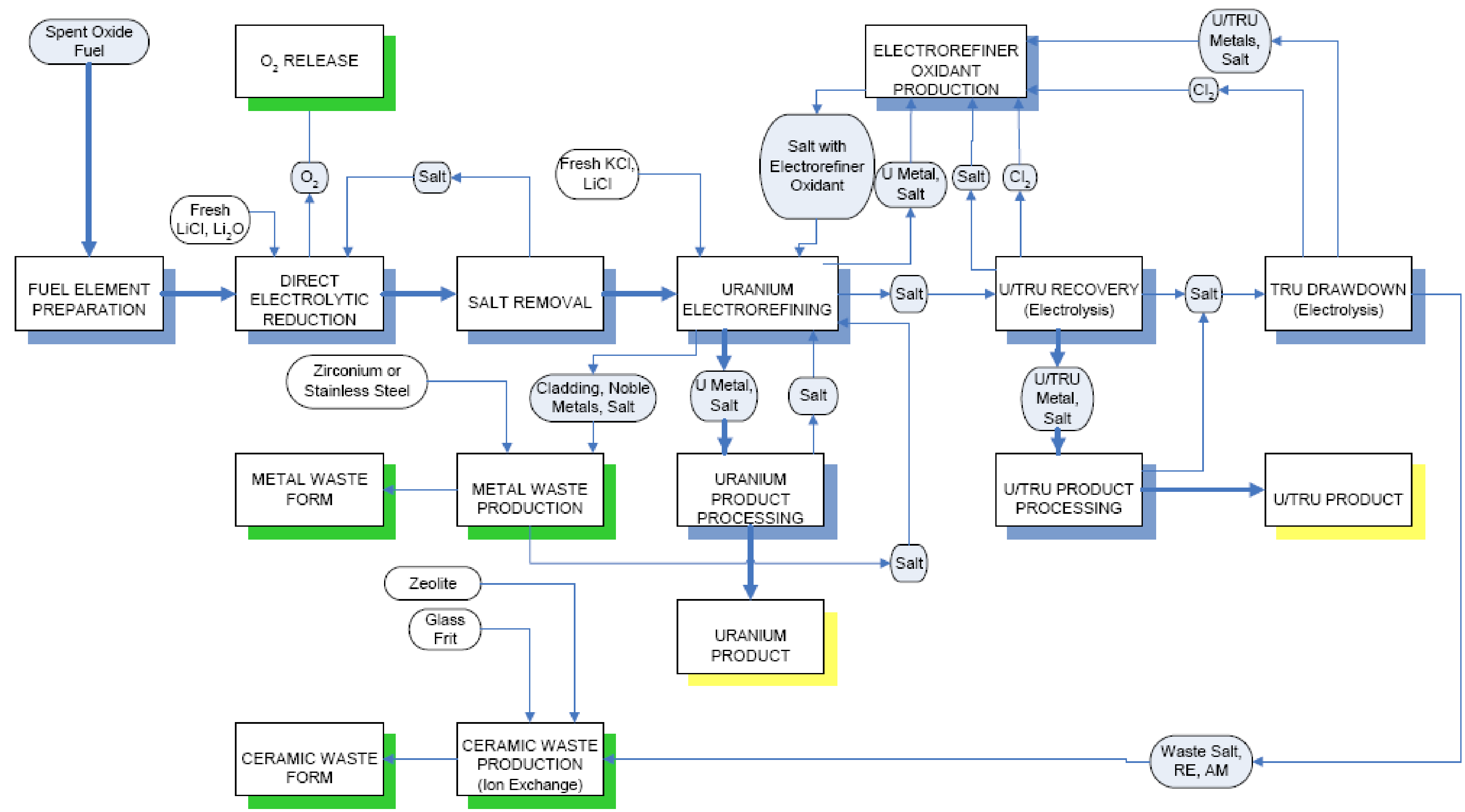
Finding: The committee finds no technical barriers to the use of electrometallurgical technology to process the remainder of the EBR-II fuel.

Recommendation: If the DOE wants an additional option besides PUREX for treating uranium oxide spent nuclear fuel, it should seriously consider continued development and implementation of the lithium reduction step as a head-end process to EMT.

The ALMR pyroprocessing flowsheet



GEH's oxide fuel processing flowsheet



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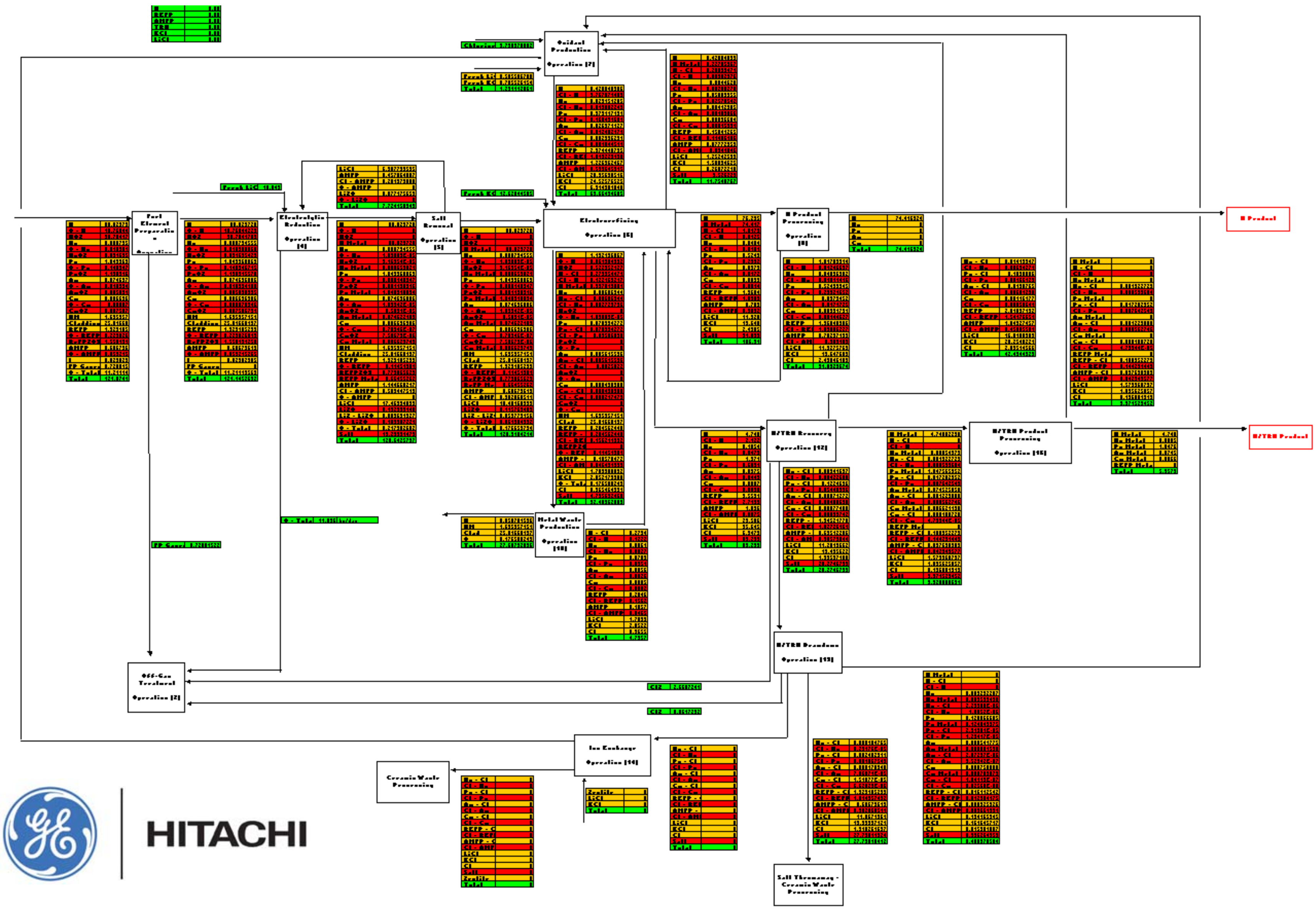
GEH's oxide fuel mass balance model



GEH's oxide fuel mass balance model

- Purpose of Model
  - Quantify the affect of varying process unit parameters on throughput and downstream processes
  - Quantify waste package generation
  - Identify key process parameters to control the minimization of waste generation

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1. What is the estimated mass of waste that must be disposed on per MTIHM processed in each of the following categories? What is the proposed disposition or management path for each type?
   a. Vitrified high-level waste
   b. Low-level waste including non-recycled uranium
   c. Intermediate-level or Greater-than-Class C waste
   d. Plant decontamination and decommissioning waste

Waste answers

1. Mass per MTIHM & disposition path?

a. Vitrified high-level waste
  - *Ceramic waste 0.5 - 0.8 MTIHM*

b. Low-level waste including non-recycled uranium
  - *Excess uranium to PTHWR market or PRISM*
  - *Low Level Waste – TBD, however considered to be small due to the dry process in inert hot cell*

c. Intermediate-level or greater than class C waste
  - *TBD, however considered to be small due to the dry process in inert hot cell*

d. Plant decontamination and decommissioning waste
  - *NRC licensing needed to better quantify this number as this is driven by building requirements.*

2. What, if any, are the additional waste management process requirements for recovering and disposing of

   a. 85Kr and 14C gases?

   b. Separate handling of 99Tc, Cs, and Sr?

   c. Separate removal of 241Am and Cm?

a. Recovery and disposal of 85Kr and 14C gases?

- The need to capture and store these gases needs a risk-based evaluation.
- Inert atmosphere cells lead to better capture efficiency.
- Kr can be capture cryogenically if capture is required.

b. Separate handling of 99Tc, Cs, and Sr?

Metallic

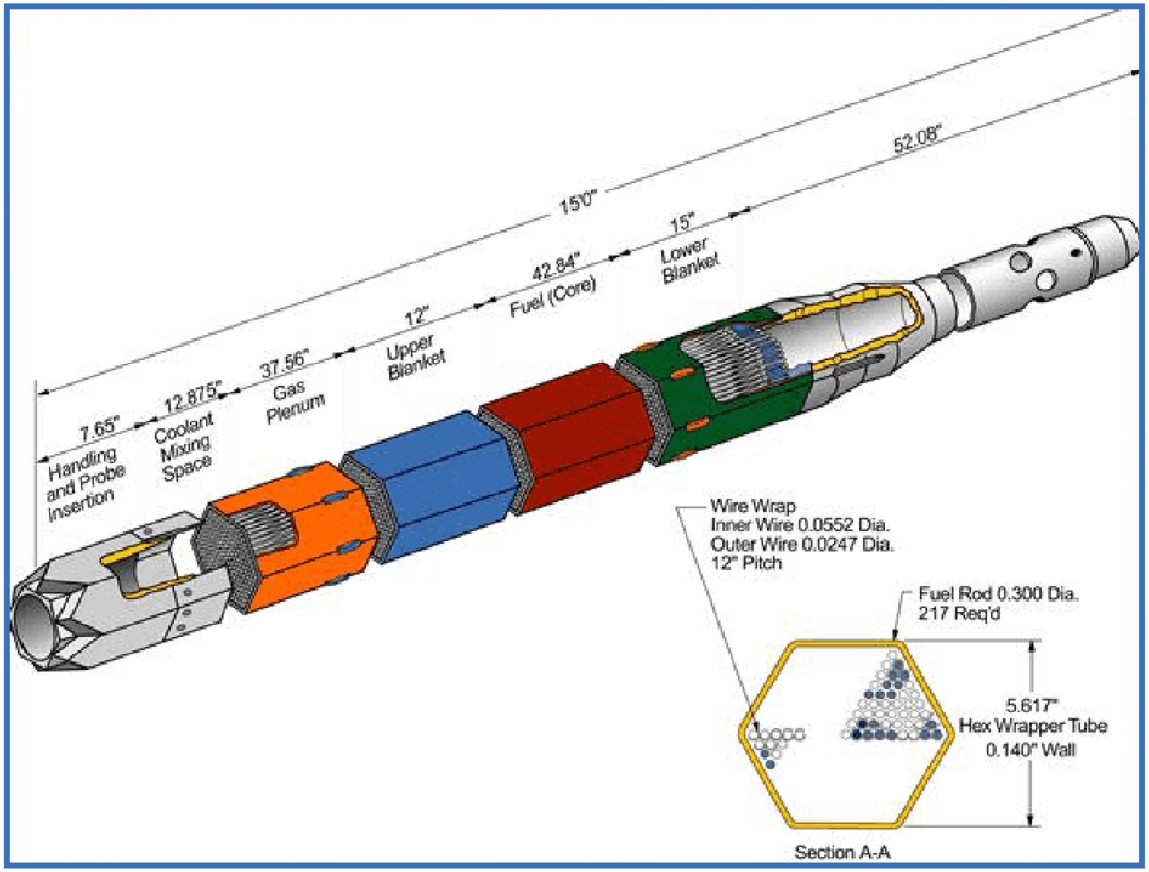
99Tc is in the metal waste form

Ceramic

Cs and Sr are in the ceramic waste form

c. Separate removal of 241Am and Cm?

No, it is loaded into fuel and fissioned



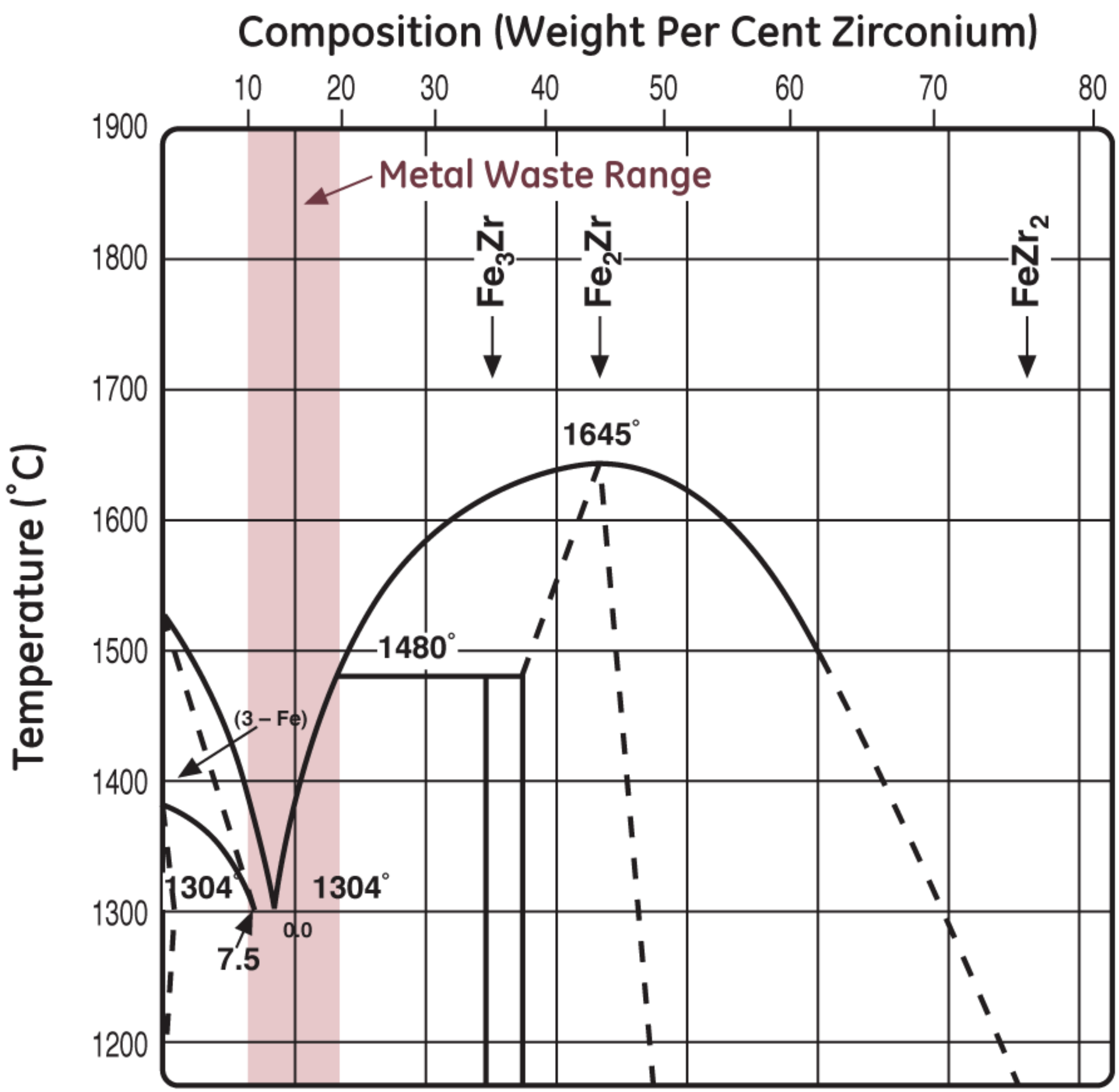
Electrometallurgical Waste Streams

- Rare earth, alkaline earth and alkali fission products form stable chlorides that remain in the salt phase and process into a ceramic waste form.
- Noble metal fission products remain in the anode process basket and are processed into a metal waste form along with cladding hulls.
- Only actinides are subject to electro-chemical transport, but minimal rare earth fission products may also get deposited along with the actinides.

Metal Waste Form

- Following electrorefining, the anode basket that contains stainless cladding hulls, fuel matrix alloy zirconium, noble metal fission products (including technetium), and adhering salt is heated in the metal waste form furnace to distill the adhering salt, and then heated to a higher temperature to consolidate the metal waste form.
- PRISM: The base alloy for metal waste will be stainless steel with zirconium concentration in the range of 5-20% to form a low melting eutectic.
- LWRs: The base alloy will be zirconium with about 15% iron, which forms even lower temperature eutectic on the other side of the Fe-Zr phase diagram.

Metal Waste Form

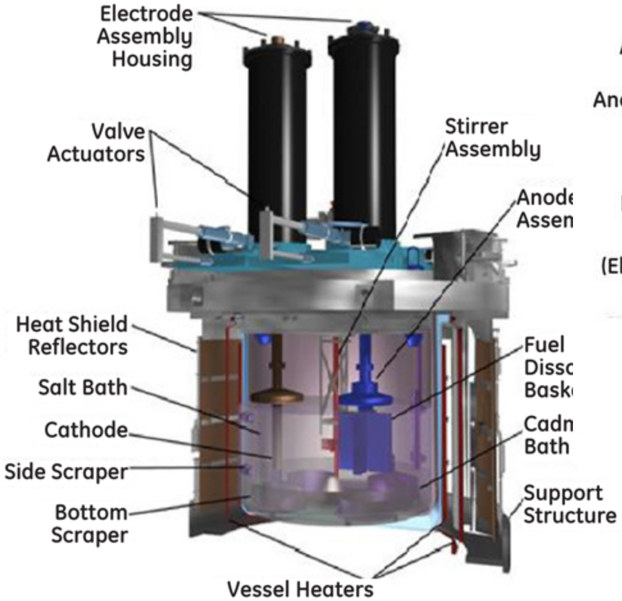


Ceramic Waste Form

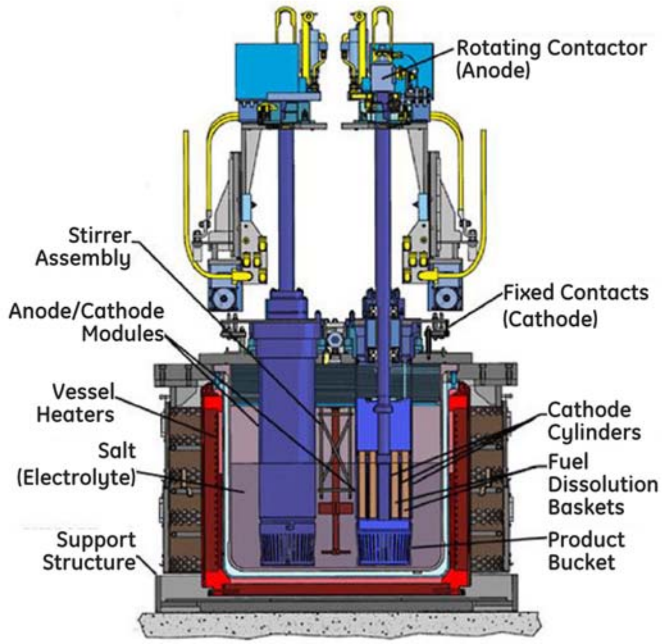
- Most of the fission products, other than noble metals, accumulate in the salt phase. When saturated, salt is contacted with zeolite.
- Fission product cations are adsorbed onto zeolite by ion exchange or occluded into molecular cages of zeolite structure.
- Zeolite, with fission products immobilized, is consolidated into a monolithic form by sintering at high temperatures combined with borosilicate glass as binder to form the ceramic waste form.
- At these high temperatures, zeolite is converted into sodalite, a stable, naturally occurring mineral.

3. What, if any, are the technical constraints limiting the capacity or throughput of the proposed facilities? What factors cause those constraints?

Scale-up Issues



Mark IV



Mark V

Commercial Deployment

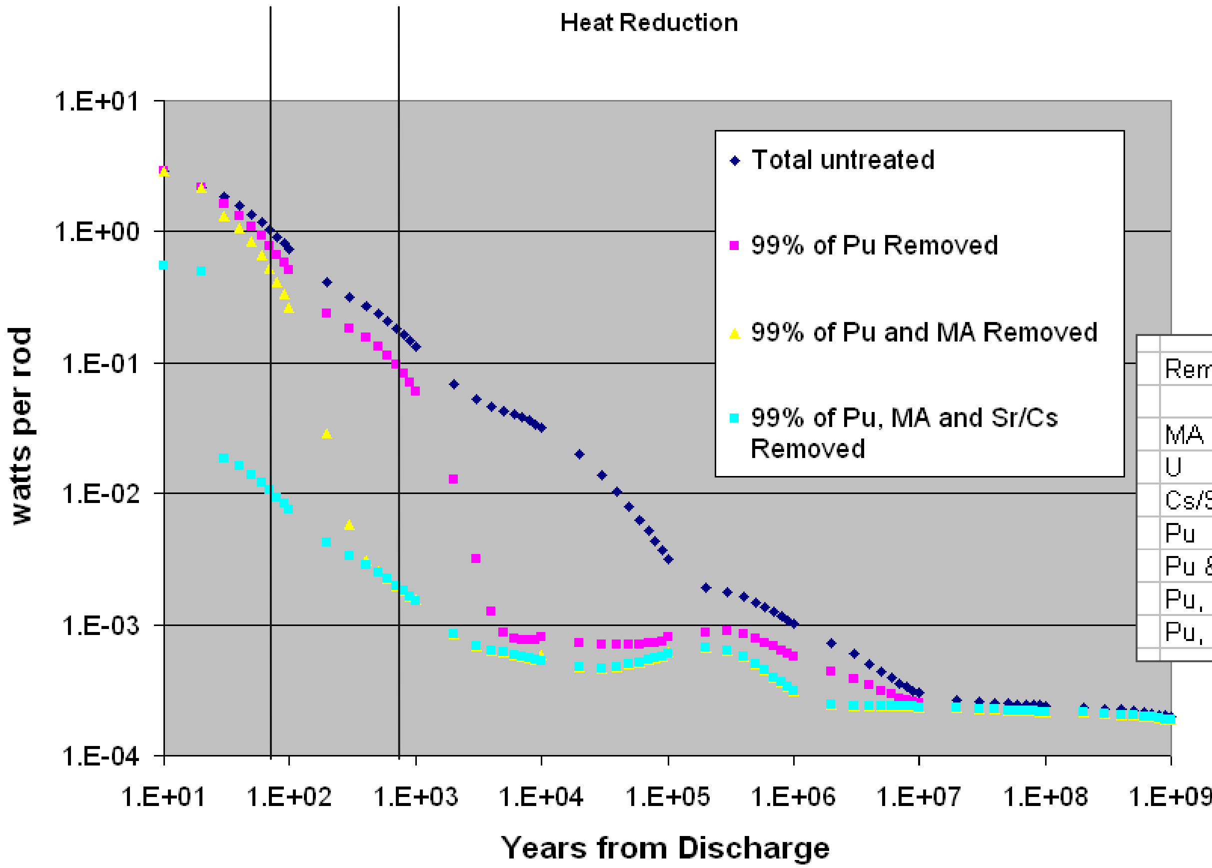
Process scales on:

✓surface area

✓current density

4. What, if any, are the projected improvements in repository performance (radiation dose at the hypothetical site boundary) associated with actinide removal? What, if any, are the projected repository capacity improvements associated with actinide removal? What analyses support answers to these?
5. What are the appropriate metrics/measures that might be used to compare alternative technical approaches in terms of their implications for waste management? Why?

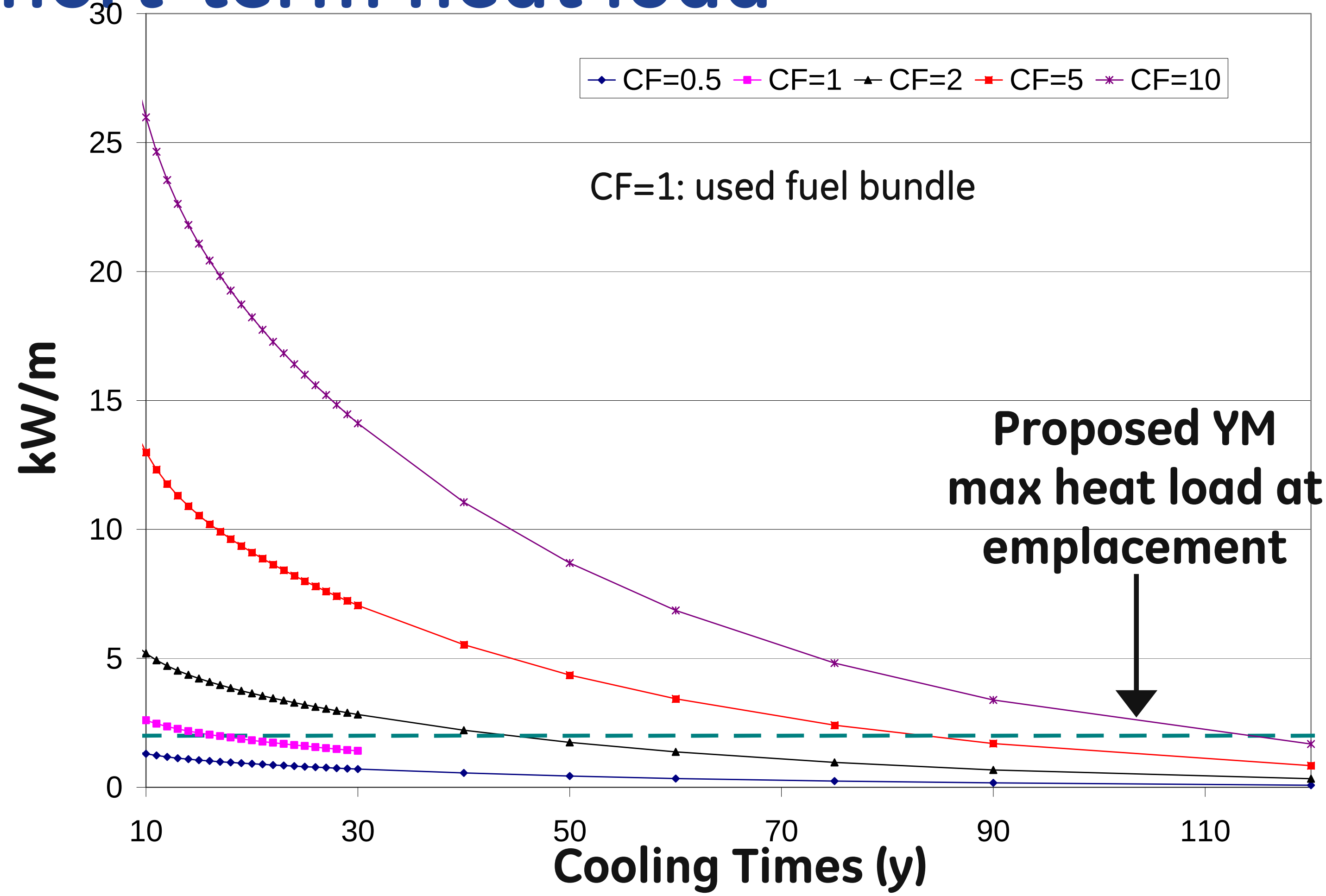
Transuranic removal is necessary for long-term heat reduction . . .



Remaining heat with 99% istope removal		
	100 years	1000 years
MA	0.99	0.99
U	1.00	1.00
Cs/Sr	0.66	1.00
Pu	0.68	0.45
Pu & MA	0.35	0.01
Pu, MA & U	0.35	0.01
Pu, MA, U & Cs/Sr	0.01	0.01

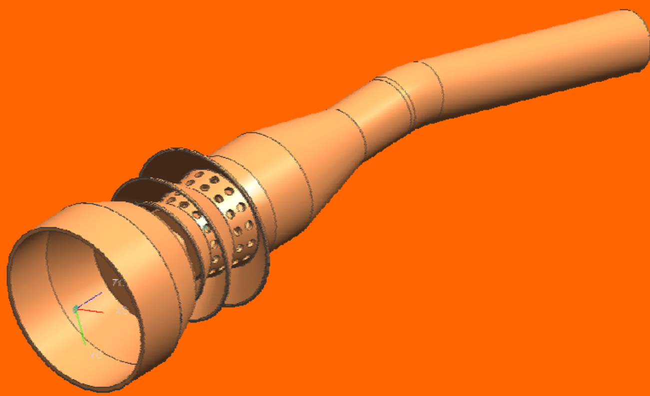
. . . however, a reduction in volume impacts the waste heat load.

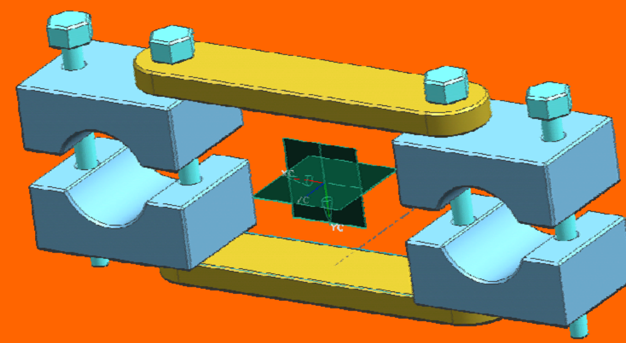
Waste reduction impact on short-term heat load

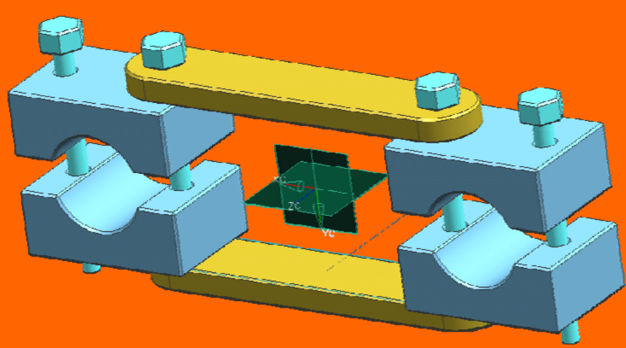


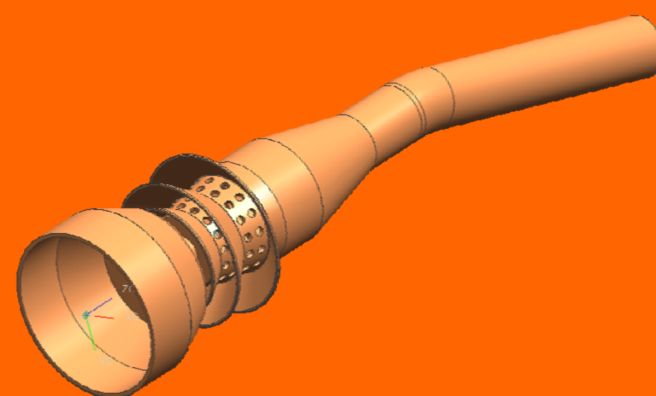
At 5x concentration, high burnup fuel needs ~80 yrs of cooling to meet kW/m heat load criteria

Summary



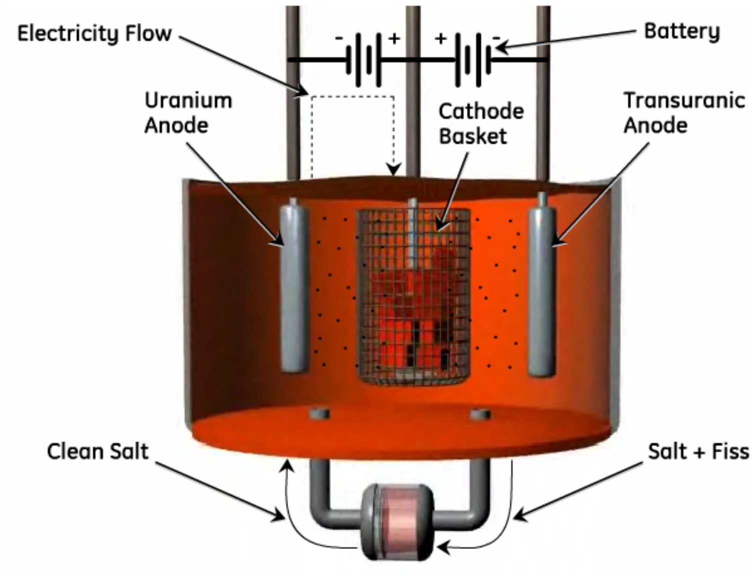






Nuclear Fuel Recycling Center

- ✓ **Based on electrometallurgical technology developed by Argonne National Laboratory** – proliferation resistant
- ✓ **Produces three products: Uranium, TRU and FP**
- ✓ **Fabricates fuel for the Advanced Recycling Reactor (PRISM)**
- ✓ **Design features include:**
  - **No liquid waste** – avoids negative environmental impact
  - **Modular/scalable** – faster construction
  - **Factory built** - high-quality construction
- ✓ **Extensive component testing**
- ✓ **Used by metals processing industries for over a century**



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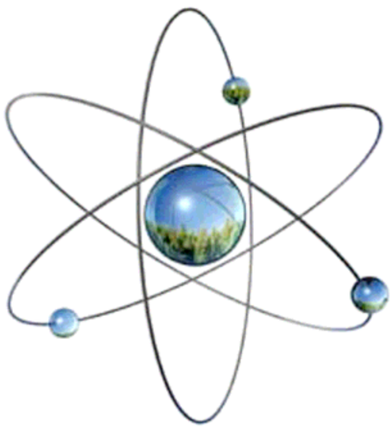
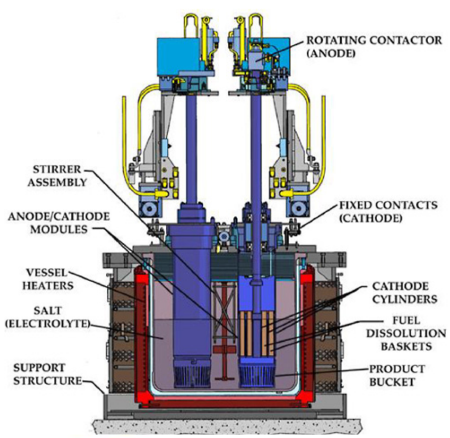
Starting the Nuclear Fuel Recycling Center



Conceptual Design



GE | HITACHI

Path 1

Licensing

- ➢ Use existing Wilmington Part 70 LWR Fuel License
- ➢ Conduct Integrated Safety Analysis (ISA)

Path 2

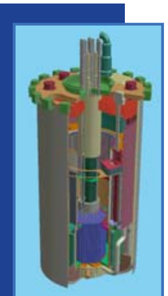
Simulation

- ➢ Build deployment simulation model
- ➢ Start design optimization

Path 3

Component Testing

- ➢ Fabricate select components
  - ➢Electrorefiner
  - ➢Cathode processor
  - ➢Fuel casting equipment
- ➢ Test components



NFRC Deployment

- Follow EBRII fuel disposal system
- Integrate simulation into design process

Benefits:

- Reduced time for prototypic separations
- Immediate ability to license under Part 70 at Wilmington, NC facility
- Completion of ISA
- Takes advantage of existing GEH processes
- Optimize design through iteration