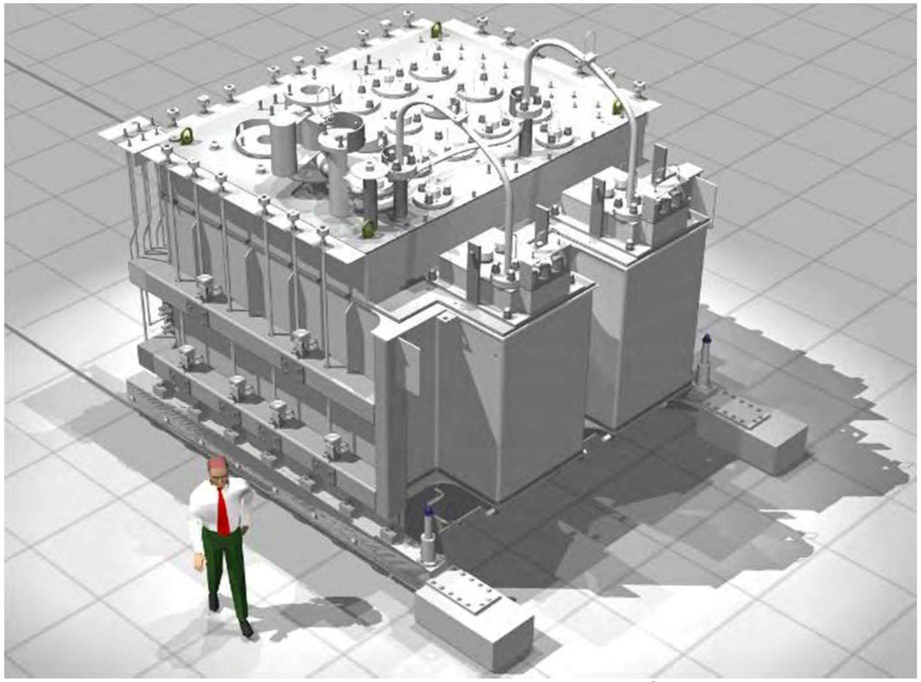


Application of Joule Heated Ceramic Melter (JHCM) Technology for Stabilization of Radioactive waste in the United States

November 3, 2015

Eric C Smith* and Brad Bowan

EnergySolutions

and

Ian L. Pegg

The Catholic University of America, Vitreous State Laboratory

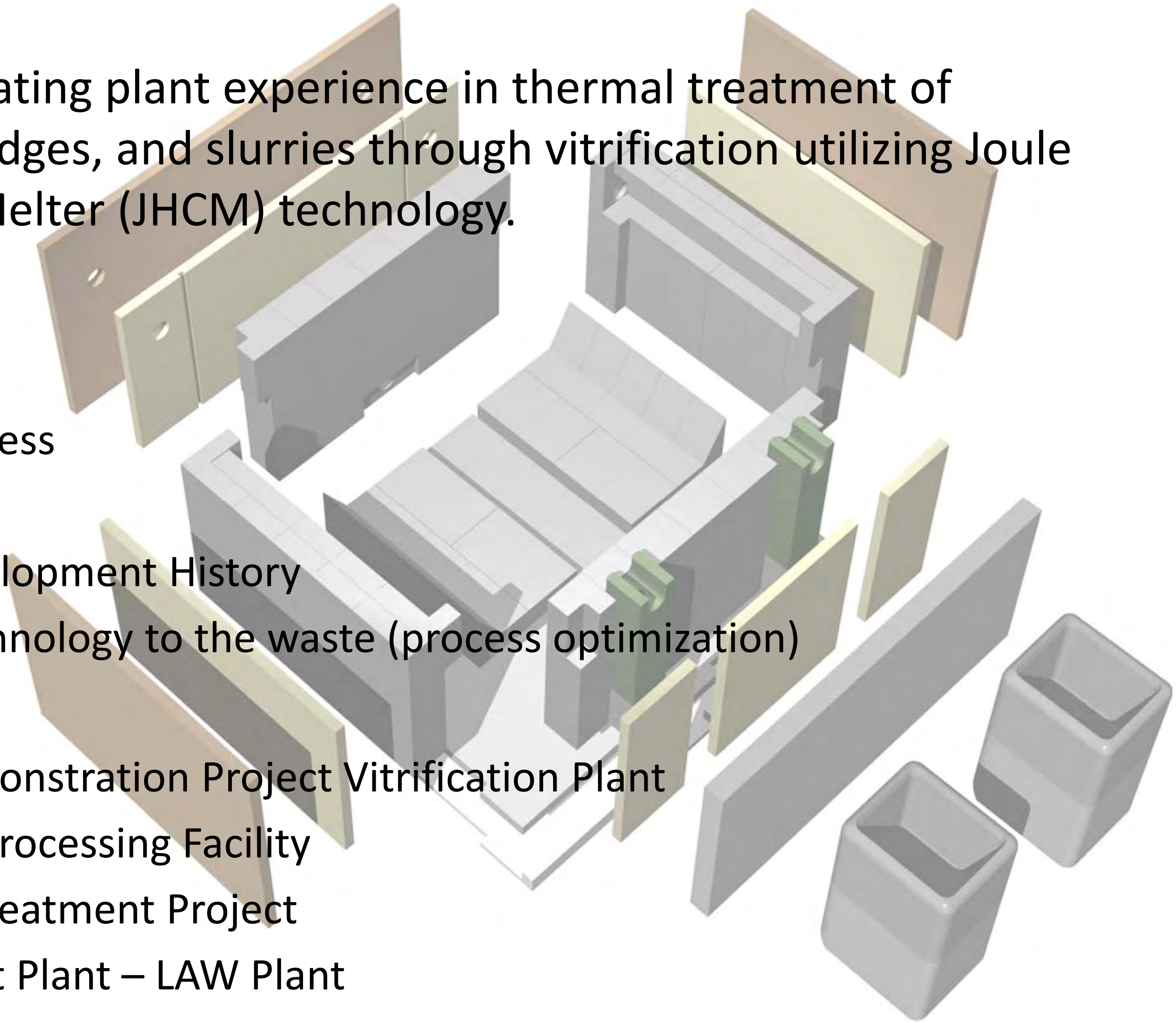
Introduction / Agenda

Purpose:

To share the U.S. operating plant experience in thermal treatment of radioactive liquids, sludges, and slurries through vitrification utilizing Joule Heated Ceramic line Melter (JHCM) technology.

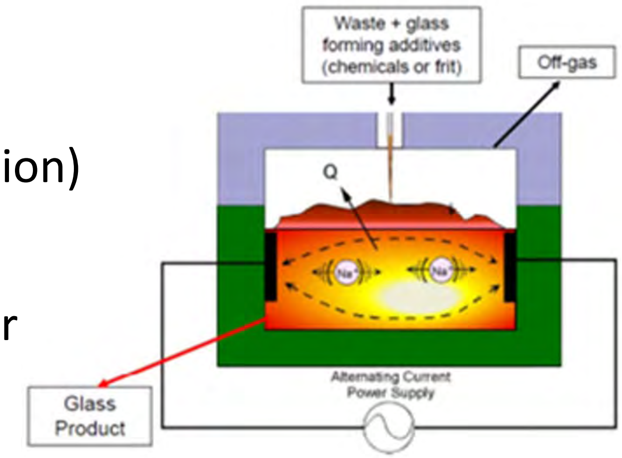
Agenda:

- Background
  - Vitrification process
  - What is a JHCM
  - Technology Development History
  - Tailoring the technology to the waste (process optimization)
- Selected Projects
  - West Valley Demonstration Project Vitrification Plant
  - Defense Waste Processing Facility
  - M-Area Waste Treatment Project
  - Waste Treatment Plant – LAW Plant



Vitrification Process

- Waste Preparation
  - The waste is received and sampled to confirm composition
  - Solids content is adjusted (evaporation or dilution)
  - Glass forming chemicals are add (Silica, Borax, Sodium carbonate, etc.)
  - Waste feed is continuously added to the melter



- Vitrification
  - Water is evaporated
  - Salts melt and decompose
  - Oxides react and melt to form molten glass
  - Organics are pyrolyzed and oxidized
  - Most metals, if present, are oxidized
    - There are limits on amount and particle size
  - Most species are incorporated into silicate glasses as their oxides; exceptions include Cl, F, I which are only incorporate to a limited extent.
  - Volatile species (such as H_2O, CO_2, NO_x, etc.) are completely lost to the off-gas stream
    - Typically contributes to significant volume reduction
  - Other species are retained in the glass melt to varying extents
- Glass is discharged into containers and cooled forming final disposal package

What is a JHCM

- Joule Heated Ceramic Melter (JHCM) description:
  - Refractory/Ceramic lined vessel for corrosion resistance
  - Sealed vessel (radionuclide/hazardous material confinement)
  - Submerged, permanent electrodes
    - The glass is the heating element
    - A/C power
  - Vertical Melting process
    - Feed introduced from above
    - Reacts on the surface of the glass
    - Glass discharged from near base of glass pool
  - Actively mixed glass pool to increase processing rate
  - Glass production rate (and waste treatment rate) directly proportional to melt pool surface area ($t/m^2/d$)

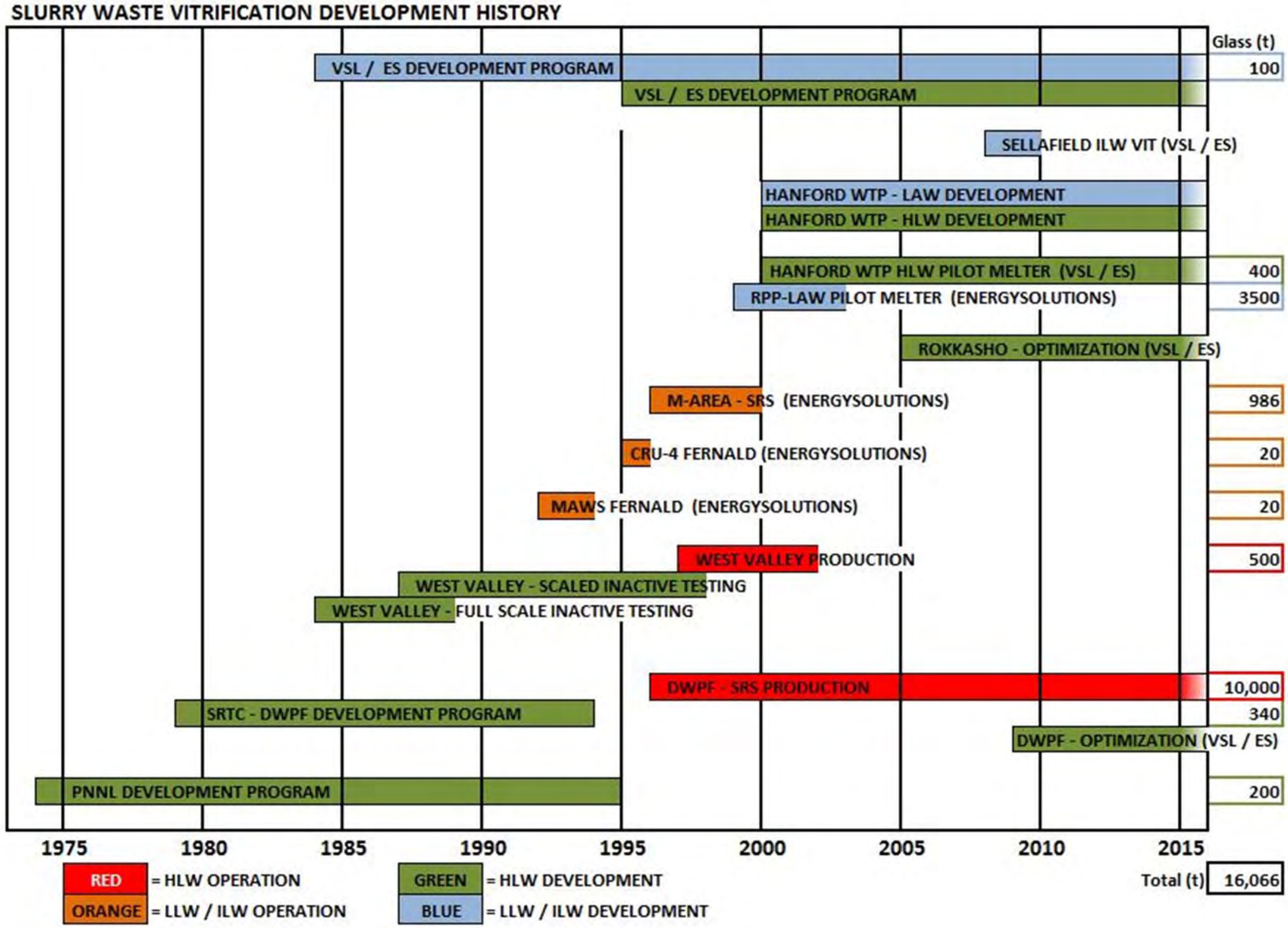
View Inside JHCM Plenum

JHCM: Other Facts

- JHCM "Hardware" versus "Software"
  - Hardware – physical equipment (i.e., the melter)
  - Software – Glass formulation
    - The facility performance can be enhanced through improved glass formulations that are essentially transparent to the engineered facility
    - Waste types/composition can be changed without physical changes
- The benefits of JHCM
  - One step processing (organics destroyed, metals oxidized, all integrated into highly stable glass matrix)
  - Very large waste volume reductions are possible (30 to 50% typical, >85% possible)
  - Reactive properties of the waste are removed
  - Exceptional stability of final waste package
- A note about the cost of vitrification
  - Cost is almost exclusively governed by waste properties and facility design requirements. Not the technology!
    - Level of confinement and shielding required
    - Facility safety related functions
  - For example, the Hanford Waste Treatment Plant (WTP) costs:
    - Facility = $15,000M
    - 4 melters = $60M (0.4%)

JHCM Development History

There are more than 4 decades of development and operating experience using JHCM vitrification for treating sludge/slurry waste in the U.S.

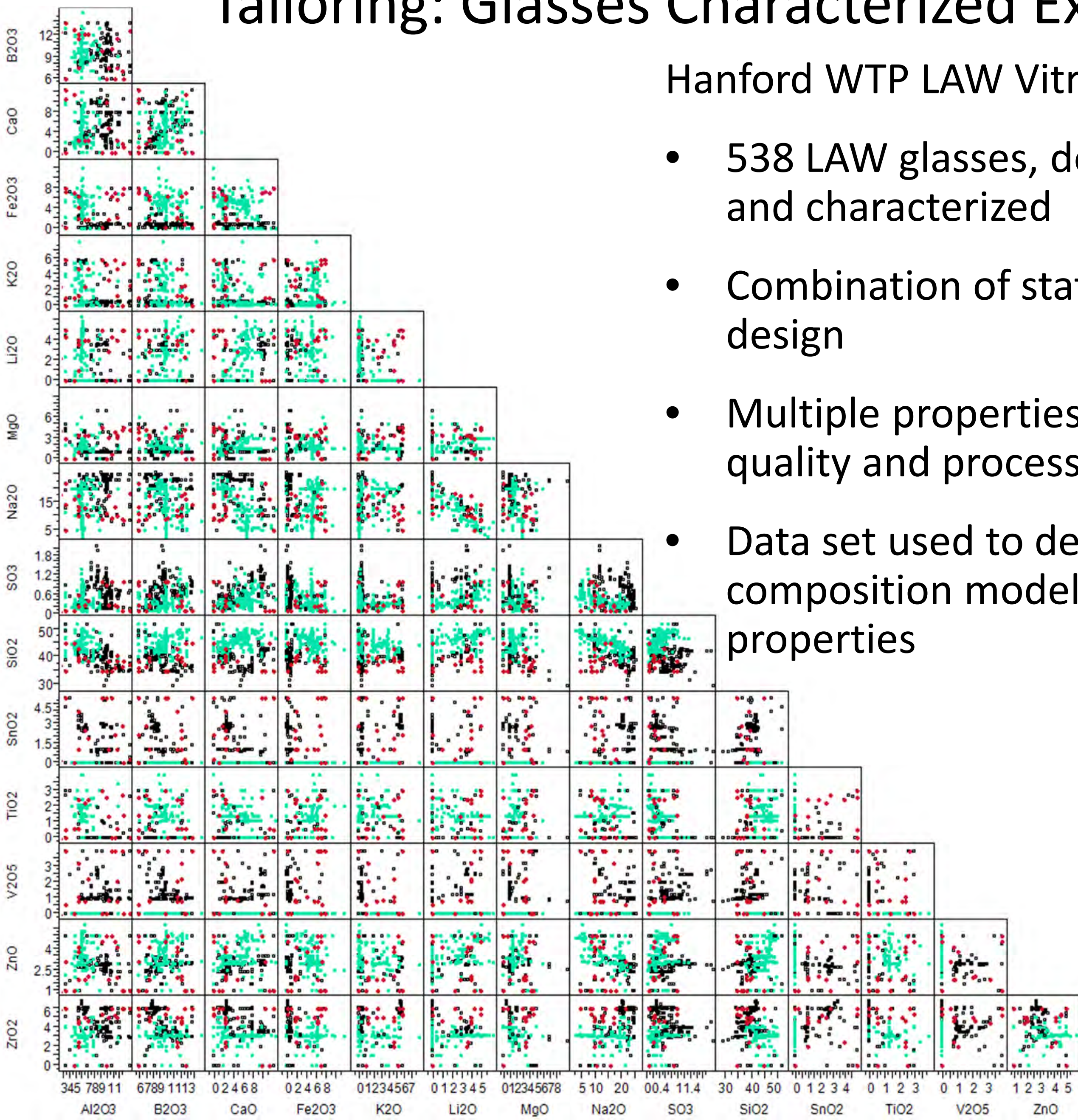


Tailoring the technology to the waste

- JHCM technology can be tailored to the waste through variations in the glass forming additives. Widely varying waste composition can be accommodated within an existing facility.
  - Higher waste treatment rate capability translates into cost savings through small plant size and/or reduced operating time
  - Increased waste loading (fraction of glass originating from waste) increases waste treatment rate and reduces volume for disposal
  - Increased glass production rate increases waste treatment rate
  - Both factors depend on waste composition and glass composition
  - Optimization of glass composition can have drastic effects on overall process economics
    - Such changes are easy to implement since they do not require hardware changes
    - Complicated by numerous components present in typical wastes
    - Problem in constrained optimization of multiple properties with respect to numerous composition variables
    - Typically requires large data sets and development of glass property-composition models

Waste Treatment Rate = **Glass Production Rate** X **Waste Loading in Glass**

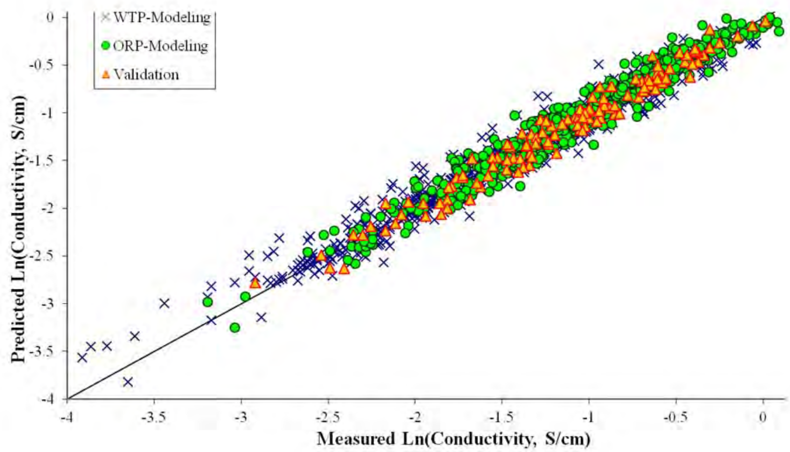
Tailoring: Glasses Characterized Example

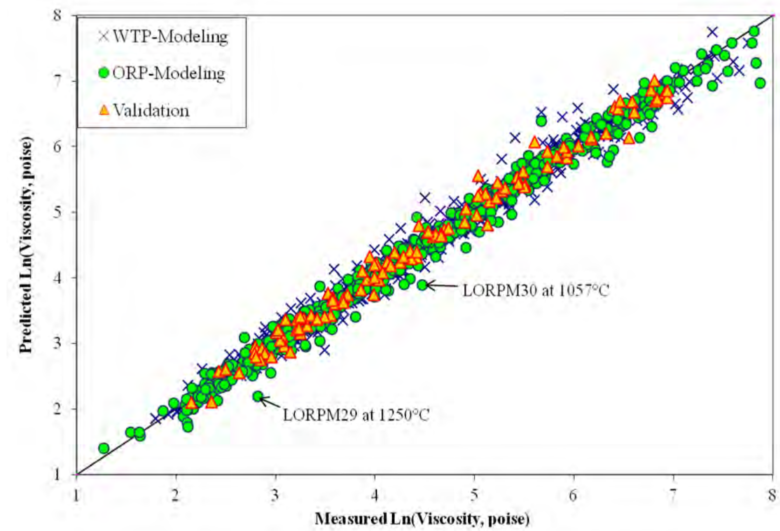


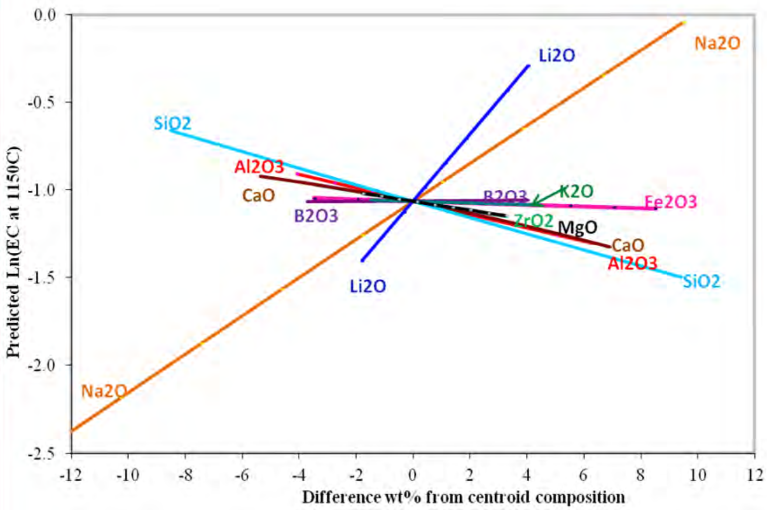
Hanford WTP LAW Vitrification:

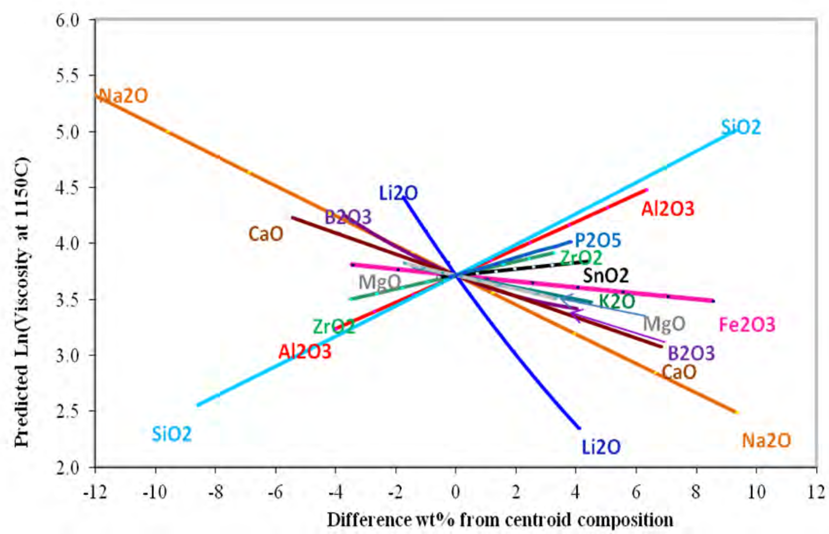
- 538 LAW glasses, designed, fabricated and characterized
- Combination of statistical and active design
- Multiple properties relating to product quality and processability
- Data set used to develop glass property-composition models for those properties

Tailoring: Glass Property Model Example



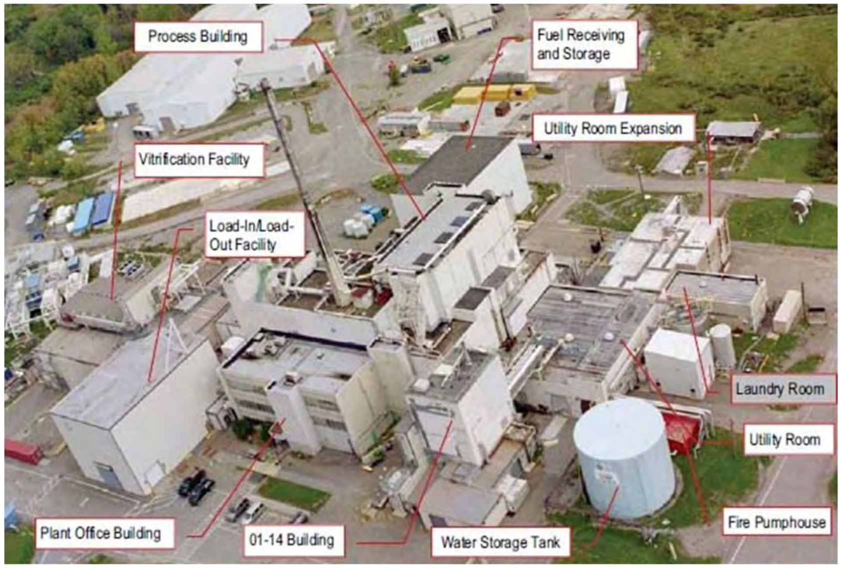






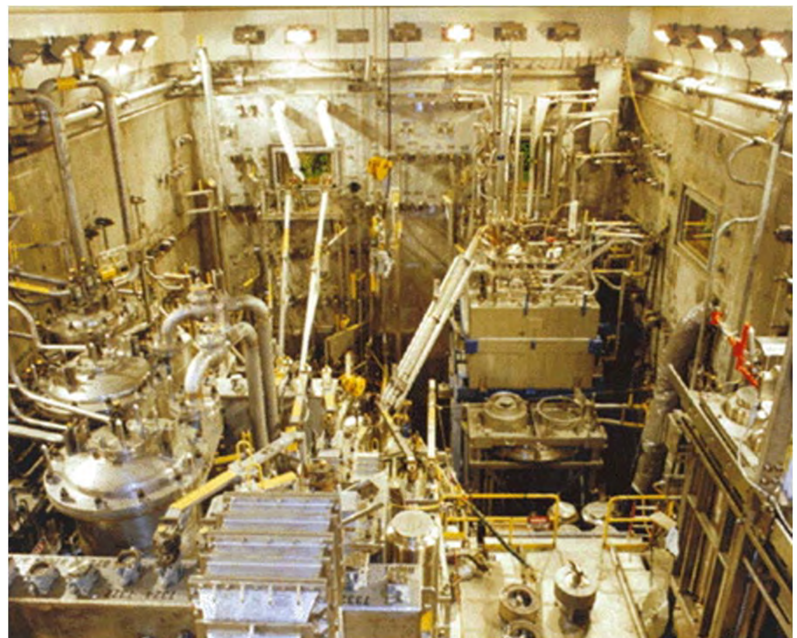
West Valley Demonstration Project (WVDP)

- Project: Privately owned commercial nuclear fuel reprocessing plant
  - Operate from 1965 – 1972 using PUREX/THOREX process
  - Abandon in 1980 and taken over by US government for cleanup
- Waste
  - Volume – 2500 m^3 of HLW stored in UGSTs
  - Activity – 888,000 TBq
  - Hazardous content:Low levels of Hg
  - Chemical form – Sludge high in OH^-, nitrate, nitrite, chromium, sulfates, halides, organics, etc.



WVDP: Process

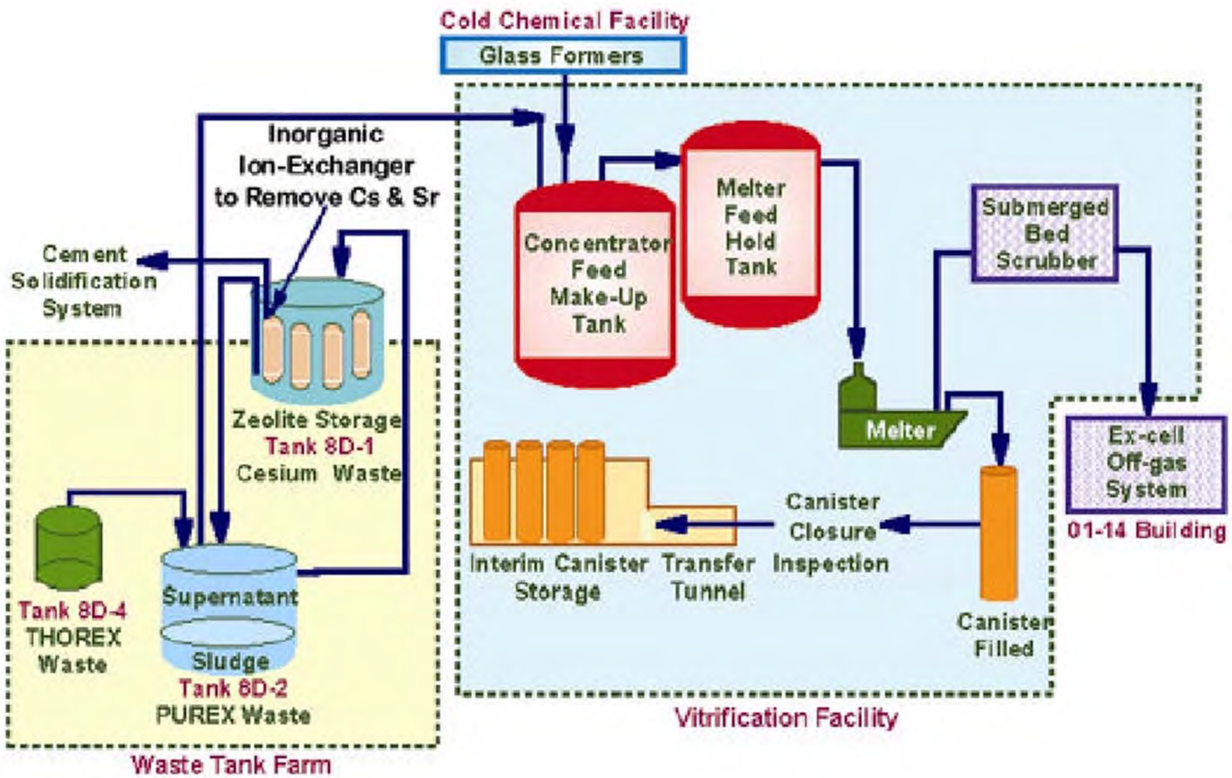
- Waste Pretreatment
  - Sludge washed for partial sodium removal (increase waste loading)
  - Ion Exchange (Zeolite) to remove Cs, Pu from liquids.
    - Zeolite blended with sludge for vitrification
    - Effluent cemented for disposal
  - Acidic THOREX stream neutralized and blended into sludge
  - Resultant waste stream was a blend:
    - PUREX sludge
    - THOREX sludge
    - Spent Zeolite media



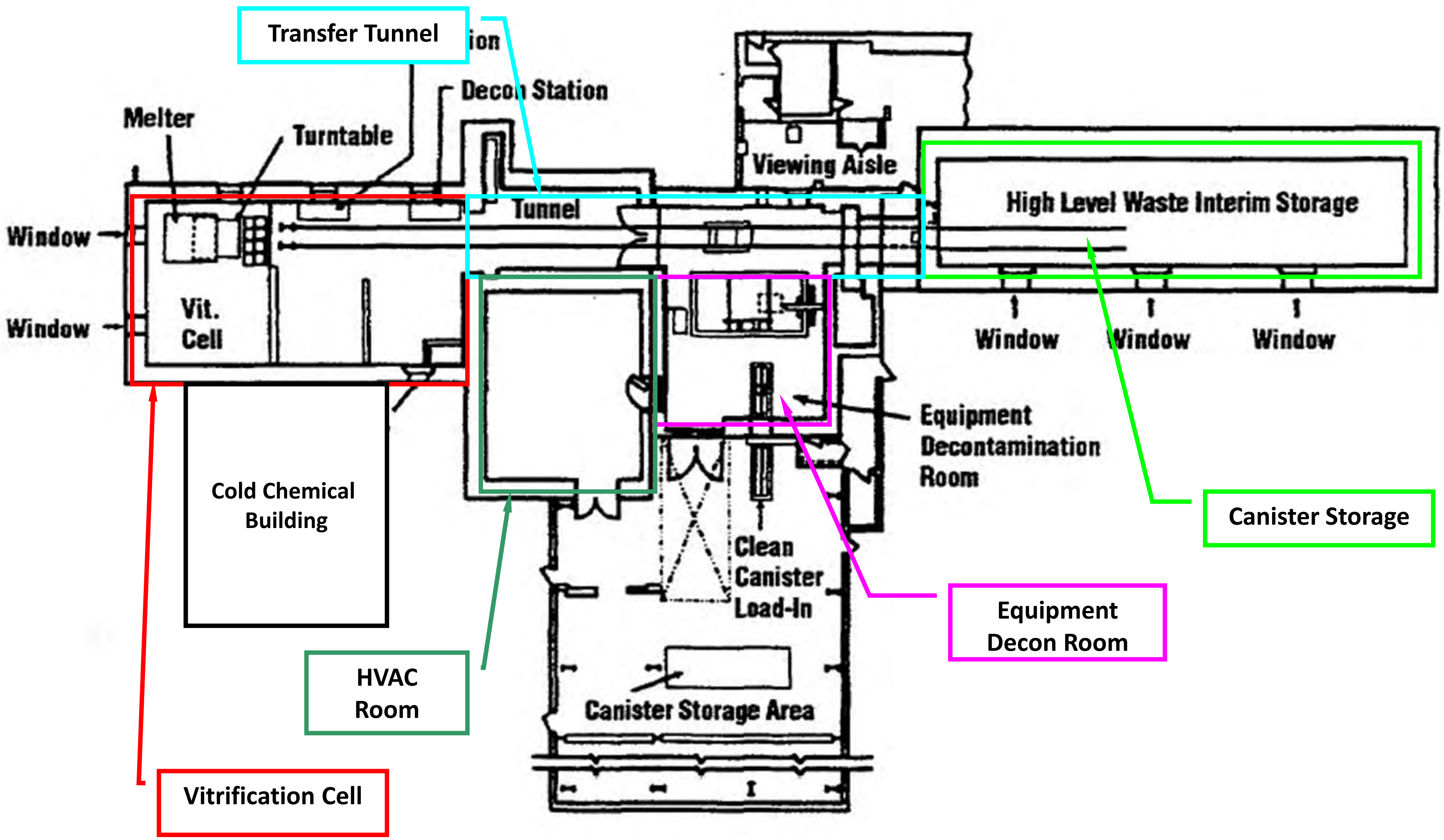
WVDP Vitrification Cell

WVDP: Vitrification Process

- Vitrification Process
  - Waste concentration and glass former addition
  - Vitrification and glass discharge
  - Melter emissions treatment
  - Container sealing and decontamination
  - Remote operation and maintenance

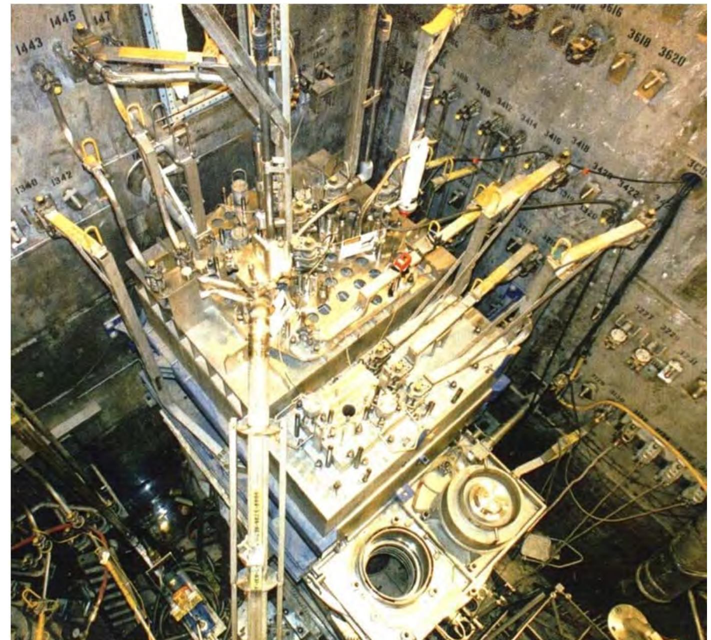


WVDP: Vitrification Plant Layout



WVDP: Melter

- Melter parameters:
  - $2.2\ m^2$ glass surface area
    - ~ 0.9 t glass per day
  - Three air-cooled Inconel 690 electrodes
  - Three-phase power
  - Fused-cast refractory lining
  - Water cooled welded SS shell
  - Two glass discharge chambers
  - Sloped bottom
  - Passive thermal expansion control



WVDP Melter

WVDP: Status

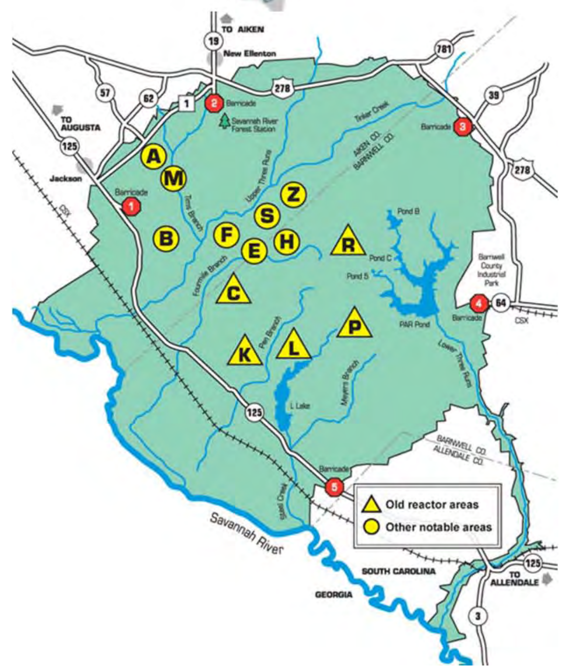
- 6 years of vitrification operations:
  - 1996 - 2002
- Bulk of waste processed in first two years
- 275 canisters of glass produced (~545 t glass)
- Borosilicate glass waste form
  - Glass formulation developed at Catholic University, Vitreous State Laboratory
  - Glass oxide basis:
    - ~19% PUREX
    - ~5% THOREX
    - ~17% Spent zeolite ion exchange media
- All waste processed and vitrification facility decommissioned
- Facility D&D completed; Facility reused for site D&D

Canisters in Storage

Empty Vitrification Cell

Savannah River

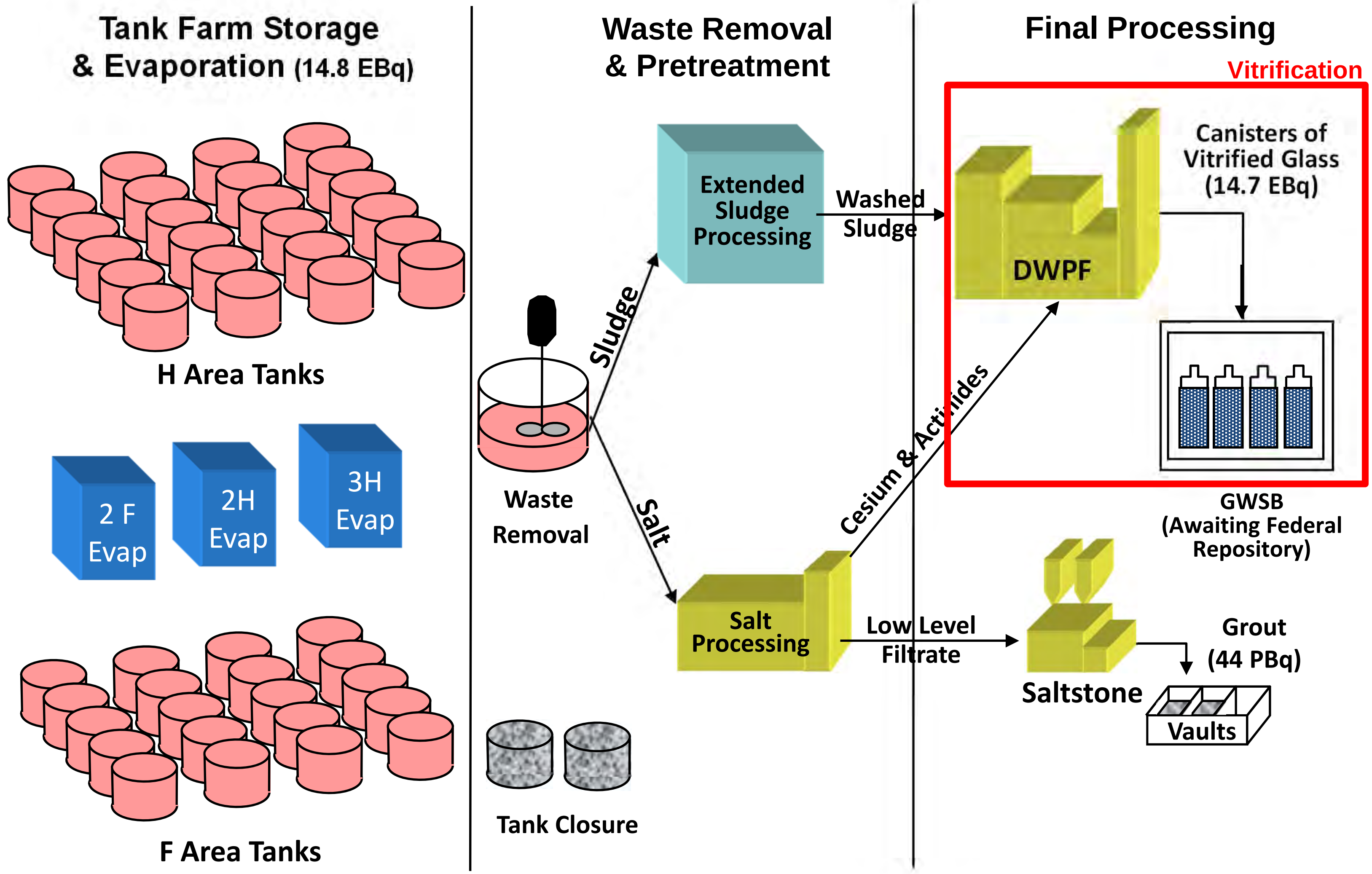
- What is the Savannah River site
  - U.S. Department of Energy nuclear weapons material production site
  - 310 square miles
  - Construction started in 1951
- What is on the site
  - Five large production reactors
  - Two reprocessing facilities
    - Processes used: PUREX and others
    - Tritium production facilities
  - 36 t of weapons grade plutonium produced



Savannah River Waste

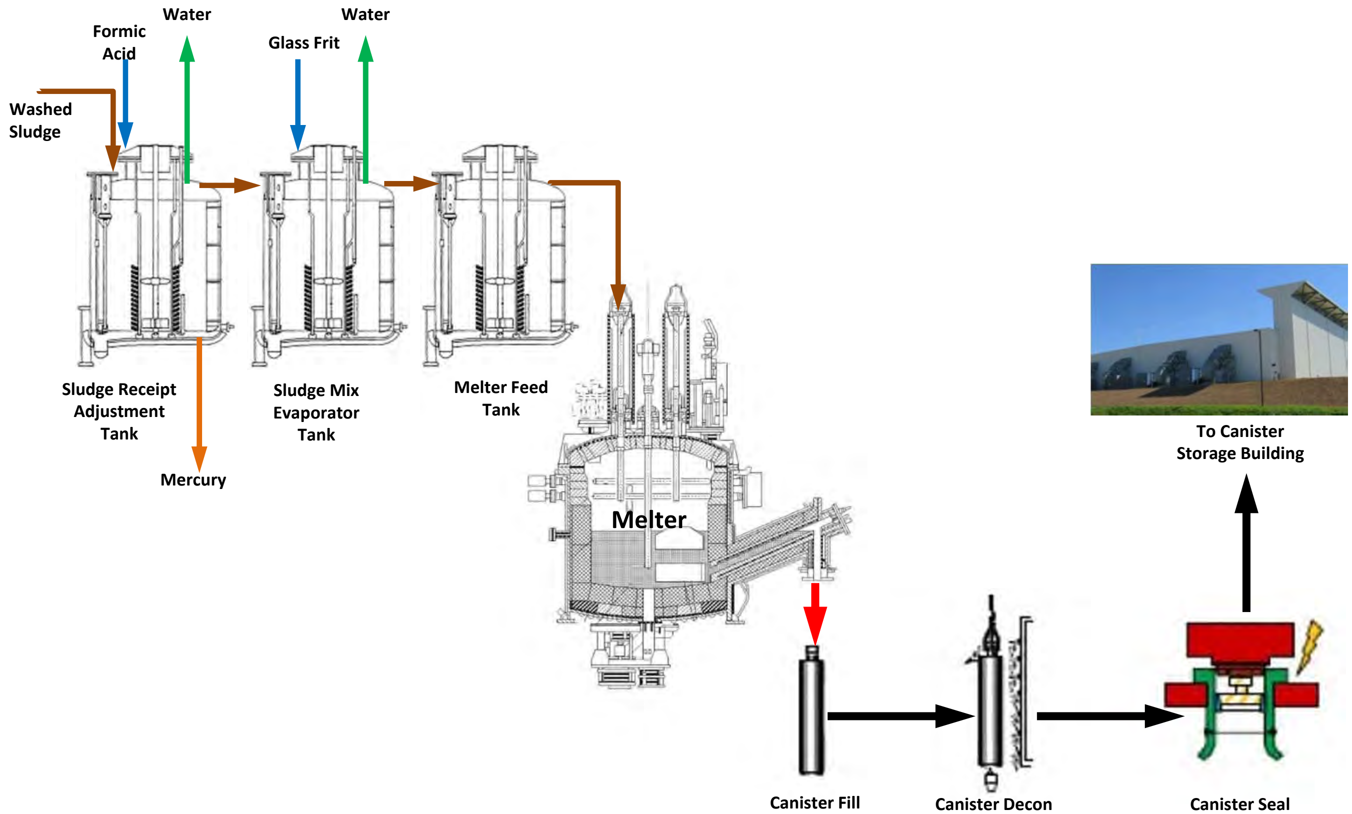
- The radioactive waste
  - 136,260 m^3 of highly radioactive waste
  - 10.4 million TBq of radioactivity
  - 150,000 t of chemical wastes
    - including nitrate, nitrite, mercury, cyanide, etc.
  - 24 “Single-Shell” Tanks
    - 2,839 to 4,921 m^3 capacity
    - 11 have leaked (one to environment)
  - 27 “Double-Shell” Tanks
    - 4,921 m^3 capacity
- All Tank waste to be treated
  - Waste is separated into HLW and LAW fractions
    - Sludge washing to remove sodium
    - Liquid
      - Adsorption/filtration for TRU removal
      - Solvent extraction for Cesium removal
  - HLW is being vitrified in the Defense Waste Processing Facility (DWPF)
  - LAW treated through cementation
  - Waste to be processed in a 40 year treatment campaign

Savannah River Process



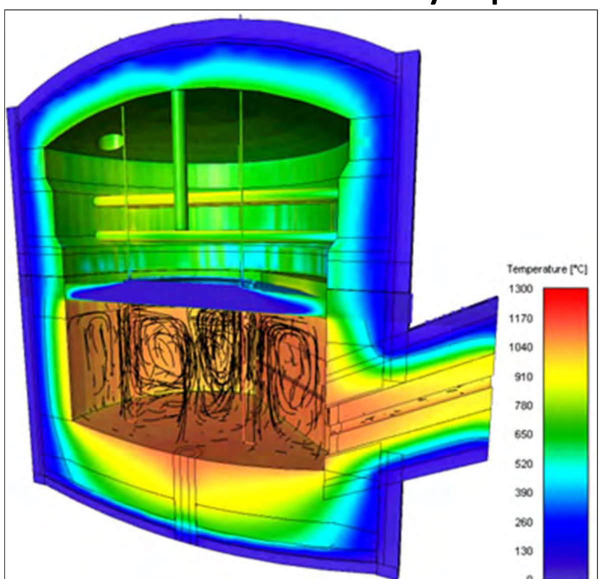
DWPF: Vitrification Process

- Vitrification Process
  - Washed sludge received and concentrated (mercury removal)
  - Glass frit is added and resulting slurry fed to melter
  - Vitrification and glass discharge
  - Melter emissions treatment
  - Container sealing and decontamination

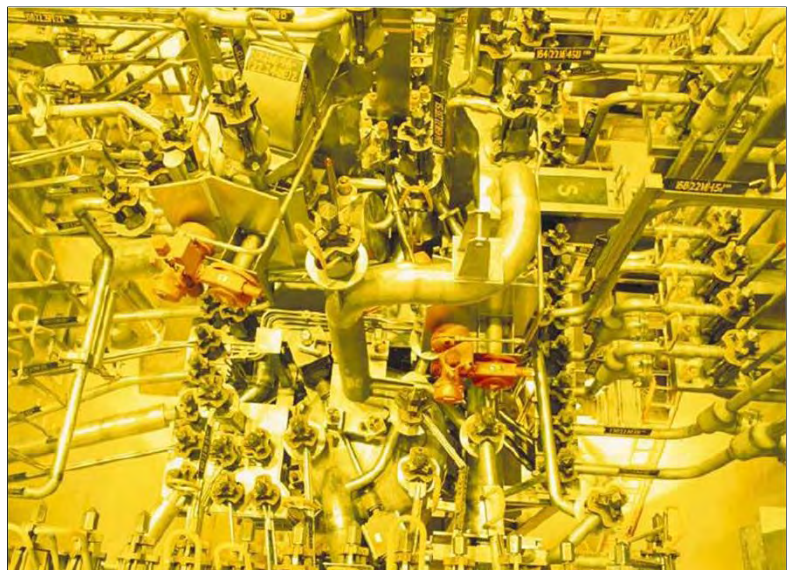


DWPF: Treatment Technology

- Melter Parameters:
  - Weight: 58 t
  - Exterior dimension (frame): 6.4m (L) x 3.4m (W) x 4.0m (H)
  - 2.6 m^2 molten glass surface area
  - 2600 L molten glass pool volume
  - Design production capacity 2 t/d (33-45 wt% waste loading)
    - Production rate recently enhanced through active glass pool mixing retrofit
  - Installed in remotely operated cell



DWPF Melter (model)


DWPF Melter Installed in Cell

DWPF: Status

- Status
  - Commissioned 1996 and in continuous operation for 19 years.
  - 20 years of operation remaining to complete waste treatment
  - 10,000 t HLW glass produced (3,965 canisters)
  - ~26,000 t of glass total to complete treatment (~8,600 canisters)

DWPF

DWPF Canister Storage Building

M-Area

- Title: Savannah River site Materials Area (M-Area) mixed waste treatment project
- Waste
  - 2,500 m^3 of Low Level mixed waste (RCRA listed plating line waste)
  - Waste contained in 11 tanks
  - Composition: sludge containing diatomaceous earth and perlite
  - Alkaline waste, high in Na, Al, P, U, Ni, nitrate
- VSL-Energy*Solutions* team won competitive procurement, 1995 – 1999
  - R&D, flow-sheet, glass formulation, design, build, operate, deactivate
  - Fixed price

SRS M-Area

M-Area Storage Tanks

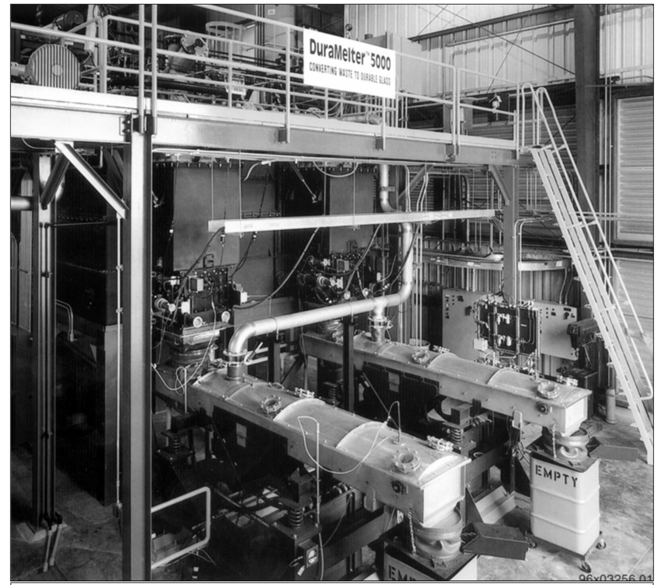
M-Area: Vitrification Process

- Glass formulation
  - Borosilicate glass formulations developed by Catholic University, Vitreous State Laboratory
  - High waste loadings (50-70%)
  - Chemical passivation to reduce refractory and electrode corrosion by high Na glass melts
  - Excellent product leach resistance
- Vitrification process:
  - Waste retrieved from tanks, combined with glass forming chemicals, and fed to melter
  - Vitrification and glass discharge
    - Glass formed into gems and collected in 270 L drums
  - Melter emissions treatment

M-Area Vitrification Facility

M-Area: Melter

- Slurry-fed JHCM
  - Mixed LLW + raw chemicals
- 5.0 m^2 glass surface area
  - Capacity: 5 t glass per day
- Air bubbler array to increase throughput
- Three electrodes
- Two-phase power
- Two air-lift discharge chambers
- Active thermal expansion control
- K3 contact refractory, AZS backup, H plenum, E riser
- Glass containment via thermal profile
- Glass discharged through "Gem" machines (product was glass marbles)



M-Area Melter

M-Area: Operation

- 44 Feed batches; 102 m^3 batch size
  - 489 t of glass product produced
- Very reliability plant operation
  - 80% total cumulative lifetime plant availability
- 2,800 270-liter drums were filled (70% volume reduction)
  - Glass sampled from 5 drums from every batch and subjected to TCLP
  - Every batch met requirements

M-Area: Status

- Status
  - Waste form delisted by U.S. EPA, allowing on-site disposal as LLRW
  - Facility D&D completed with area restored to brown field
  - Vitrification technology transferred to and implemented at WTP

Glass Waste Drums Awaiting Burial

Melter Emplacement in Burial Ground

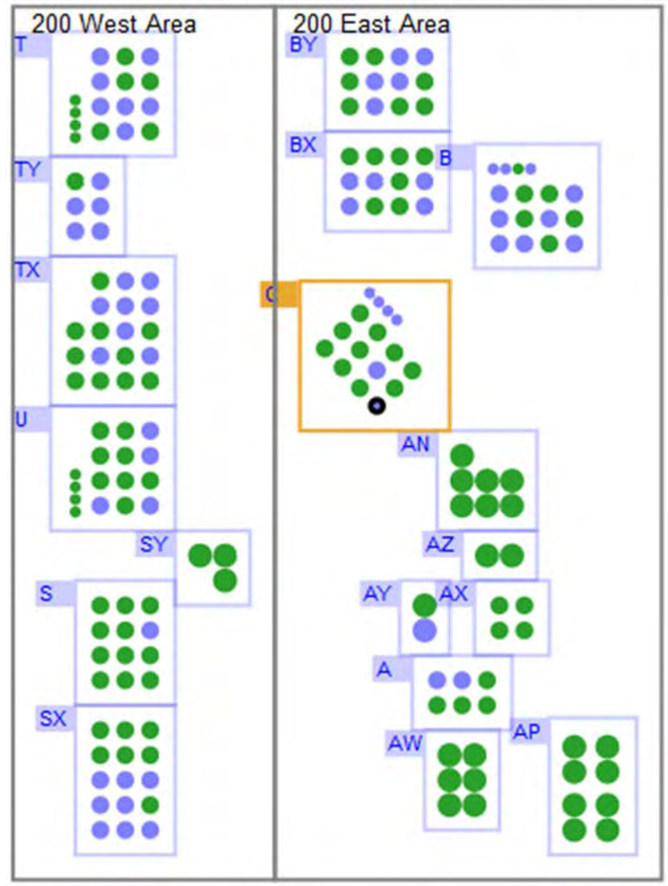
M-Area D&D Completed

Hanford

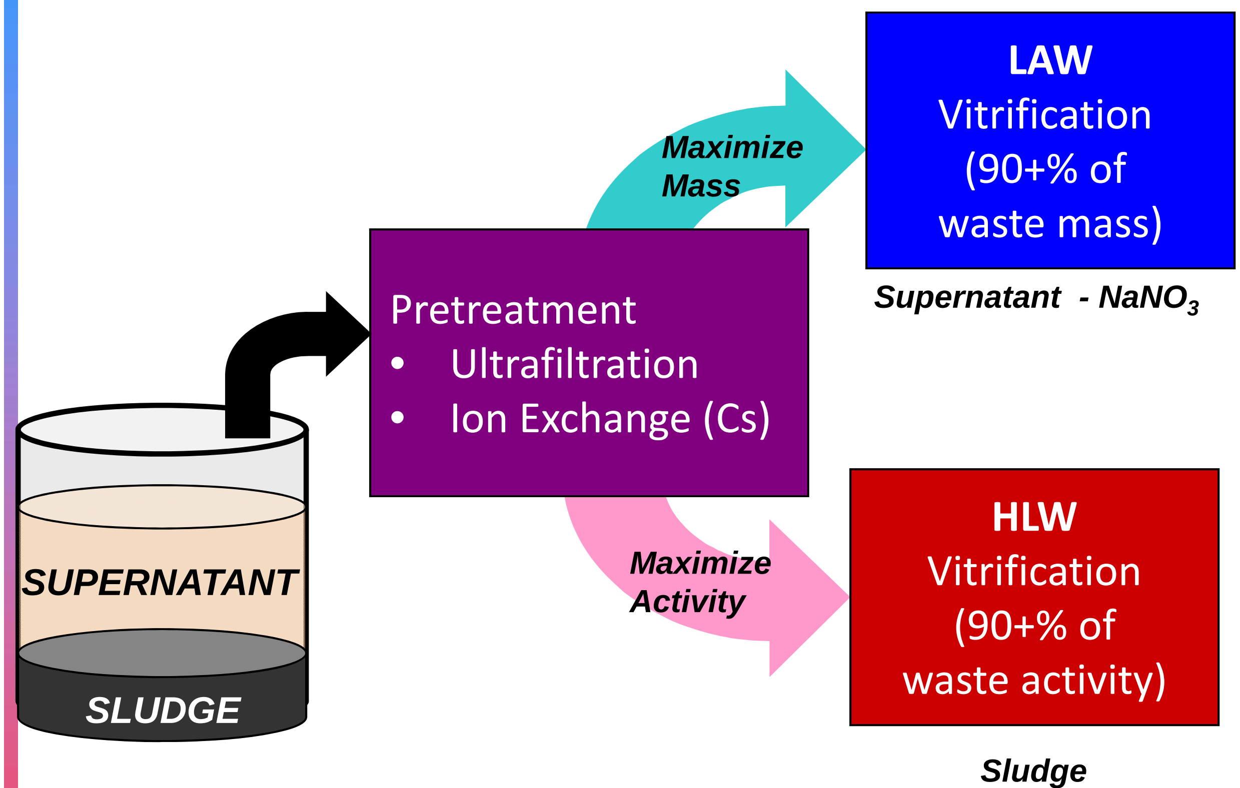
- What is the Hanford site
  - U.S. Department of Energy nuclear weapons material production site
  - 500 square miles
  - Construction started in 1944 (Pu for Nagasaki bomb)
- What is on the site
  - Nine large production reactors
  - Five reprocessing facilities
    - Processes used: Bismuth phosphate, Uranium recovery, REDOX, PUREX, Cs/Sr recovery, & others
  - 111 t of weapons grade plutonium produced

Hanford

- What happened to the waste
  - The short answer is that it is all still there stored in underground tanks
  - 213,000 m^3 of highly radioactive waste
  - 6.5 million TBq of radioactivity
    - 1000 kg of Plutonium in waste
  - 218,000 t of chemical wastes
    - including nitrate, nitrite, chromium (-6), sulfates, halides, organics, etc.
  - 149 “Single-Shell” Tanks
    - 190 to 4,000 m^3 capacity
    - 67 known or suspect leaking tanks
    - 4,000 m^3 and 37,000 TBq leaked to the soil
  - 28 “Double-Shell” Tanks
    - 4,000 to 4,400 m^3 capacity
    - 1 confirmed leaking into secondary containment
- All Tank Waste to be Vitrified
  - Waste to be separated into HLW and LAW fractions
  - HLW and LAW to be vitrified by separate facilities
  - Waste to be processed in a 30 Year treatment campaign



Hanford Waste Treatment Plant (WTP)



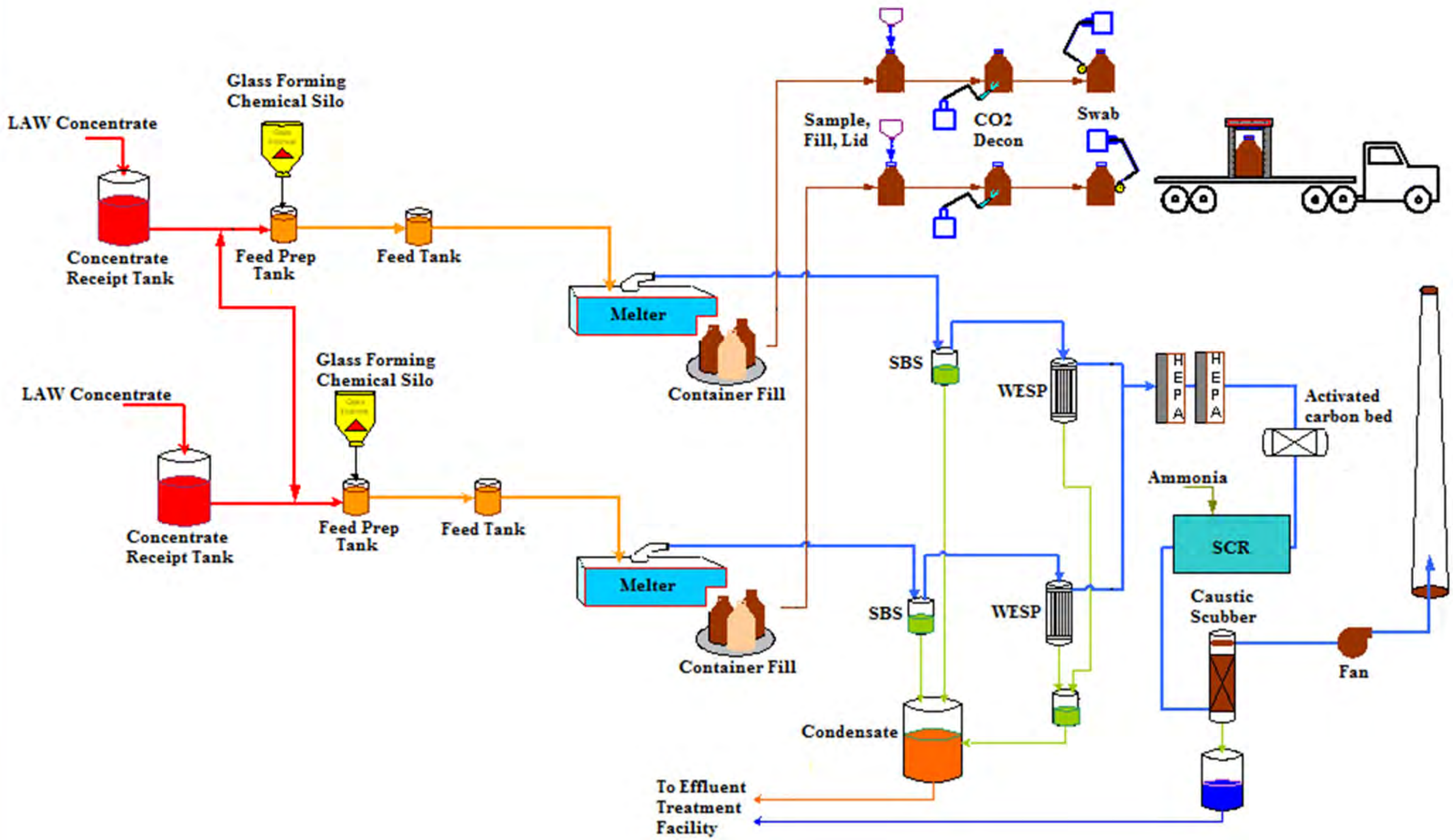
- **Meet WAC**
- **Maximize Waste Loading**
- **Manage Sulfate**
- **Manage Halides**
- **Glass Product Stays at Hanford**

- **Meet WAC**
- **Maximize Waste Loading**
- **Maximize Melter DF's**
- **Manage Noble Metals**
- **Glass Product to be transferred to Yucca Mountain or Alternative**

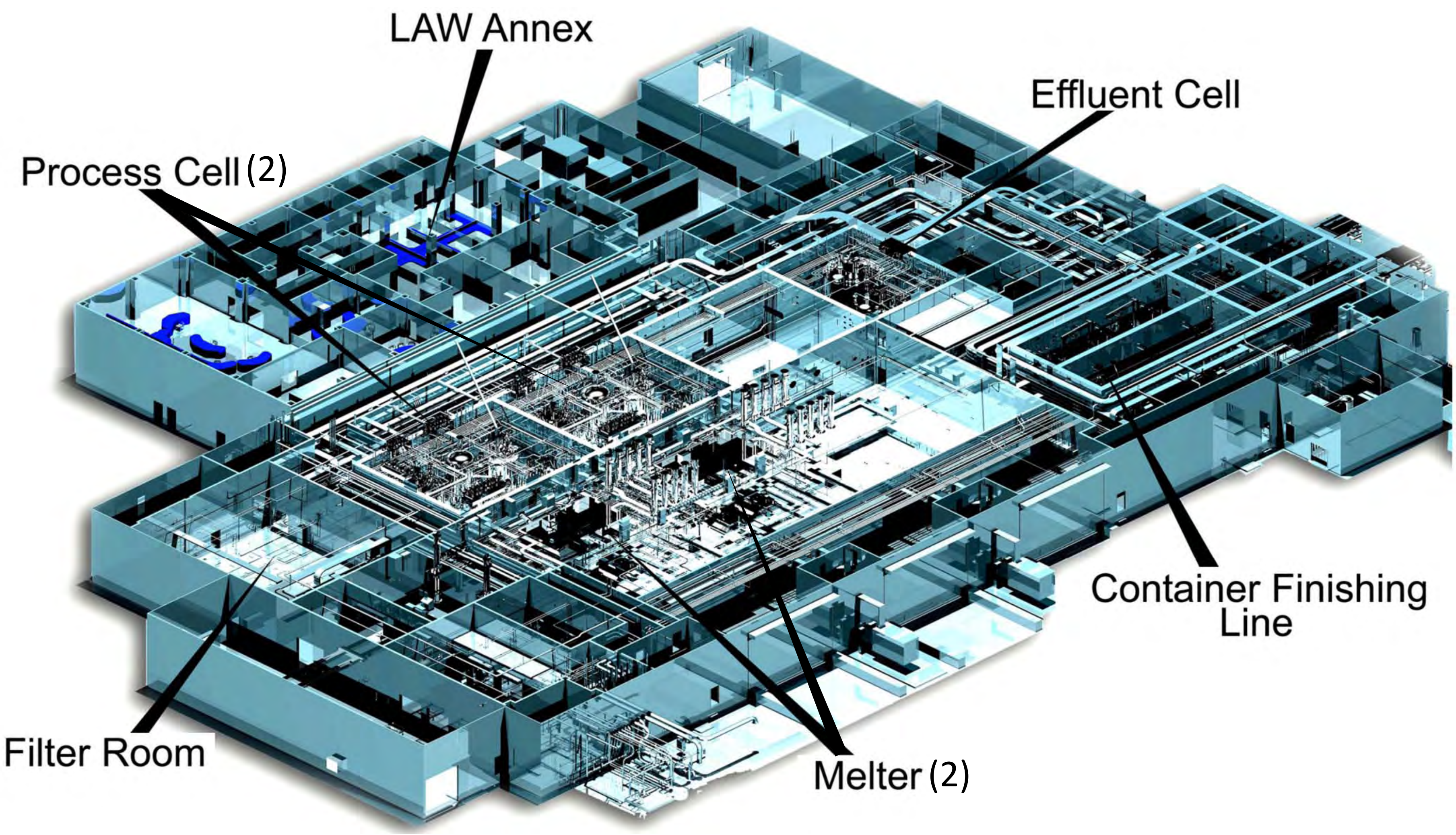
WTP: Design Requirements

- WTP elected to vitrify waste utilizing JHCM
- WTP processing requirements were extremely challenging
  - HLW glass production rate – 6 t/d @ 0.4 $t/m^2/d$ rate
  - LAW glass production rate – 30 t/d @ 1.0 $t/m^2/d$ rate
- The state of technology at the time (1998) in US
  - HLW – 1 MT/day from DWPF and WVDP (2.5 m^2 of glass pool area)
  - LAW – 5 MT/day from SRS M-Area facility (5 m^2 of glass pool area)
- Key issues that needed to be solved:
  - Very large physical melter size scale up
    - HLW – 2.2 to 4 m^2 ; LAW – 5 to 10 m^2
  - Very large processing rate scale up
    - HLW – 1.0 to 6 MT/day ; LAW – 5 to 30 MT/day
  - Troublesome waste components
    - HLW – Pt/Rh/Ru, PO_4, Bi, Cr, S ; LAW – S, Cl, and much Na
  - Widely varying waste composition ($BiPO_4$, Redox, & Purex processes; Uranium and Thorium fuel source)

WTP: LAW Vitrification Process

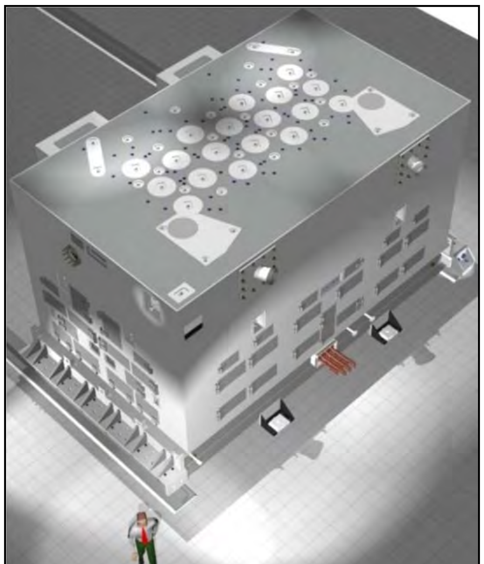


WTP: LAW Facility Layout



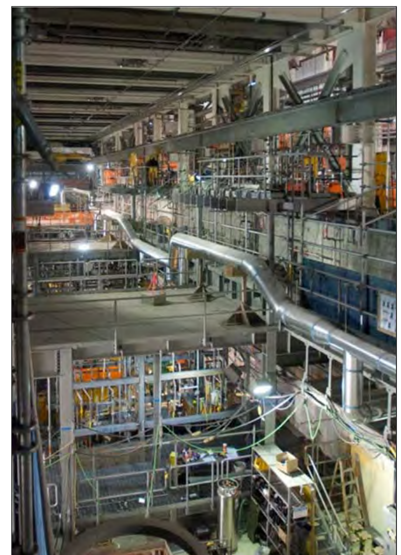
WTP: Treatment Technology - LAW

- LAW Production = 30 t glass/day (achieved through active glass pool mixing technology)
  - Weight: 299 t
  - Exterior Dimensions: 9m (L) x 6.6m (W) x 4.8m (H)
  - 10 m^2 glass pool surface area
  - 7630 L molten glass pool volume
  - Design production: 2 melters at 15 t/d each (35-45% waste loading)
  - Installed in gallery (melter provides shielding)



LAW Melter (model)

LAW Melter During Installation



LAW Melter Gallery

WTP: LAW Status

- Status
  - Construction of the plant continues
  - Highly successful development program
    - Glass formulations have been developed by the VSL for all waste streams
    - Large increases in glass waste loadings have been achieved reducing the final waste volume for disposal
  - Hot operations scheduled for 2022
    - LAW facility to start first
    - Followed by pretreatment and HLW
  - Glass to be produced
    - LAW – 527,838 t (95,825 LAW containers) – Local shallow burial
    - HLW – 31,968 t (10,586 HLW canisters) – Geologic repository

Waste Treatment Plant (WTP)

- The numbers:
  - $15,000,000,000 and >20 years to design/build
  - 263,000 cubic yards of concrete (26,300 concrete trucks)
  - 930,000 feet of piping (170 miles)
  - 40,000 tons of structural steel, enough to build three Eiffel Towers
  - 5,000,000 feet of cable and wire (900 miles)

LAW Facility

- LAW Vitrification Facility
  - 89% design complete
  - 86% procurement complete
  - 67% construction complete

Conclusion

- Conclusions
  - JHCM has successfully treated sludge/slurry wastes at production scale
  - Substantial cost savings have been achieved through waste volume reduction
  - The treated waste forms are highly stable and have meet all disposal requirements

- Contact information:

  - Eric Smith: esmith@energysolutions.com
  - Brad Bowan: BBowan@EnergySolutions.com
  - Ian Pegg: ianp@vsl.cua.edu