Pacific Northwest
NATIONAL LABORATORY

High-Level Waste Management Cost Drivers

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U.S. DEPARTMENT OF ENERGY BATTELLE

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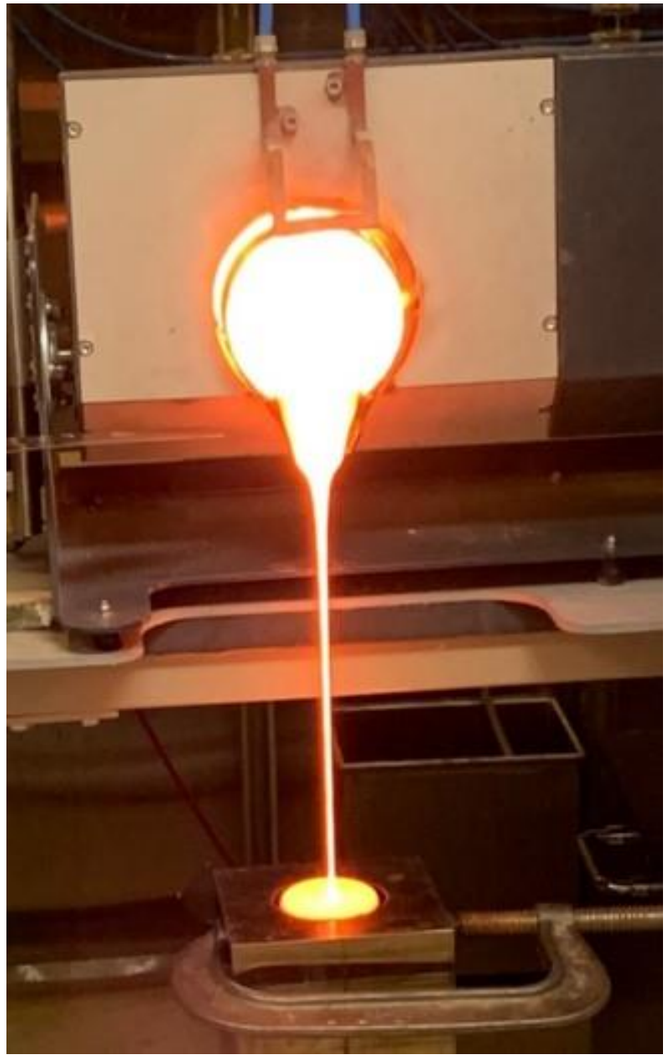
Outline



Simulated HLW glass pour at PNNL

- Baseline HLW treatment (vitrification)
- Example facility layouts
- Capital cost drivers/relationships
- Operating cost drivers/relationships
- A note on storage, transportation, disposal costs
- How to make significant improvements
- Where to turn for more details

Vitrification is the Reference Technology for Treatment of HLW from Aqueous UNF Recycling

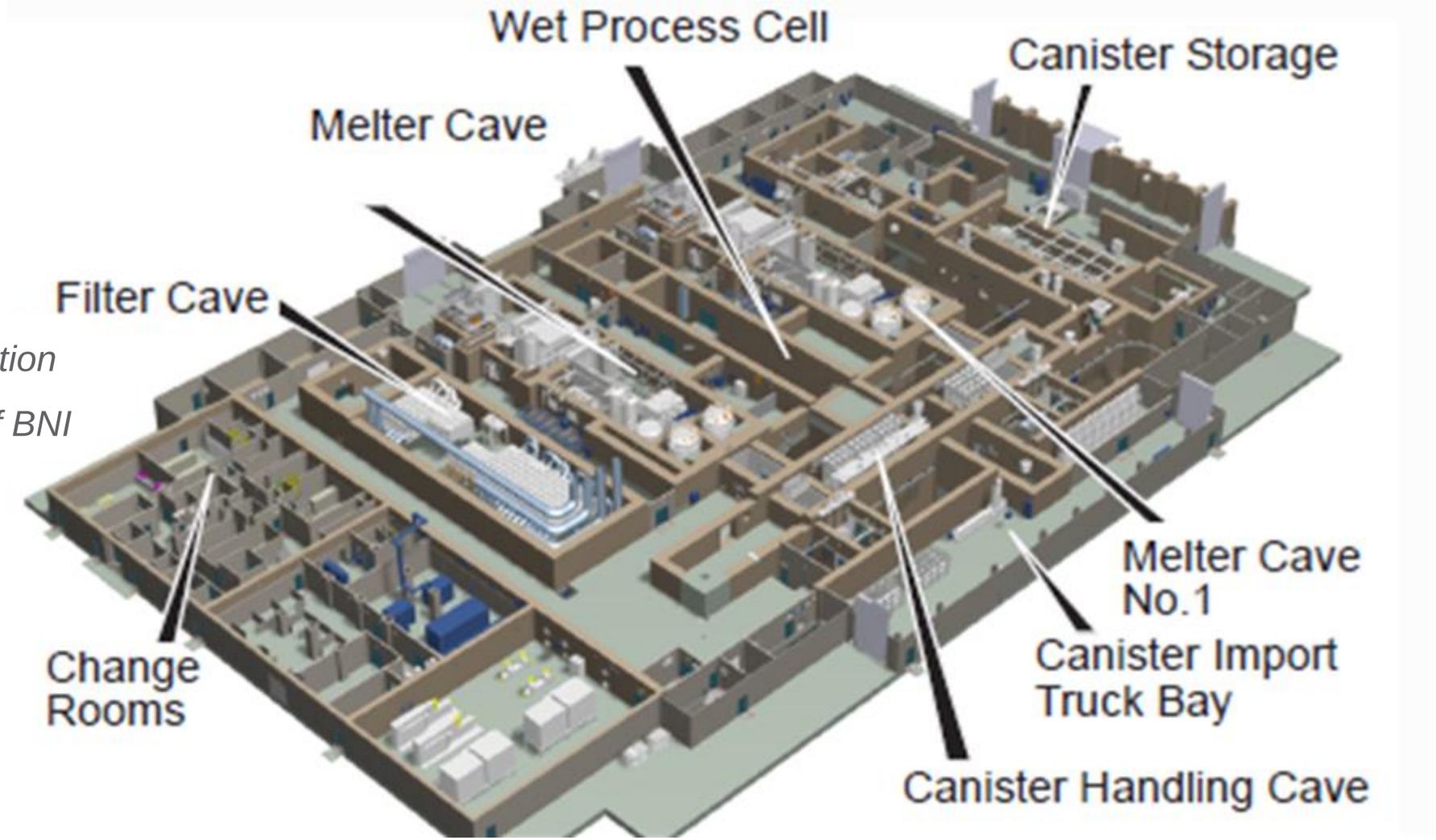
- Waste vitrification is successfully deployed world-wide
  - first deployed at full scale in France, 1978
  - largest plant under construction at Hanford in U.S.
- Costs and cost drivers are well established for vitrification

Plant	Location	Waste	Melter	Startup
AVM	Marcoule, France	HLW	HWIM	1978
WIP	Trombay, India	HLW	HWRM	1985
WIP	Tarapur, India	HLW	HWRM	1985
Radon	Moscow, Russia	ILW	LFCM CCIM	1985 1999
Pamela	Mol, Belgium	HLW	LFCM	1985
MCC	Mayak, Russia	HLW	LFCM	1987
R7	LaHague, France	HLW	HWIM CCIM	1989 2010
WVP	Sellafield, UK	HLW	HWIM	1990
T7	LaHague, France	HLW	HWIM	1992
TRP	Tokai, Japan	HLW	LFCM	1995
DWPF	Savannah River, U.S.	HLW	LFCM	1996
WVDP	West Valley, U.S.	HLW	LFCM	1996
VICHR	Bohunice, Slovakia	HLW	HWIM	1997
AVS	Tarapur, India	HLW	LFCM	2008
UVF	Ulchin, ROK	ILW	CCIM	2009
VEK	Karlsruhe, Germany	HLW	LFCM	2010
WIP	Kalpakkam, India	HLW	LFCM	2012
RRP	Rokkasho, Japan	HLW	LFCM	TBD
WTP	Richland, U.S.	HLW LAW	LFCM	TBD

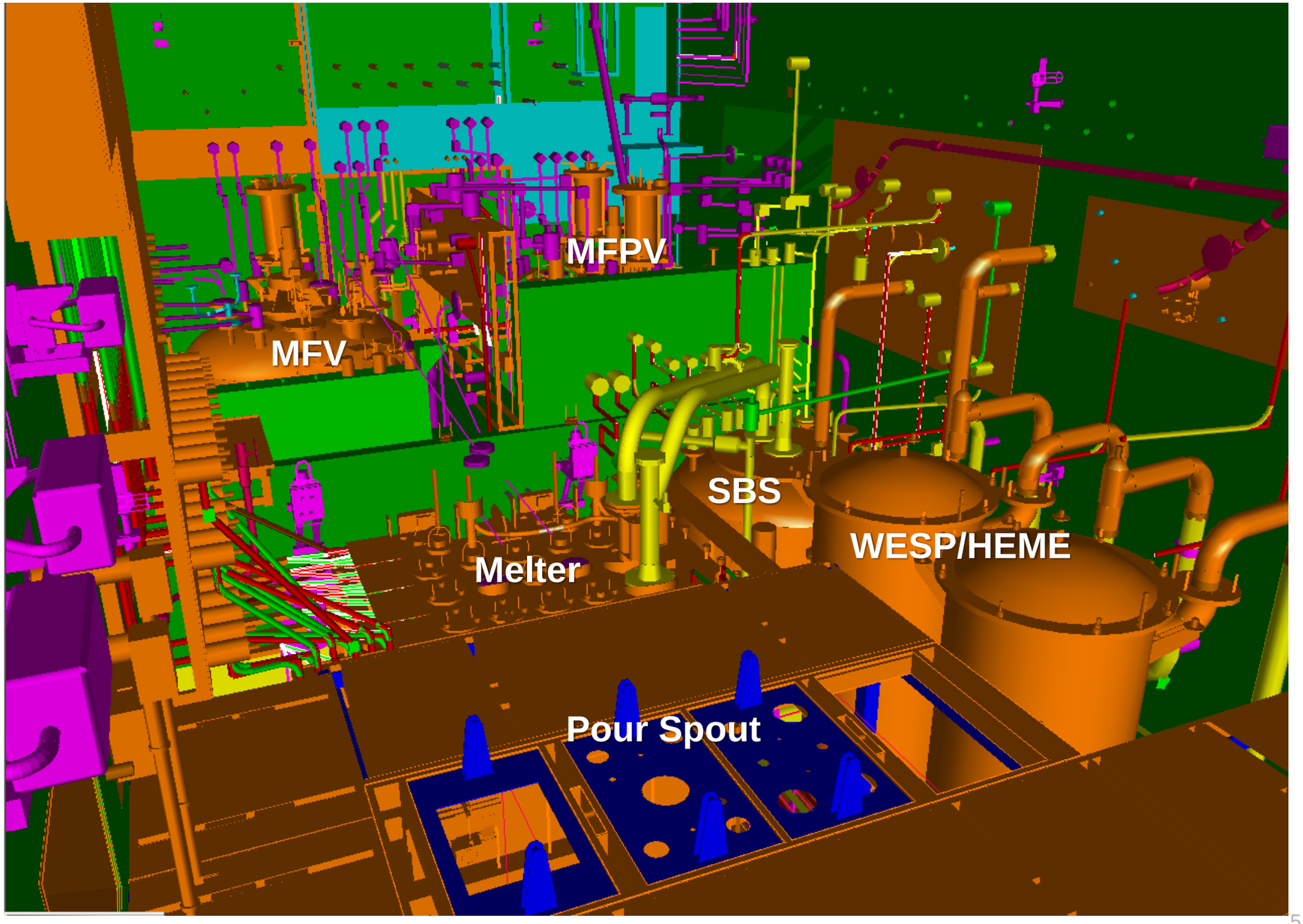
AVM -- Atelier de Vitrification Marcoule
AVS – Advanced Vitrification System
CCIM – cold-crucible induction melter
DWPF – Defense Waste Processing Facility
HWIM -- hot-walled induction melter
HWRM – hot-walled resistance melter
LFCM – liquid-fed ceramic melter
MCC – Materials and Chemical Combine
RRP – Rokkasho Reprocessing Plant
TRP – Tokai Reprocessing Plant
TRP – Tokai Reprocessing Plant
WIP -- Waste Immobilisation Plant
WVDP – West Valley Demonstration Project
WVP – Waste Vitrification Plant
UVF -- Ulchin Vitrification Facility
VEK -- Verglasungseinrichtung Karlsruhe
WIP – Waste Immobilization Plant
WTP – Hanford Tank Waste Treatment and Immobilization Plant

Example Vitrification Facilities (WTP)

WTP HLW vitrification facility, courtesy of BNI

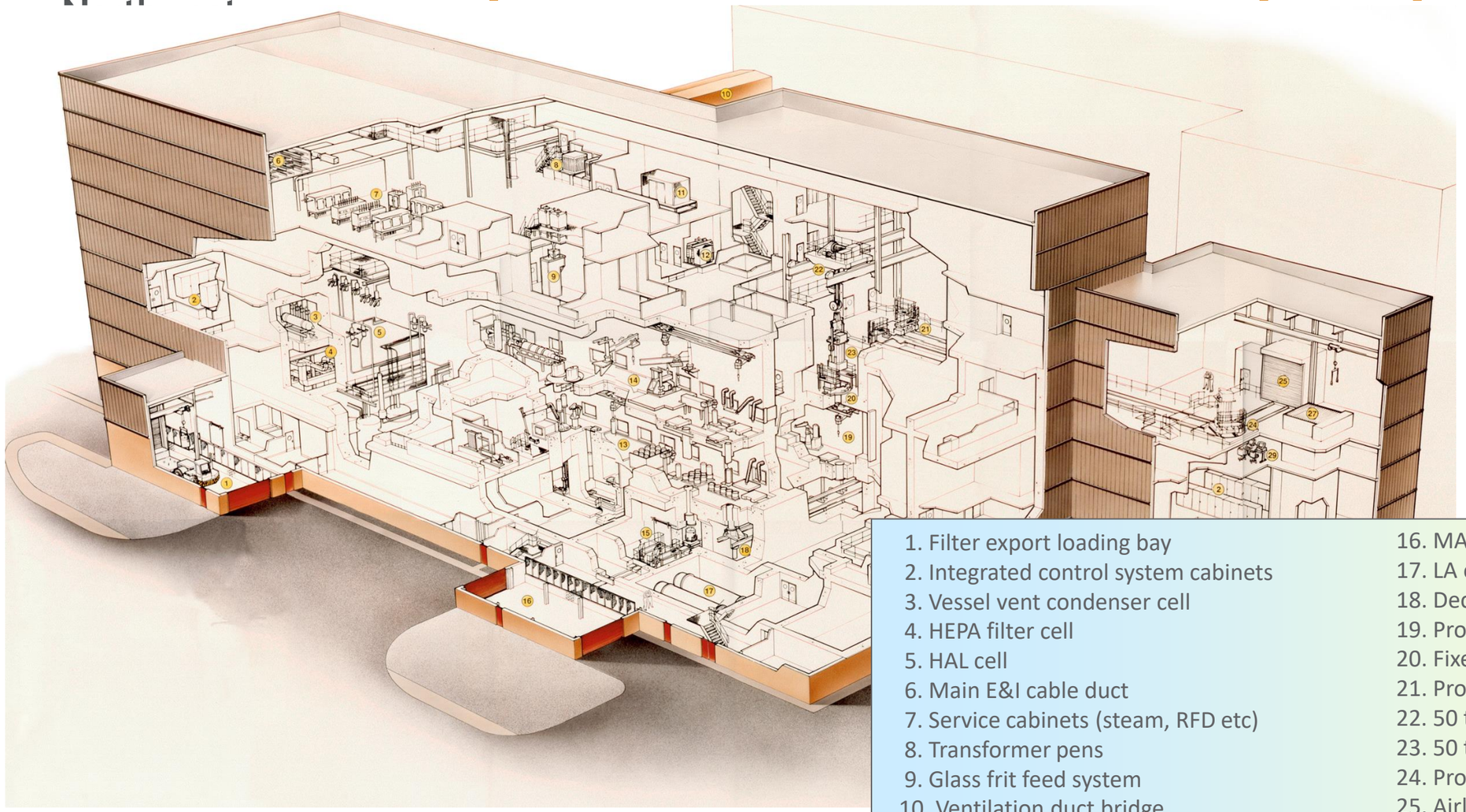


WTP HLW Melter Cave



WTP HLW melter cave, courtesy of BNI

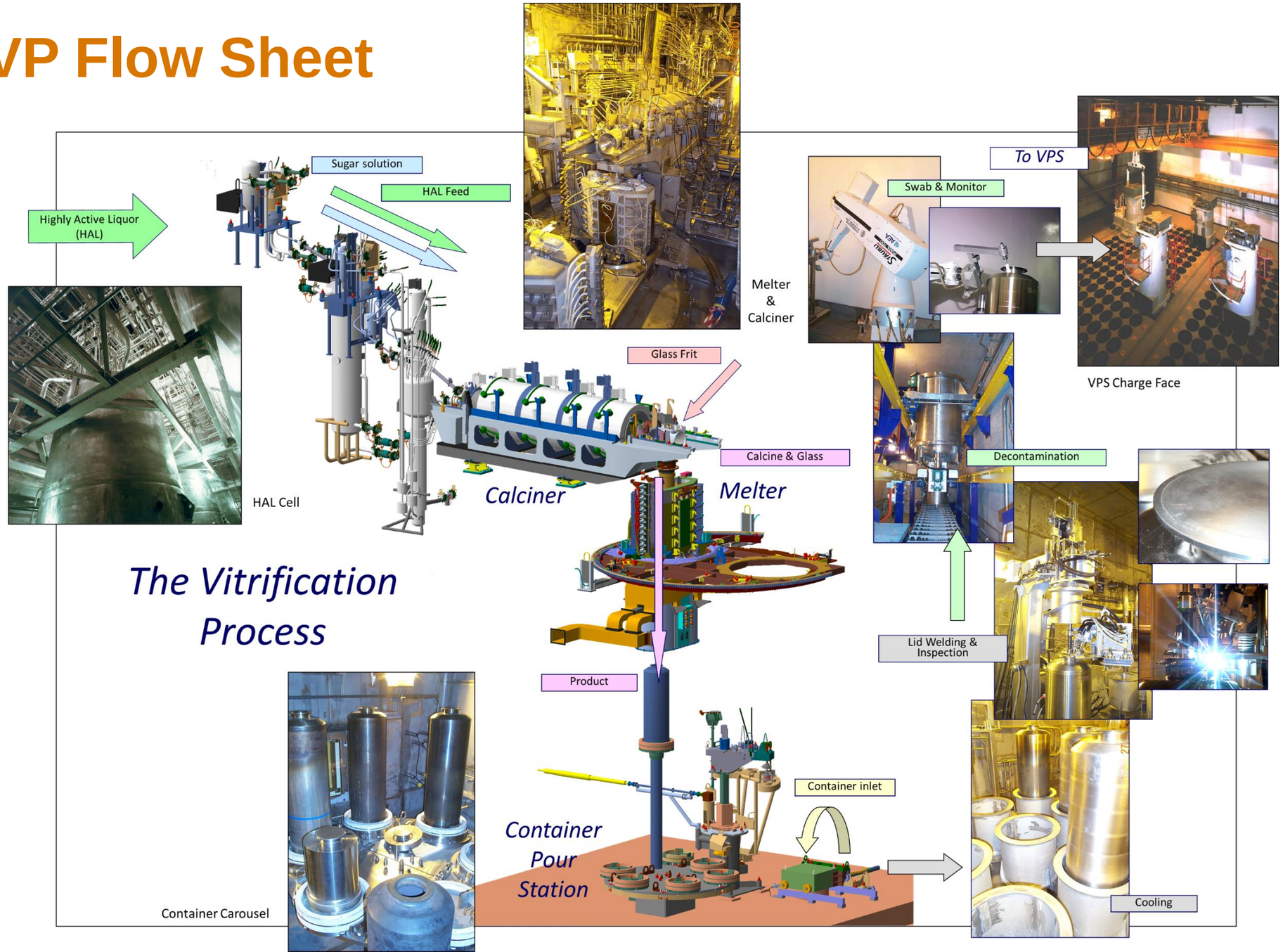
Example Vitrification Facilities (WVP)



Sellafield Waste Vitrification Plant Line 3, courtesy of NNL

1. Filter export loading bay
2. Integrated control system cabinets
3. Vessel vent condenser cell
4. HEPA filter cell
5. HAL cell
6. Main E&I cable duct
7. Service cabinets (steam, RFD etc)
8. Transformer pens
9. Glass frit feed system
10. Ventilation duct bridge
11. Electrostatic precipitation switch gear
12. ESP system
13. Pour cell
14. Vitrification & breakdown cell
15. MA export system
16. MA export loading bay
17. LA effluent cell
18. Decontamination Cell
19. Product container control cell
20. Fixed gamma gate
21. Product flask bogie
22. 50 tonne product flask crane
23. 50 tonne product flask
24. Product flask turntable
25. Airlock to VPS
26. Compressor house
27. Roller shutter door
28. MA export (Lines 1&2)
29. Integrated control system operator interface

WVP Flow Sheet



Sellafield Waste Vitrification Process, courtesy of NNL

Capital Cost Drivers

1. Size of facility → cost of concrete and steel
   - High dose areas (inside hot cell)
   - Requiring seismic stability
   - Height is more expensive than area
2. Design costs are a significant portion of capital cost
   - Capital projects generate as much paper as concrete
   - QA, nuclear safety, etc.
3. Design is driven more by managing off-normal events than conducting the day-to-day process (e.g., seismic and ash fall)
4. Melter is a relatively small fraction of the overall facility size (see example layouts)
   - Process off-gas treatment, feed preparation systems, HVAC, canister decon/handling, secondary wastes, maintenance, sampling/laboratory, frit/glass former management, cell/facility off-gas treatment, power supplies, control systems

Capital Cost Rules of Thumb

- Typical budget breakouts are:
  - 20% engineering
  - 20% procurement
  - 25% construction
  - 20% testing/commissioning
  - 15% management/oversight
- Cost generally scale by plant capacity:
  - $cost_B = cost_A \left(\frac{capacity_B}{capacity_A}\right)^n$
  - n values range from 0.3 to 0.7
  - EAS studies assume n = 0.41
  - n = 0.37 for Hanford HLW to Savannah River DWPF

- Potential Improvements
  - Capacity (see equation)
  - Simplify process
  - Reduce off-gas treatment size/complexity
    - ✓ WTP/DWPF designed to remove NOx, iodine, particulates/aerosols, technetium, organics, acid gases, *mercury*
    - ✓ Scaled to gas flowrate and amounts of contaminants to remove
  - Amount of storage (feed and glass)
  - Secondary waste management
  - Simplify maintenance
  - Reducing safety/regulatory risks
    - ✓ Reducing design requirements to manage risks
    - ✓ Reduce risks by improved understanding

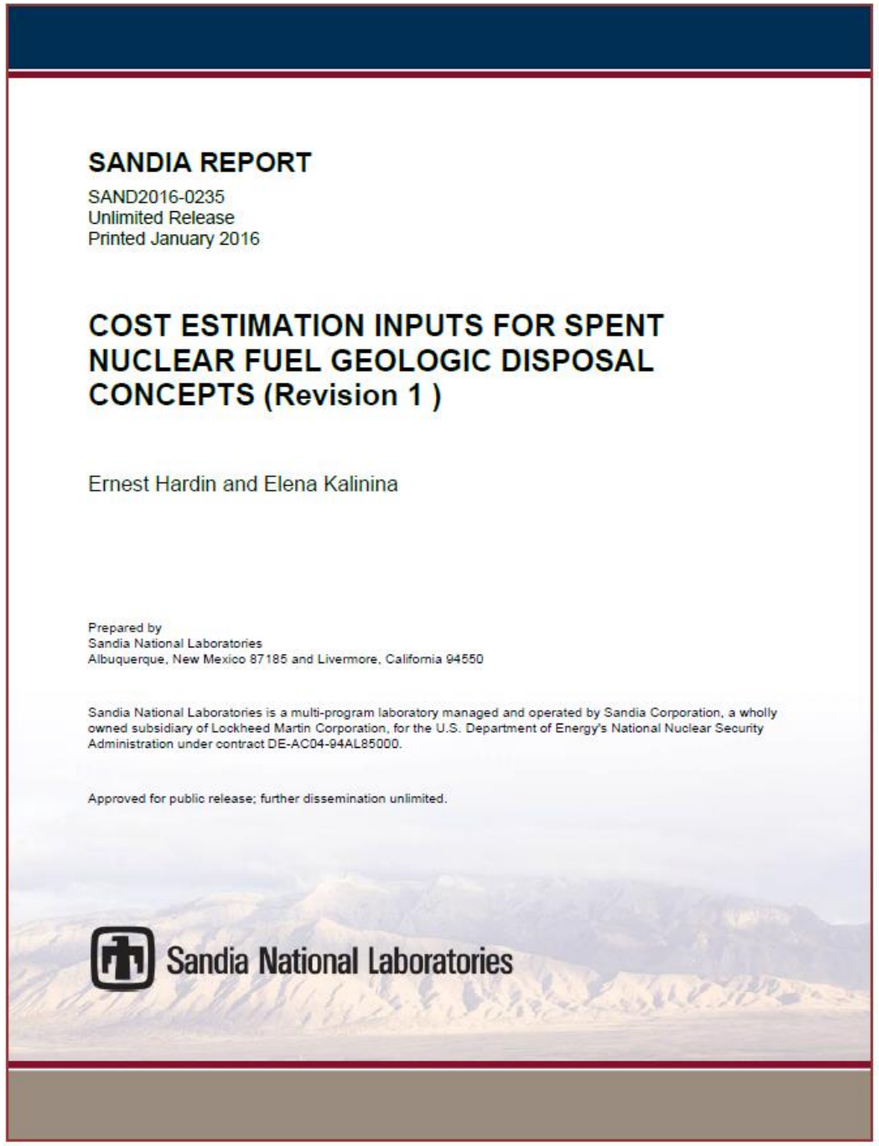
Operating Cost Drivers

- Primarily driven by headcount for facility operations/maintenance
- Example activities that require higher staffing
  - Equipment or procedures requiring more hands-on operation and/or maintenance
  - Materials movements
  - Mechanical handling equipment (operations and maintenance)
  - Regular decisions (e.g., formulation, heat treatment schedule, filter changes, etc.)
  - Decontamination operations prior to maintenance
  - Use of manipulators/cranes
  - Sampling and analyses
  - Strict government oversight
  - Generally, operating close to limits require more human attention
  - Calibration and routine checks of instruments
- Around-the-clock operations (24/7/365)
  - Operating costs increase when going from single- to double-shift to 24/7/365
  - Processes that can be primarily conducted in single-shift would significantly reduce operating costs

Waste Form Storage and Transportation Costs

- Waste storage cost drivers: **heat** and **volume**
  - Smaller volume is less expensive (smaller footprint)
  - Fewer packages less expensive (less handling)
  - Passive cooling is less expensive (both from need for forced air and managing off-normal events)
    - ✓ Heat tolerance to waste form phase changes (centerline temps) and also to structural materials stability (cement phase changes)
  - Accident scenarios (credible or otherwise)
    - ✓ Will waste form generate respirable fines if provoked?
    - ✓ Will waste form release RN if wet?
- Transportation costs driven by **number of shipments, sizes and weights of packages**
  - Requires waste form stability to meet regulatory requirements (temperature, respirable fines, water soluble, flammable, free liquid, etc.)

Disposal Cost Drivers



SANDIA REPORT

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COST ESTIMATION INPUTS FOR SPENT NUCLEAR FUEL GEOLOGIC DISPOSAL CONCEPTS (Revision 1)

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- Geologic disposal has fixed and incremental costs, waste forms affect incremental costs with primary drivers:
  - Total heat (trade-off between decay storage cost and disposal cost)
  - Number of waste packages (determined by waste form volume and heat)
  - Size/weight of waste packages if significantly different than those for commercial SNF
  - Durability of waste form if WF half-life is > half-life of primary dose contributors (e.g., reduced reliance on engineered barriers)

Opportunities for Improvements

- Improve vitrification
  - Higher waste loading (while maintaining durability, thermal stability, process equipment constraints)
  - Improved NOx management (instead of calciner, SCR, etc.)
  - Reduce off-gas treatment requirements (while meeting environmental regulations)
  - Fewer process steps (can decon, calcination, etc.)
- Different waste treatment processes
  - Ideally smaller footprint, simplified off-gas treatment, lower staffing
  - Maintain safety
  - Durability can range from lower to higher
    - ✓ Lower will still need to meet storage/transportation safety requirements and non-hazardous for disposal (use EBS/NB to ensure repository performance)
    - ✓ Higher will need to be on order of $<10^{-6}$ y^{-1} fractional rates to have impact

More Details

- Waste management baseline:
  - Vienna, J. D., et al. 2015. *Closed Fuel Cycle Waste Treatment Strategy*. FCRD-MRWFD-2015-000674, PNNL-24114, Pacific Northwest National Laboratory, Richland, WA.
  - Gombert, D., et al. 2008. *Combined Waste Form Cost Trade Study*. GNEP-SYSA-PMO-MI-DV-2009-000003, Idaho National Laboratory, Idaho Falls, ID.
- General cost evaluations:
  - INL. 2017. *Advanced Fuel Cycle Cost Basis – 2017 Edition*. INL/EXT-17-43826, Idaho National Laboratory, Idaho Falls, ID.
- Disposal costs:
  - Hardin, E. and E. Kalinina. 2016. *Cost Estimation Inputs for Spent Nuclear Fuel Geologic Disposal Concepts (Revision 1)*. SAND2016-0235, Sandia National Laboratories, Albuquerque, NM.
  - NEA. 1993. *The Cost of High-Level Waste Disposal in Geologic Repositories, An Analysis of Factors Affecting Cost Estimates*, OECD/NEA, Paris, France.
- Heat management:
  - Hardin, E., T. Hadgu, H. Greenberg, and M. Dupont. 2012. *Parameter Uncertainty for Repository Thermal Analysis*, FCRD-UFD-2012-000097, Sandia National Laboratories, Albuquerque, NM.

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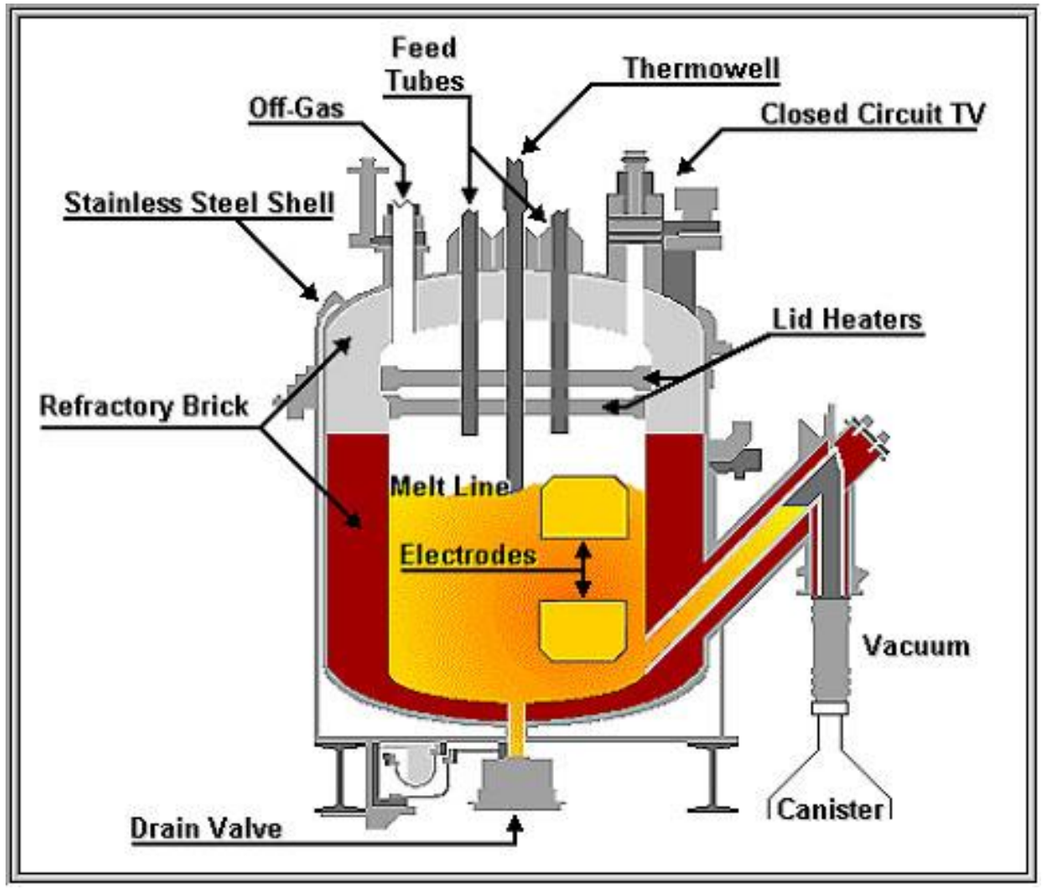
Thank you

Vitrification Processes

- Waste vitrification processes vary in the way that the melter feed is prepared, dried, and fed to the melter and how the melter is heated

Concept	Melter Feed	Glass Contact Material	Heating Method
Liquid Fed, Ceramic Melter	Mix frit/additives to HLW, directly feed slurry onto melt surface	Ceramics	Joule-heat the melt using submerged electrodes
Hot Walled Induction Melter	Calcine waste, meter waste and frit onto melt surface	Metal	Inductively heat the metal container (low frequency)
Cold Crucible Induction Melter	Calcine waste, meter waste and frit onto melt surface	Solid Glass	Inductively heat the melt (radio frequency)
Hot Walled Resistance Melter	Meter frit and HLW onto melt surface	Metal	Resistively heat the metal

Example Liquid Fed Ceramic Melter (LFCM)



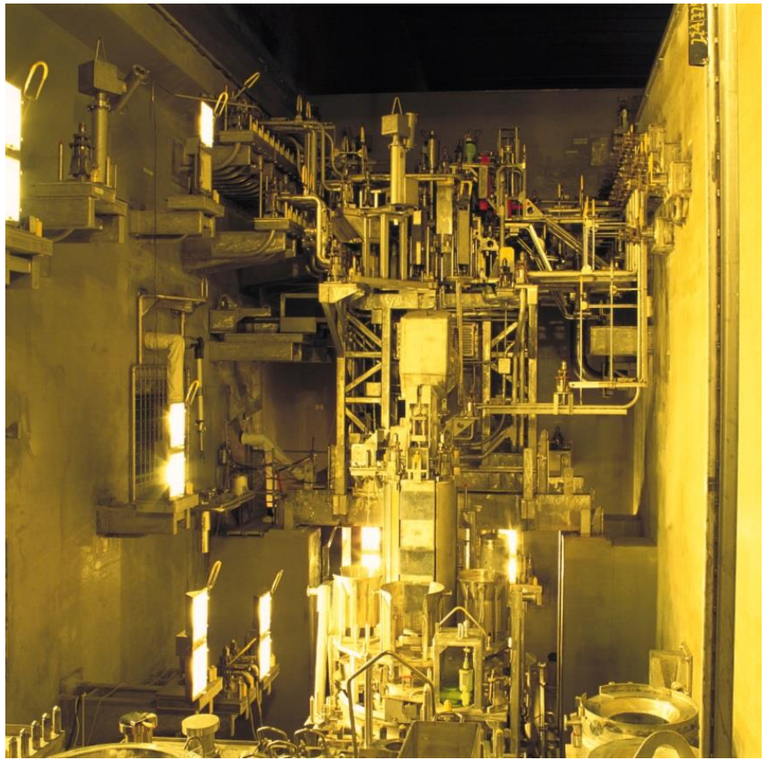
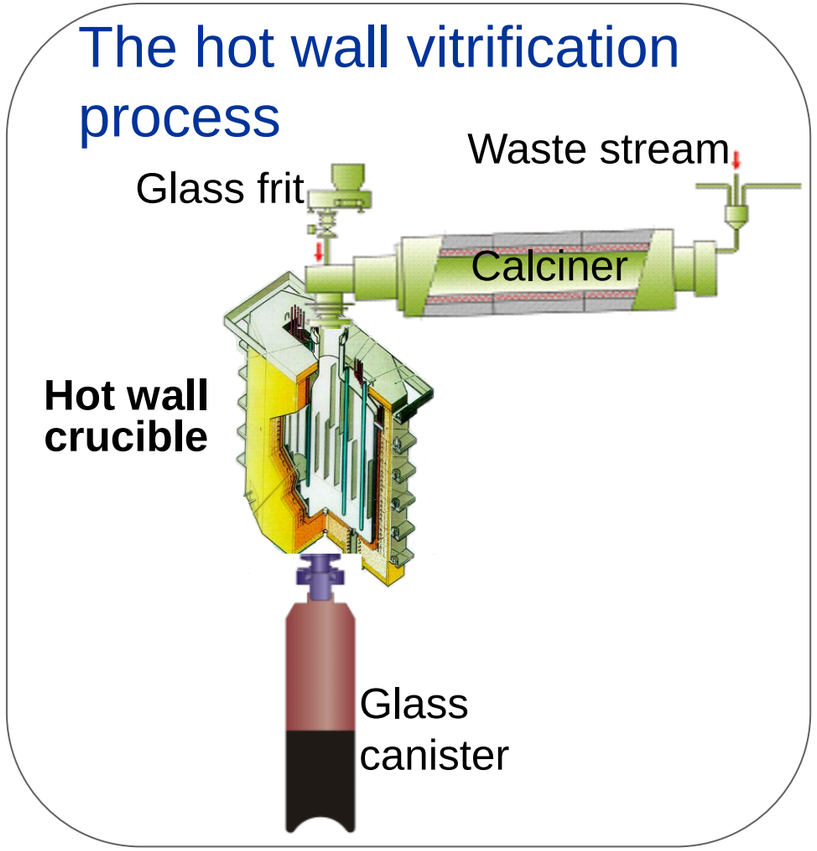


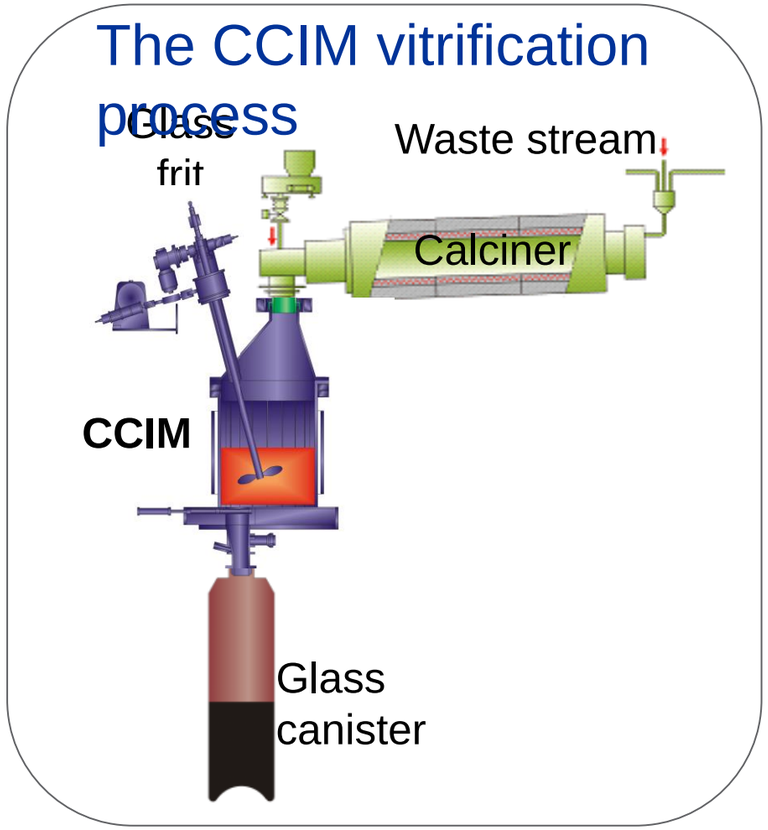
Diagram and Photo of Defense Waste Processing Facility melter, courtesy of Department of Energy

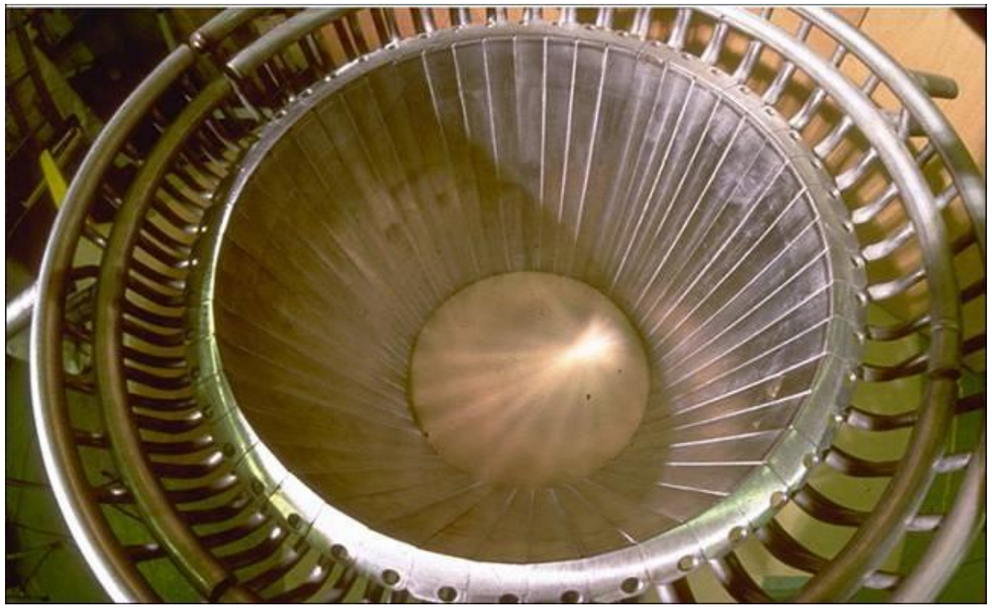
Example Hot Walled Induction Melter (HWIM) with Calciner



Hot-walled induction melter diagram, courtesy of CEA, and photograph, courtesy of AREVA

Example Cold Crucible Induction Melter (CCIM)





Photograph and diagram of cold crucible induction melter, courtesy of CEA-Marcoule