THE HANFORD SITE

Hanford: Remediation of the Tank Waste Legacy

Enhanced Waste Glass Program

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U.S. Department of Energy

September 25, 2023

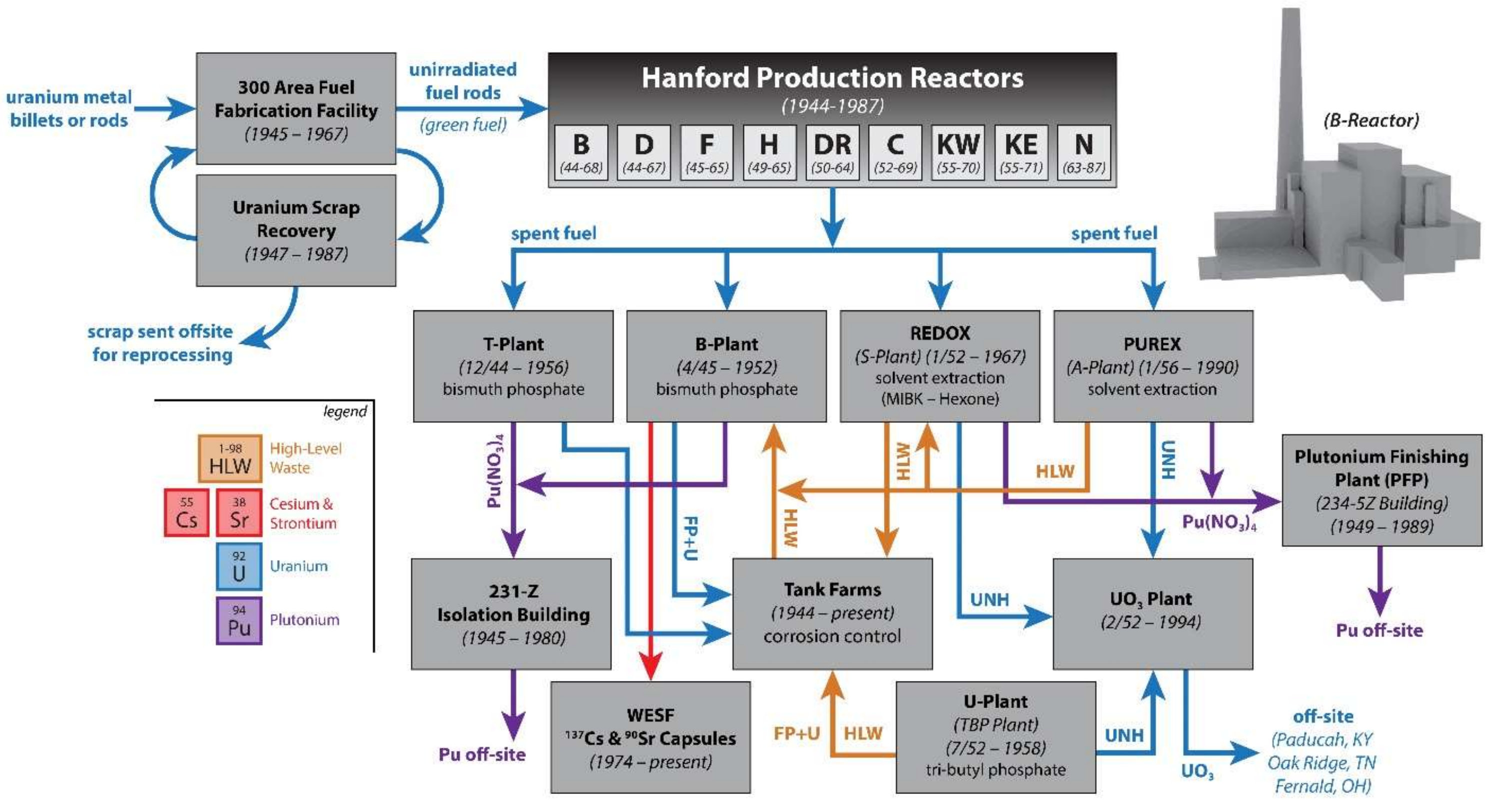
Key Messages

- Enhanced Waste Glass Program goal
- Challenges and approaches for vitrification at Hanford
- Advanced low-activity waste (LAW) and high-level waste (HLW) glass formulations allow the additional flexibility to reconsider feed vectors to the Waste Treatment and Immobilization Plant (WTP)
- Performance enhancements through improved glass formulations are essentially transparent to the engineered facility

Enhanced Waste Glass Program

- The overall goal and work performed is to expand the flexibility of the as-delivered WTP. Using chemistry to expand the waste loading or enhance the tolerance for artificially conservative component limits (e.g., aluminum, chromium, halides, phosphates, sulphates). Limits set back in the mid-1990s
- Glass chemistry and melting efforts report back to the ability to allow far greater processing capacity that can be introduced to the WTP as sustained operations are initiated and operator(s) experiences are realized
- Understanding of the influence of glass former and waste components on the feeding and processing of our waste will allow for the inclusion of common practice machine learning controls of the as designed/delivered WTP

Generation of Hanford Tank Wastes



[this drawing was modified from DOE/RL-2000-43]

9 reactors, 4 fuel reprocessing flowsheets, 100,000 MT fuel processed

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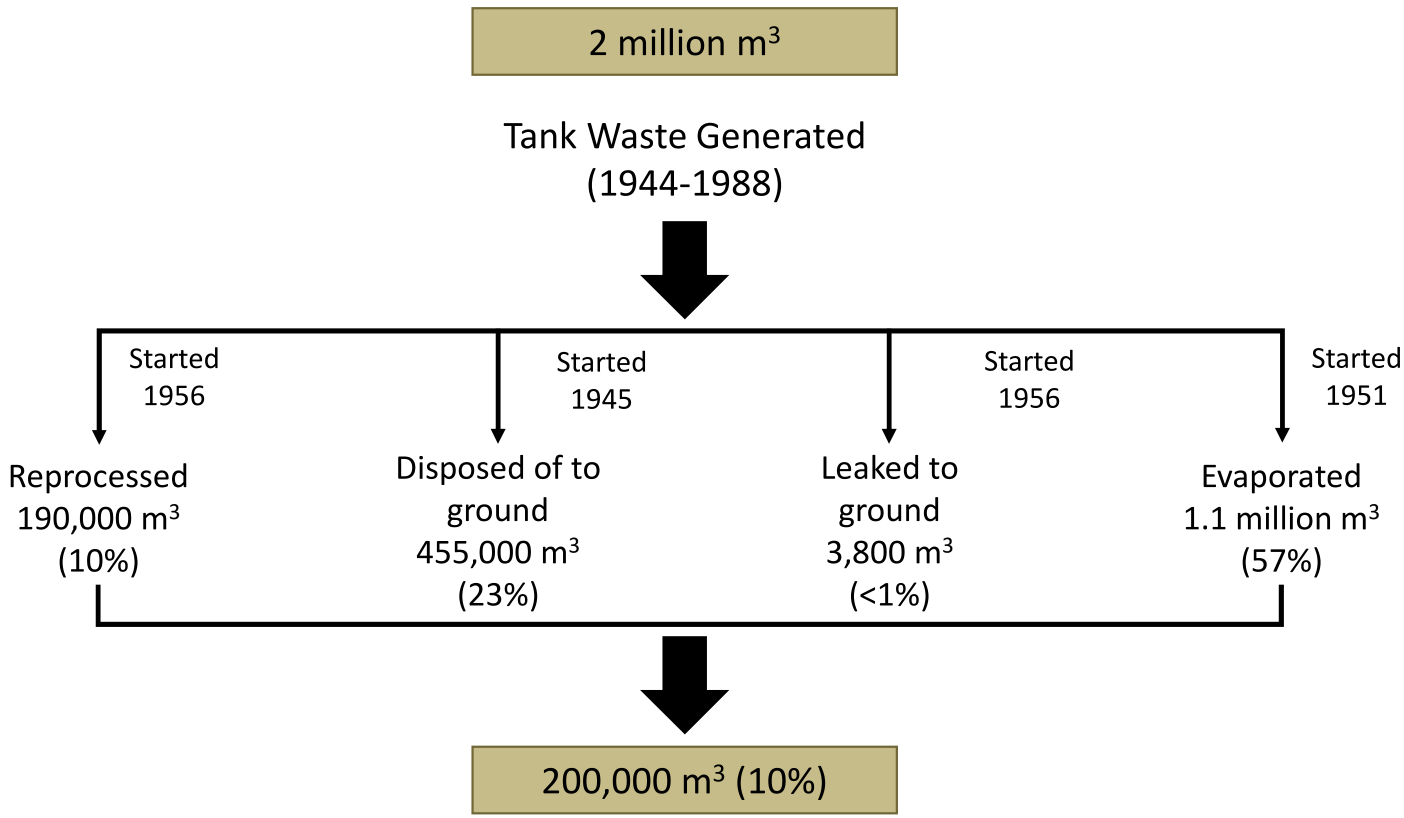
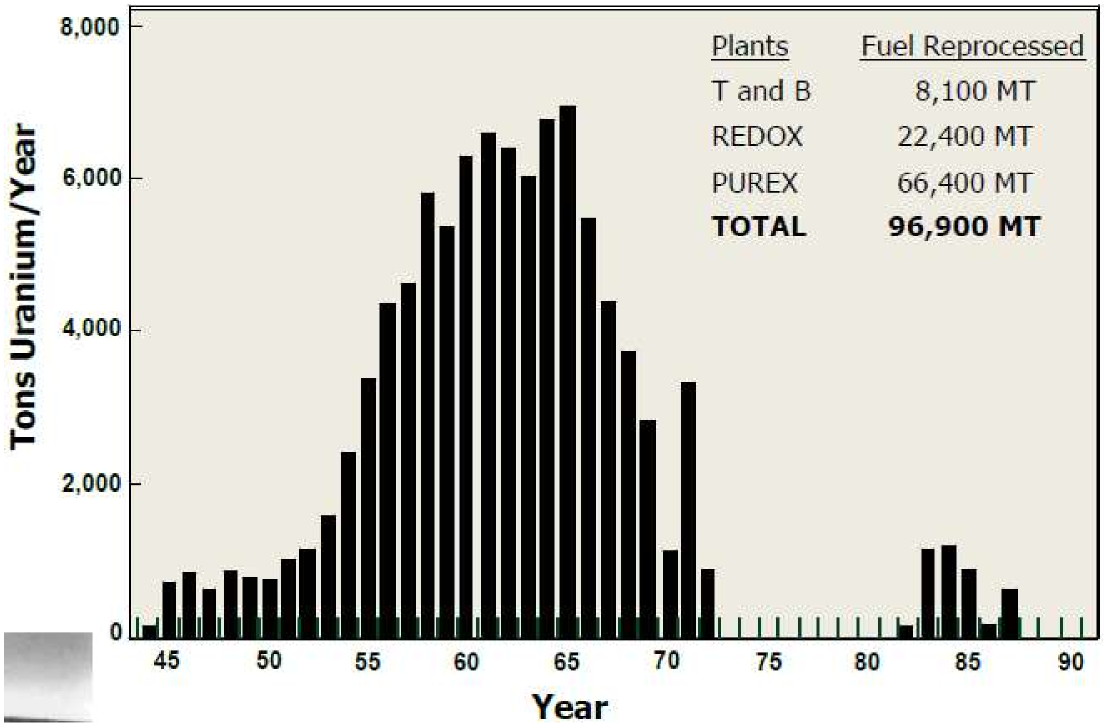
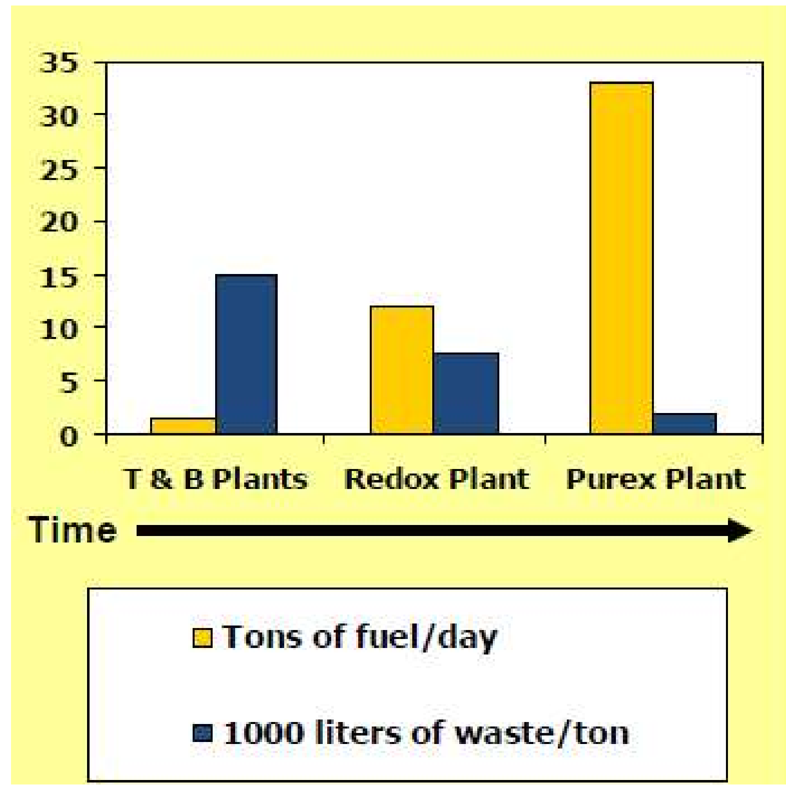
Hanford History



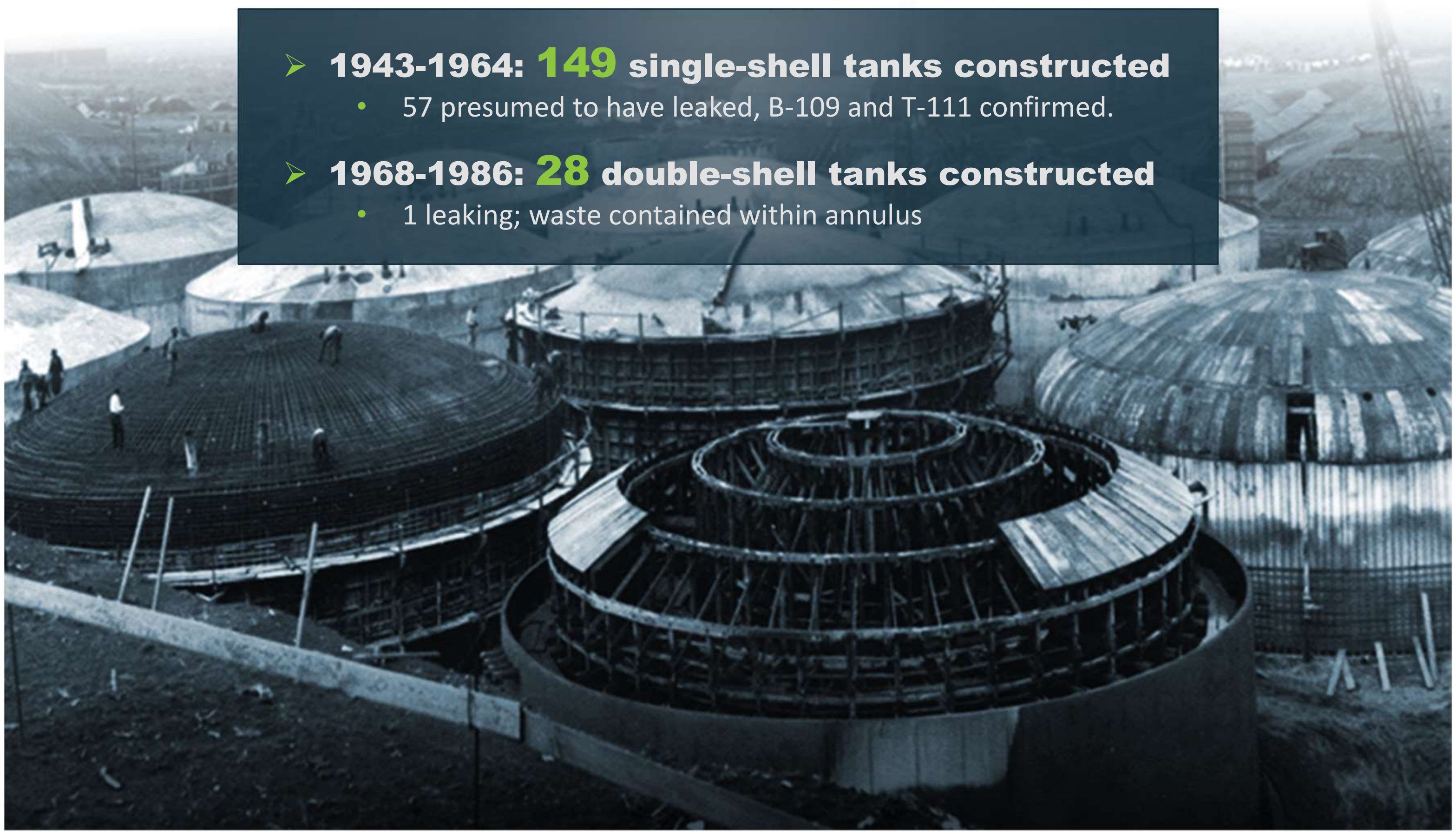
Hanford History (cont.)





Background

- **1943-1964: 149 single-shell tanks constructed**
  - 57 presumed to have leaked, B-109 and T-111 confirmed.
- **1968-1986: 28 double-shell tanks constructed**
  - 1 leaking; waste contained within annulus



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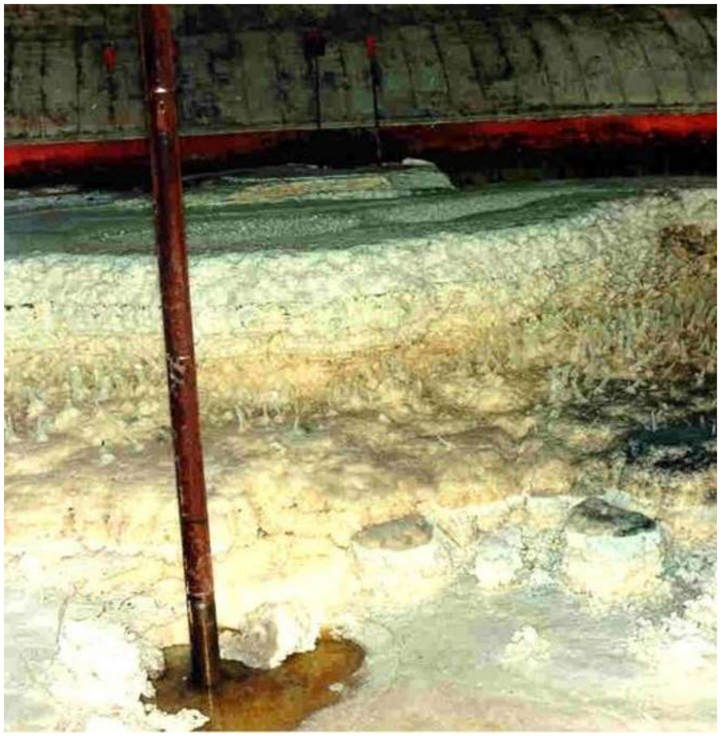
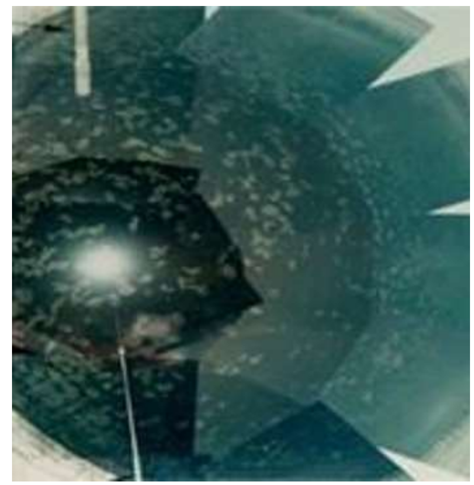
Tank Waste Characterization / Feed Control to Waste Treatment and Immobilization Plant



Saltcake – 23 million gallons

Sludge – 12 million gallons



Supernate – 21 million gallons

Saltcake

- Water soluble
- White to black (usually light brown)
- 10 to 50% water
- High in sodium, aluminum, anions, cesium-137

Herting and Barton Tank Chemical and Radionuclide Inventories: Source, Occurrence, and Speciation, 2008

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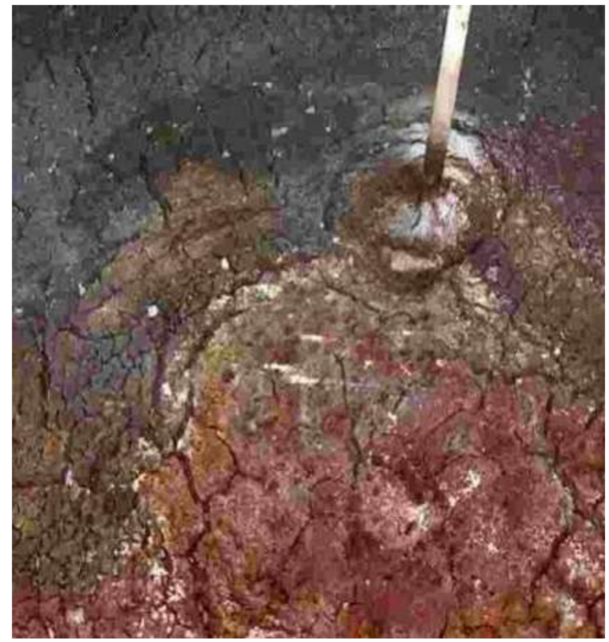
Sludge – Tank T-111


Sludge and debris – Tank SX-114


Sludge – Tank S-112

Sludge (cont.)

- Wet mud
- Water insoluble
- White to black (usually dark brown)
- 50 to 80% water
- High in iron, aluminum, silicon, manganese, strontium-90 and transuranic salts

Herting and Barton Tank Chemical and Radionuclide Inventories: Source, Occurrence, and Speciation, 2008

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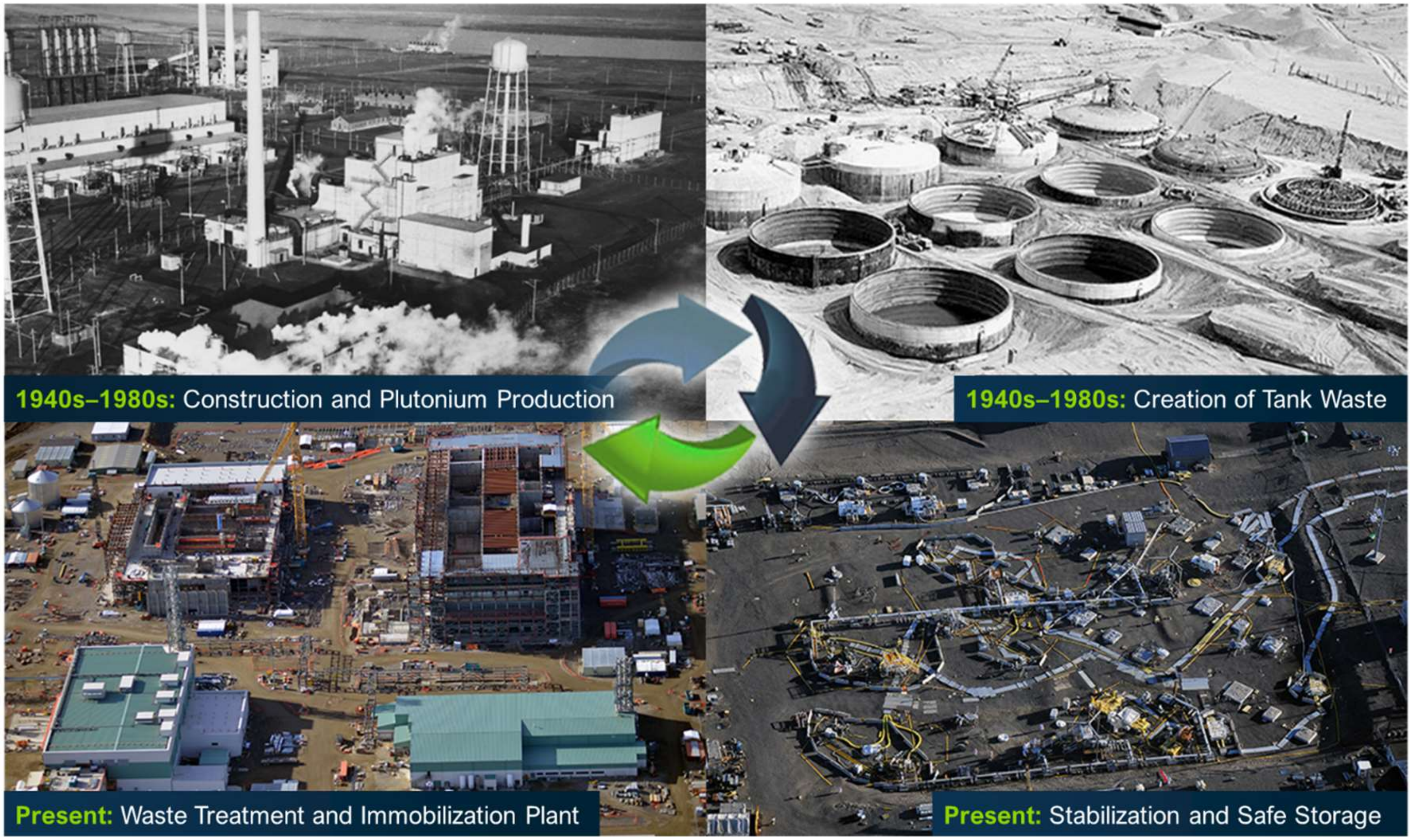
Tank Waste Chemical Constituents from Best Basis Inventory

Ion	Mass Percentage	Primary Process Contributing
NO_3^-	35.2	Nitric acid additions from fuel dissolution, Bismuth Phosphate Process (BPP), Reduction Oxidation (REDOX), and Plutonium Uranium Extraction (PUREX)
Na^+	31.8	Neutralizing, corrosion control, and solvent wash
NO_2^-	8.2	Corrosion control
CO_3^{2-}	6.7	Atmospheric absorption and solvent wash
Al^{3+}	5.6	Cladding removal and REDOX
PO_4^{3-}	3.2	BPP, Thorium Extraction, cesium/strontium recovery
SO_4^{2-}	2.3	BPP, REDOX, PUREX, cesium/strontium recovery
$C_2O_4^{2-}$	1.0	Oxalate precipitation
TOC	0.8	Several
F^-	0.8	Cladding removal, BPP, REDOX
Fe^{3+}	0.8	PUREX, BPP, REDOX, corrosion product
K^+	0.7	Uranium recovery, solvent wash, neutralization, corrosion control
Cl^-	0.6	Chemical impurity, uranium recovery
Si^{4+}	0.5	Diatomaceous earth, PUREX, REDOX
U^{4+}, U^{6+}	0.4	BPP
Cr^{3+}, Cr^{6+}	0.4	BPP, corrosion control, corrosion products
Bi^{3+}	0.4	BPP
Zr^{4+}	0.3	Cladding removal
Ca^{2+}	0.2	Several
Other	0.1	Includes nearly the entire periodic table

ENERGY

HANFORD

Hanford Site Historical Overview



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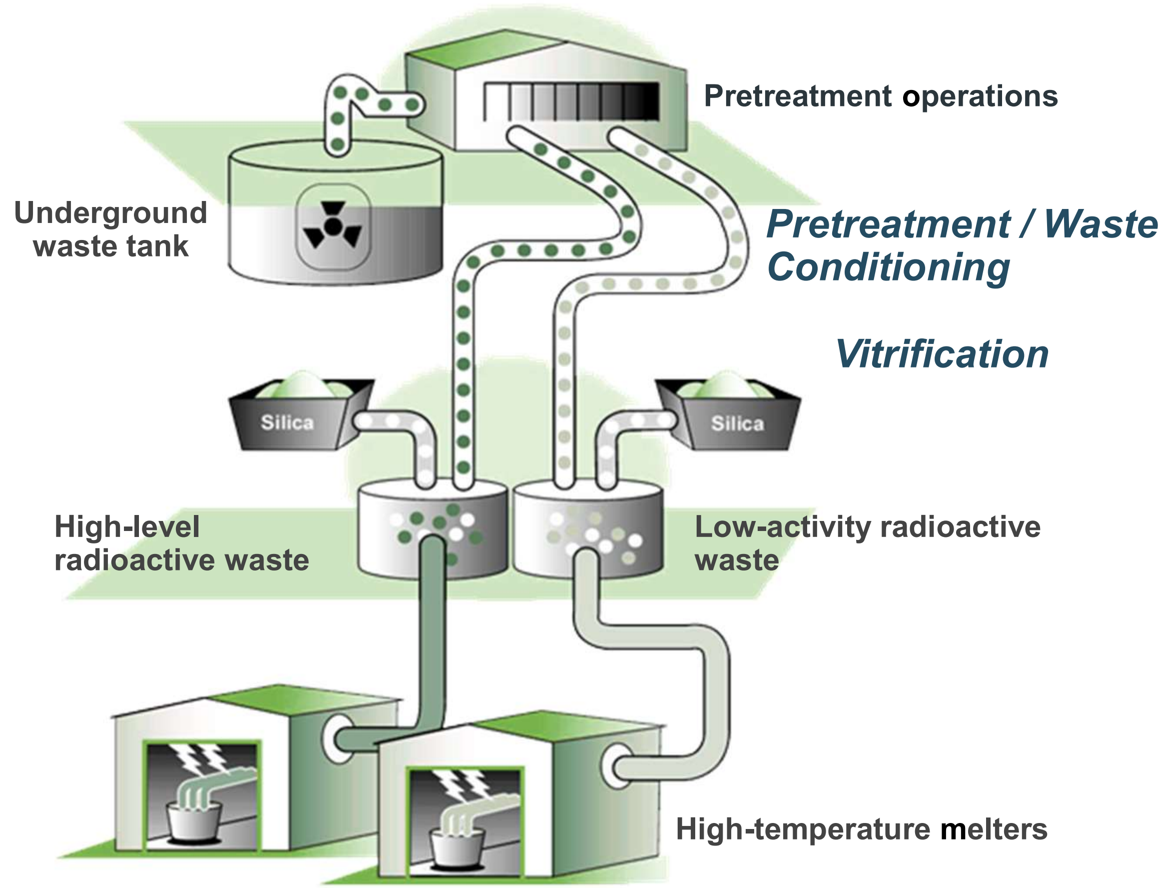
Waste Treatment and Immobilization Plant Site

Western-facing aerial of Waste Treatment and Immobilization Plant, June 2022

Facilities Existing (or Planned) at Waste Treatment and Immobilization Plant

Facility Name	Abbreviation	Description
Pretreatment Facility	PT Facility	Receives waste and separates it into LAW and HLW
Low-Activity Waste Facility	LAW Facility	Receives LAW, mixes with glass forming chemicals (GFC), vitrifies mixture to form immobilized low-activity waste glass, treats process gases
High-Level Waste Facility	HLW Facility	Receives HLW, mixes with GFCs, vitrifies mixture to form HLW glass, treats process gases
Analytical Laboratory	LAB	Analyzes samples from WTP operations, supplies data for safe operations, qualifies glass for disposal
Tank-Side Cesium Removal System (operated by tank operations contractor)	TSCR	Treats liquid waste to remove radioactive cesium and solids and delivers LAW to LAW Facility
Effluent Management Facility	EMF	Evaporates LAW liquid effluents into concentrated and diluted streams for recycling and treatment/disposal, respectively
Supplemental LAW Treatment (to be designed and built)	SLAW	Operation to treat LAW fractions over the treatable fraction

Vitrification Process



Waste Treatment and Immobilization Plant Baseline Treatment Mission Projections

	BNI/WTP Baseline Models	2008 TUA[a] Baseline
HLW Canisters	18,400	14,838
LAW Containers	145,000	91,400
Total Canisters and Containers	163,000	106,238

[a] The “2008 models” were altered in anticipation of our work.

BNI = Bechtel National, Inc.
HLW = high-level waste
LAW = low-activity waste
TUA = tank utilization assessment
WTP = Waste Treatment and Immobilization Plant

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Glass Science Activities and Accomplishments

Office of River Protection Glass Science Activity	Program Objective	Impact or Desired Result on the Mission
• Glass Program	• Broaden glass compositional region of acceptable glasses • Reduce Complexity or eliminate caustic dissolution in the Pretreatment Facility	• Reduce WTP mission duration • Provide greater WTP operational design flexibility • Improve process equipment reliability • Meet waste disposal criteria • Improve cost efficiency (operations, maintenance, mission)
• Update HLW glass models • Increase Al_2O_3 concentrations • Increase Cr_2O_3 concentrations • Develop alternative nepheline formation model	• Reduce Pretreatment Facility process. Reduce or eliminate oxidative leaching in Pretreatment Facility; minimize carry-over plutonium • Increase tolerance for SO_3 and sodium waste loading in LAW	• Offer flexibility in the feed vector • Increase waste loading
• Update LAW glass models • Increase SO_3 solubility	• Increase Na_2O concentrations in glass while maintaining process and product performance requirements	• Offer flexibility in the feed vector • Reduce the LAW effluent • Increase waste loading, reduce need for supplemental treatment • Crossover: May be applicable to Defense Waste Processing Facility (DWPF) washing strategies • Crossover: Could support DWPF glass formulation efforts, assuming Na_2O management is still an issue for future operations with the Salt Waste Processing Facility

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Glass Science Activities and Accomplishments (cont.)

Office of River Protection Glass Science Activity	Program Objective	Impact or Desired Result on the Mission
• Improve single-pass technetium retention	• Simplify supplemental treatment • Reduce secondary waste	• Reduce the LAW effluent
• Cold cap and melter modeling • Development of lab-scale melter/research lab-scale melters (cold and radioactive) for cold cap dynamic studies • Provide key input for modeling and understanding of waste-feed-to-glass processes • Technetium volatility/retention	• Develop and validate models to define testing needs and assist in plant operations • Provide key input for modeling and understanding of waste-feed-to-glass processes • Support to the Integrated Disposal Facility (IDF) Performance Assessment – partitioning of technetium in offgas system	• Reduce the LAW effluent • Provide process information for glass model development • Reduce uncertainty and risk in design underpinning and operations • Validated models can provide efficient first approximations for plant issue resolution and lower cost of testing
• Demonstrate alternative glass contact refractory	• Identify a refractory offering needed durability • Understand buildup of certain materials of interest, melter or offgas (cesium, SO_3 salts, halides)	• Eliminate the dependence on a single source for melter K3 and E brick refractory • Mitigate or avoid effect on plant availability

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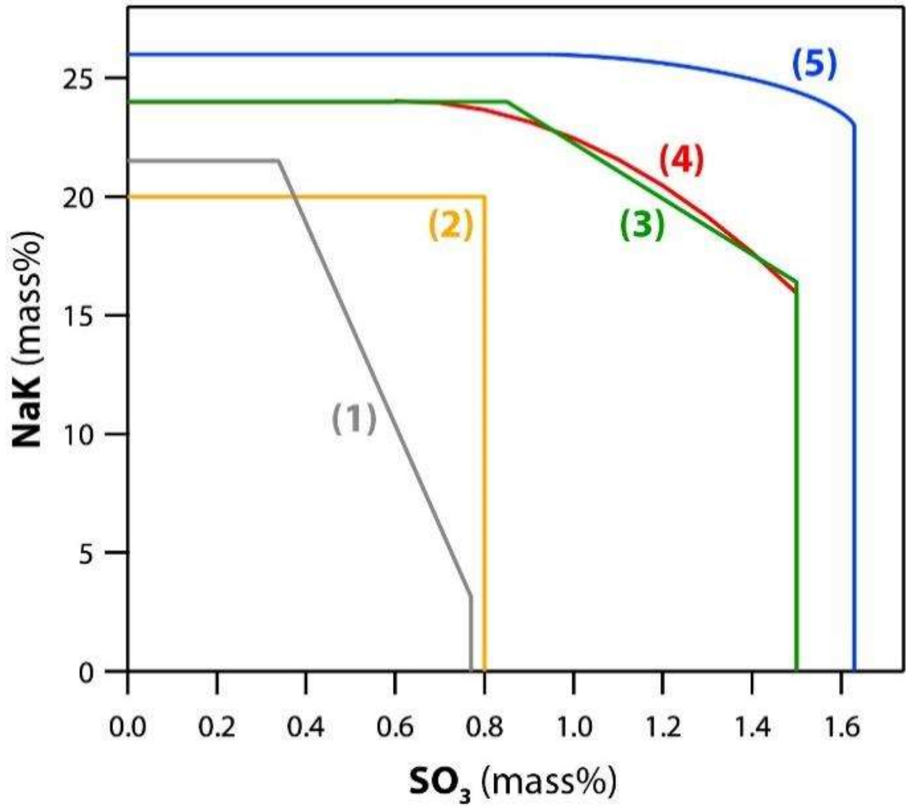
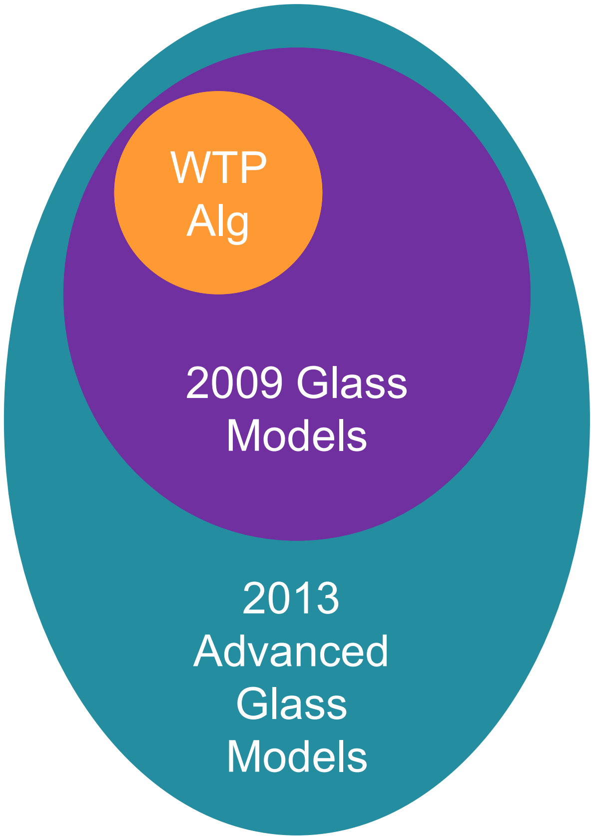
Waste NaK (= Na_2O+0.66K_2O) and SO_3 Loading (Mass%)



(1) ORP-56326, (2) ORP-68871, (3) PNNL-25835, (4) VSL-19R4460-1, (5) PNNL-30932

Office of River Protection Enhanced Waste Glass Work

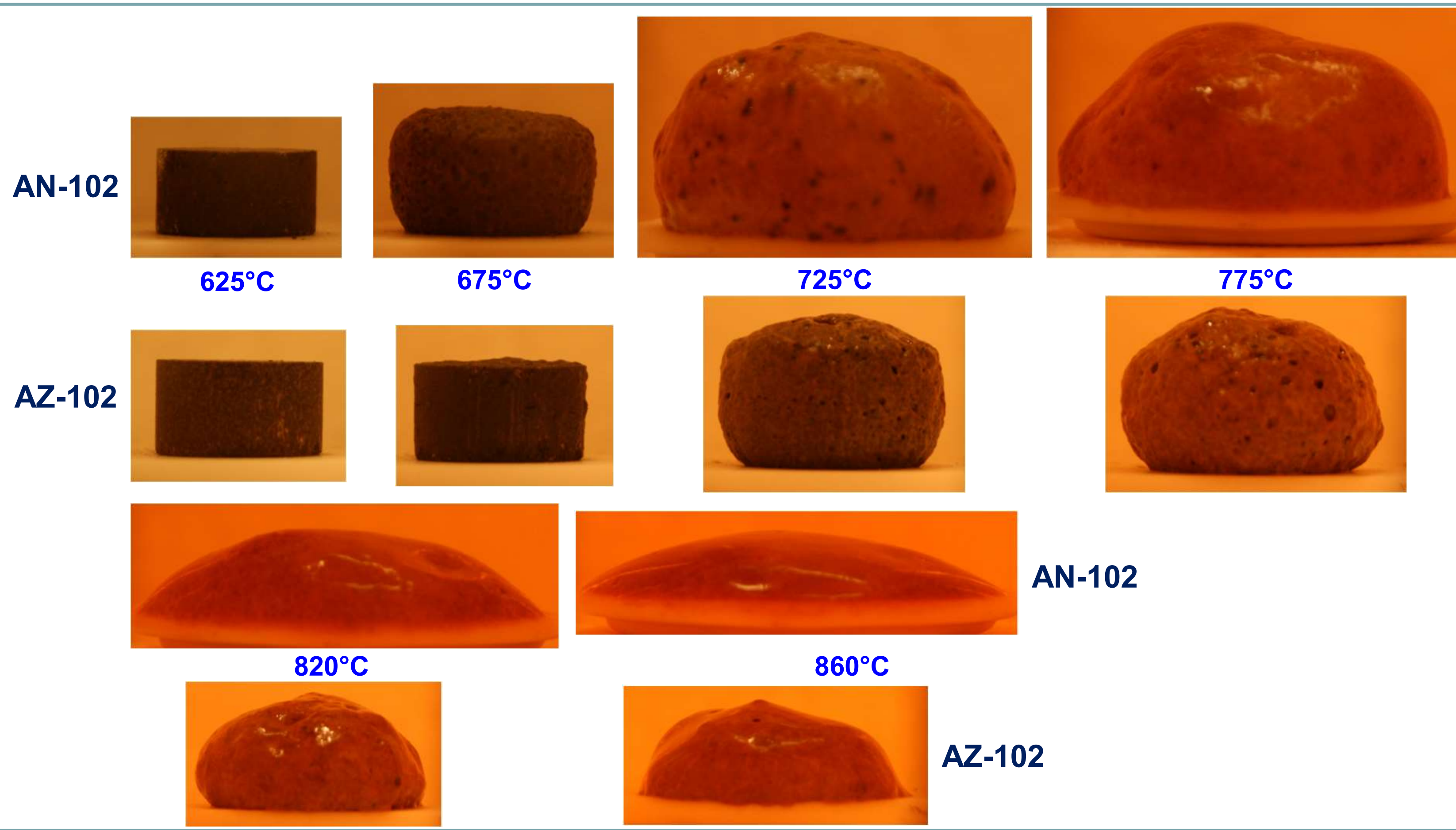


- Recent glass testing has covered significantly broader composition space and new methods have reduced conservatism
- Large increases in loadings of aluminum, chromium, sodium and sulfur have been demonstrated at laboratory and melter scales

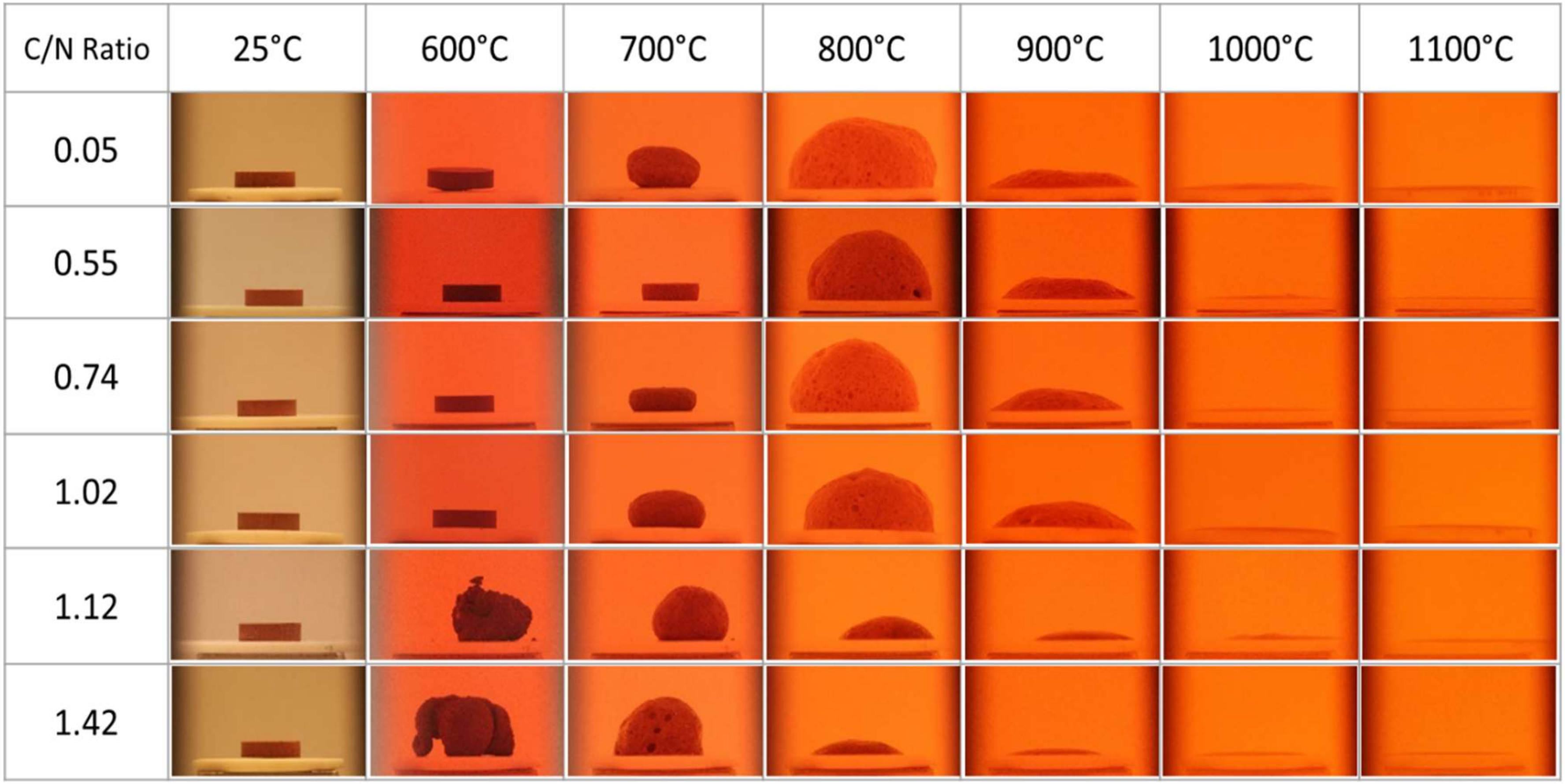
HLW Comp	WTP Baseline	HTWOS Models	Advanced Models	Demonstrated
Al_2O_3	13	20	28	>30
Cr_2O_3	0.6	1.2	3	6
Na_2O	20	21.4	23	26
SO_3	0.44	0.6	1.6	1.9

HTWOS = Hanford Tank Waste Operations Simulator

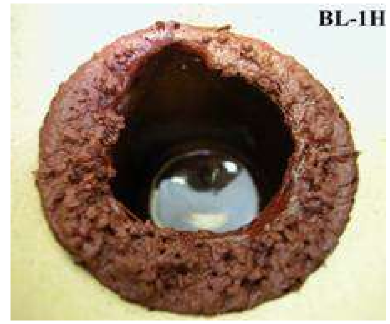
Feed Pellet Expansion



Pellet Profiles vs. Carbon/Nitrogen Ratio and Temperature



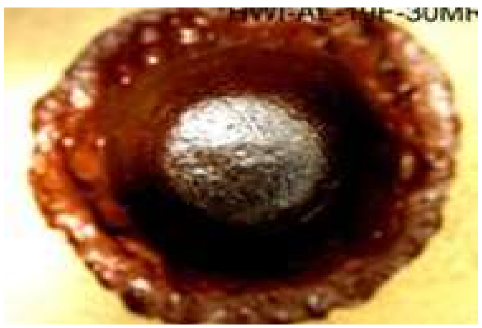
Melting High-Aluminum Feed



30 min | 45 min | 60 min

Reaction Time

Initial formulation



30 min | 60 min

Improved formulation

Improvements confirmed in one-third scale pilot melter tests

Glass Formulation Options

- Interpolation between successful glass compositions
  - Successfully used for WTP baseline LAW glass formulation (validated)
  - Reduce risk of process upsets
  - Necessitates significant conservatism
- Numerical optimization using property models and constraints
  - Successfully used for WTP baseline HLW glass formulation (validated)
  - Reduces conservatism
  - Easily handles unanticipated waste feed compositions
  - Directly addresses process uncertainties

Formulating Glass

$$g_i = Ww_i + (1\text{-}W)a_i$$

$$P = \widehat{P}_T\,(g_1, g_2, \ldots, gn)$$

For a given waste composition (w_i),
determine mineral addition (a_i),
to obtain glass composition (g_i),
with optimized properties (P),
and maximized waste loading (W)

The selection of properties to be optimized depends on melter technology and glass acceptability criteria

Summary of Component Concentration Effects on Immobilized Low-Activity Waste Glass Properties

Oxide	Al_2O_3	B_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	Li_2O	MgO	Na_2O	SiO_2	SnO_2	TiO_2	ZnO	ZrO_2	Other
Viscosity	↑	↓	↓	↔	↔	↓	↓	↓	↓	↑	↑	↓	↔	↑	–
EC	↔	↔	↔	↔	↔	↑	↑	↔	↑	↓	↔	↔	↔	↔	–
Crystal	↑	↓	↓	↑	↑	↓	↓	↔	↓	↓	↑	↑	↑	↑	NiO, MnO
PCT	↓	↓	↔	↔	↔	↑	↑	↑	↑	↓	↓	↓	↔	↓	–
VHT	↓	↓↔	↔	↔	↔	↑	↑	↔	↑	↓	↓	↓	↔	↓	–
Nepheline	↑	↓	↑	↔	↔	↑	↑	↔	↑	↓	↔	↔	↔	↔	–
Salt	↑	↓	↓	↑	↔	↓	↓	↔	↓	↑	↔	↔	↔	↔	SO_3, Cl, $V_2O_5^{-}$
TCLP	↓	↑	↔	↔	↔	↑	↑	↔	↑	↓	↓	↔	↑	↓	–
Corrosion	↓	↔	↔	↓	↓	↑	↑	↔	↑	↓	↓	↔	↓	↓	–

↑ = increase property
↓ = decrease property
↔ = small effect on property
Multiple arrows are for nonlinear effects; the first is for lower concentrations and the second for higher concentrations.
"Corrosion" denotes corrosion of glass contact materials (primarily Monofrax™ K-3 and Inconel™ 690).
TCLP = toxicity characteristic leaching procedure
VHT = vapor hydration test
EC = electrical conductivity
PCT = Product Consistency Test

- Glass formulation algorithm: Enable WTP to implement enhancements in glass formulation (which expanded the glass composition envelope to reduce risk and allow for broader range of waste feeds)
- Glass data in areas of high uncertainty: Reduce conservatism and increase precision in property prediction (allows for increased loading)
- Expand glass composition boundaries: Increase process flexibility and allow for broader range of waste composition variations
- Cold cap and melt dynamics: Enables prediction of processing performance from melter feed composition/additives, allows manipulation of performance by changes in additives, and provides capability to respond to WTP melter processing issues rapidly and efficiently

Pacific Northwest National Laboratory (cont.)

- Integrated melter modeling: Once built and validated, modeling tools and simulations are often more efficient than physical testing and can be run prior to testing to ensure the right tests are designed and performed
- Melter offgas testing capability: Complete and demonstrate adaptive vitrification evaluation system offgas testing capability. System will allow generation and testing of representative melter offgas from short-duration tests.
- Glass-former testing and evaluation: The raw material supply chain will continue to change throughout the life of the WTP. Efficient evaluation and qualification of glass formers will remain key to maintaining full throughput operations and avoiding potential issues.

Idaho National Laboratory

Integrated melter model development: Improve the fidelity of the integrated melter model to describe the relevant physics occurring in the molten glass, melter atmosphere and cold cap, as well as their interfaces. Continue to develop and incorporate submodels to represent the complex, coupled electromagnetic, hydrodynamic, chemical and thermal phenomena. Identify data that can be used to develop submodels for incorporation into the integrated melter model for melters at various scales:

- Implement new cold cap submodel in integrated melter model
- Implement an improved representation of plenum gases in the integrated computational fluid dynamics (CFD) model
- Develop CFD model of full-scale LAW melter
- Validate computational models
- Assist with the development of a test-melter system

Savannah River National Laboratory

- Sample analysis: Savannah River National Laboratory (SRNL) provides support for Pacific Northwest National Laboratory (PNNL) in generating LAW and HLW glass property-composition data
- Nepheline crystallization studies: SRNL continues to develop the structural integrity of residual glass model developed in fiscal year 2020 by investigating the influences on chemical durability caused by altering the composition/concentration of minor components
- Refractory corrosion: Performed jointly with PNNL to estimate the degradation rate of melter refractory block and materials. It is known that the predictive life of melter refractory block is conservative, as demonstrated by performance of these materials such as in the DWPF.

Savannah River National Laboratory (cont.)

- Production and performance of high-sulfur-concentration waste glasses: Provide further insight into the practical aspects of glass production with high sulfur loading. Thus far there has been a disparity between the thermodynamic solubility limit in laboratory crucible testing and the measured retained sulfur content in large-scale test reactors, with larger retention values corresponding to larger-scale testing.
- Crystal-tolerant glasses: Experiments utilizing the full-scale, room-temperature WTP HLW melter riser system have demonstrated a degree of robustness to pouring, despite accumulations of particles in the throat and riser

University of Chemistry and Technology

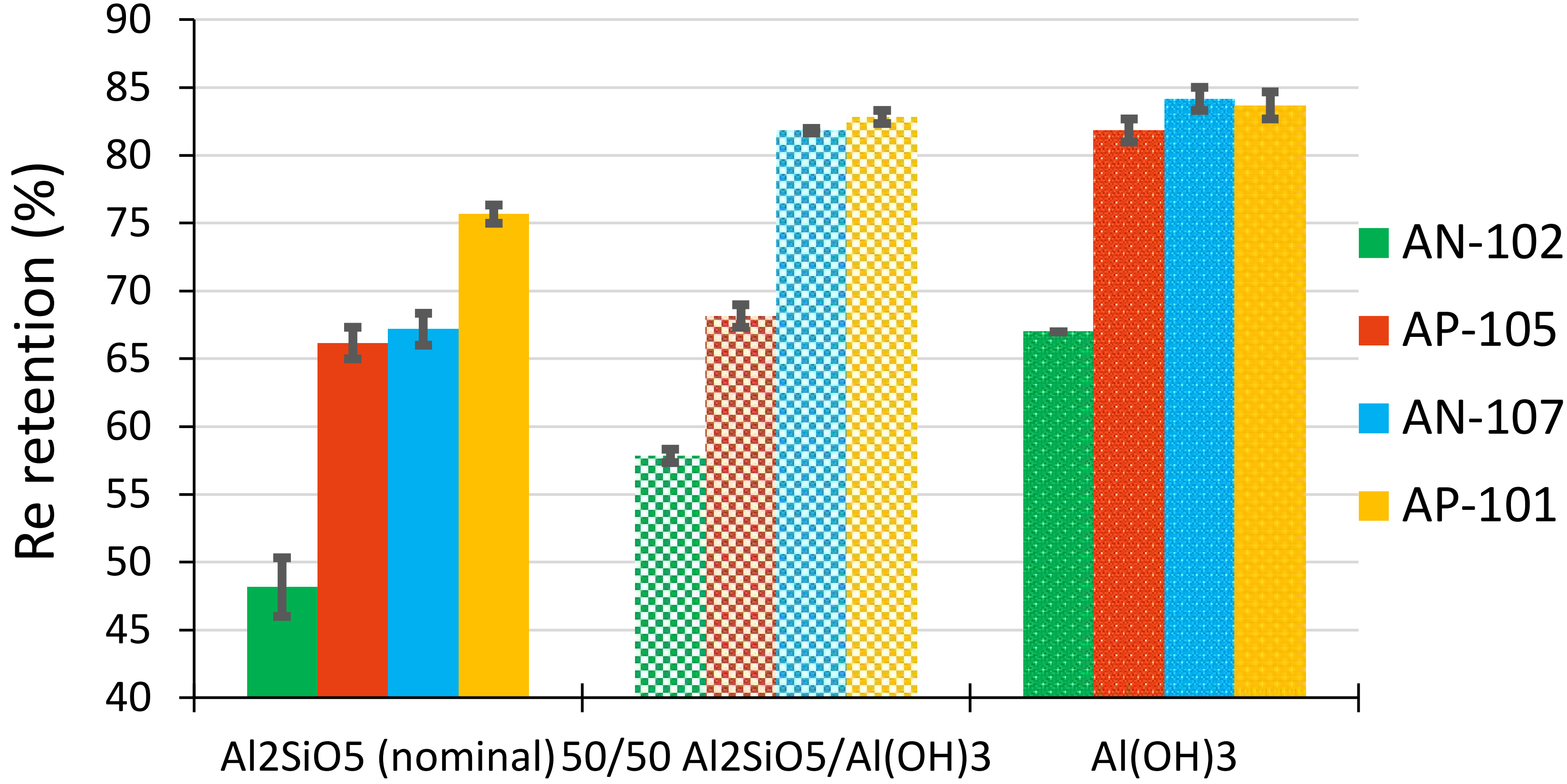
- Development of advanced cold cap model – cold cap bottom and conversion rate: Current work on the cold cap addresses factors affecting the heat transfer from the molten glass into the cold cap using the boundary layer theory to develop a relationship estimating the melting rate of feeds with different compositions
- Development of advanced cold cap model – foaming in the presence of water vapor: The morphology of the foam layer at the cold cap bottom and the temperature at the foam bottom-melt boundary is directly related to the melting rate
- Development of advanced cold cap model – LAW feeds: Developed a mathematical model that reasonably estimates the melting rate and the temperature profile in the HLW feed cold cap

University of Chemistry and Technology (cont.)

- Cold cap formation – interaction between slurry and cold cap, cold cap rheology: One of the problems resulting in the deficiency of current batch melting models is that they do not include feed rheology or simulate the flow of reacting materials using apparent viscosities or other empirical parameters
- Collaboration with Idaho National Laboratory on cold cap model implementation: The goal of cold cap studies is to incorporate the advanced cold cap model in the full CFD glass melter model as its integral component

(Modest Office of River Protection funding results in more significant financial support from the Czech Ministry of Education, Youth and Sports Project)

Effect of Aluminum Source on Technetium/Rhenium Retention



University of Nevada – Reno Scope

- The team has developed a non-friable, carbon foam material with iodine capture capacity of approximately 813 milligrams of iodine per gram of sorbent
- The mechanical robustness, compatibility with the components in the offgas, ease of fabrication, and commercial availability of the base material has allowed this material to be downselected for further study in a pre-pilot-scale system
- The goal of this effort is to deliver a procurement specification by establishing the performance bases; engineering the carbon foam to have the potential to be implemented into the primary and guard beds for the removal of mercury, iodine and acid gases (hydrochloric acid and hydrofluoric acid). A pre-pilot-scale system to test the mercury, iodine, and acid gas sorption capacity in a simulated LAW offgas (composition of offgas provided in the mechanical datasheet for activated carbon adsorber 24590-LAW-MVD-LVP-00003) is operational.

Washington State University and Rutgers Scope

- Research the suppression of foaming in the melt due to changes in the redox behavior
- Research means to increase Na_2O and SO_3 loading in glass to avoid salt segregation in the melter
- Increase the solubility of volatile radionuclides in LAW glasses (e.g., technetium and halides [chlorine and iodine-129])
- Suppress crystallization in LAW glasses, which is generally not considered to be a problem in LAW glasses. However, the addition of some oxides (e.g., ZrO_2 or SnO_2) to these glasses, in a pursuit to increase their chemical durability (measured by vapor hydration test), tends to promote crystallization
- Control K-3 refractory corrosion to increase the melter lifetime, which will be a major problem during the vitrification of direct-feed low-activity waste

Consortium for Risk Evaluation with Stakeholder Participation Scope

- The goal of our project is the selection of test(s) more reproducible and at least as easy to implement as compared to the current tests (e.g., ASTM C1663-09 and ASTM C1285-14) and (most importantly) more representative of performance under the conditions in the IDF. Recent contaminant release science has concluded that:

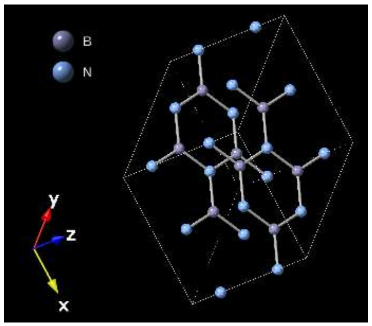
  Waste testing should provide information about potential contaminant release from a waste in the context of the anticipated disposal or utilization conditions. Thus, testing should reflect the range of conditions (e.g., pH, water contact, etc.) that will be present in the waste and at its interface with its surroundings during the long term.

- Testing and evaluation of resulting low-activity vitrified waste (LAW glass) must be used as part of a performance assessment to estimate the rate and extent of glass corrosion and release of radionuclides for periods from 1,000 to 10,000 years

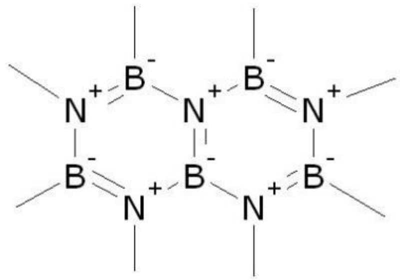
Sheffield-Hallam University Scope

- Integrated durability across HLW canister with nepheline: Hanford waste glasses are currently conservatively limited to compositions that do not appreciably form nepheline ($NaAlSiO_4$) tied to potential effects on chemical durability of glass
- Density of Hanford glass melts: Density of quenched crucible melts of simulated and actual waste glasses have been effectively modeled. However, very limited data exists on melt density. Because control of melter operation relies on glass level, which in turn relies on melt density in the melter, understanding how composition and temperature affect melt density is of import to WTP operation.
- Viscosity model expansion: Empirical models correlating Hanford waste-glass composition to viscosity have found significant success with relatively low uncertainty and scientifically understandable component effects. However, these models are based on viscosity measurements in the temperature range from roughly 950°C to 1,250°C and extrapolation to higher viscosity (lower temperature) is not viable

Boron Nitride: An Alternative to Organic Reductants



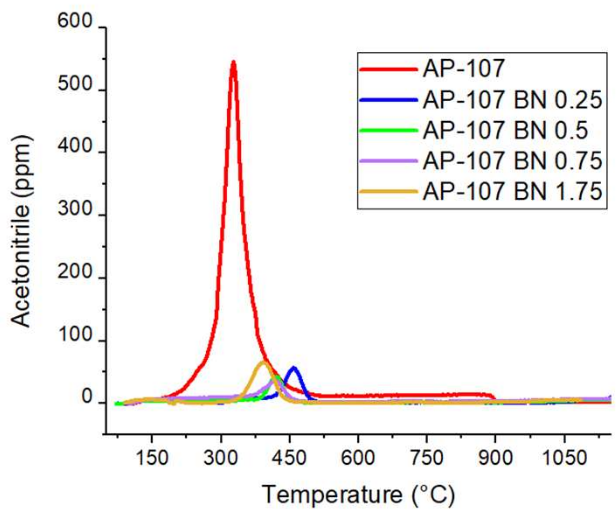
Crystal structure of BN

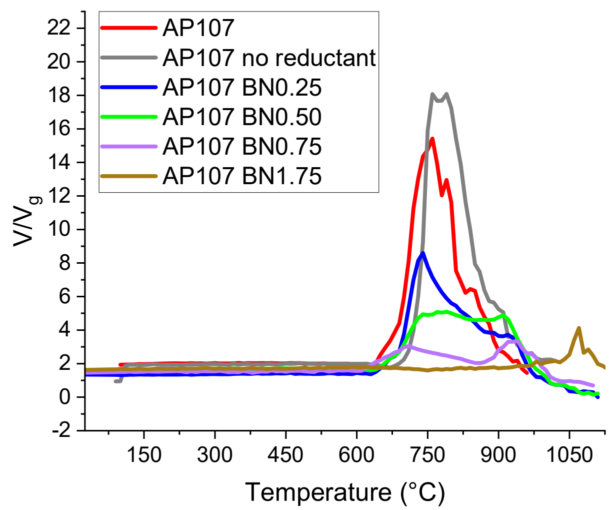


Designed Tank AP-107 feeds at molar ratio “BN/N” = 0.25, 0.50, 0.75, 1.75[a]

The theoretical total boron in the glass is accomplished by removing the necessary amount of H_3BO_3 glass-former to each successive run.

[a] *1.75 is the maximum before H_3BO_3 would be negative.*





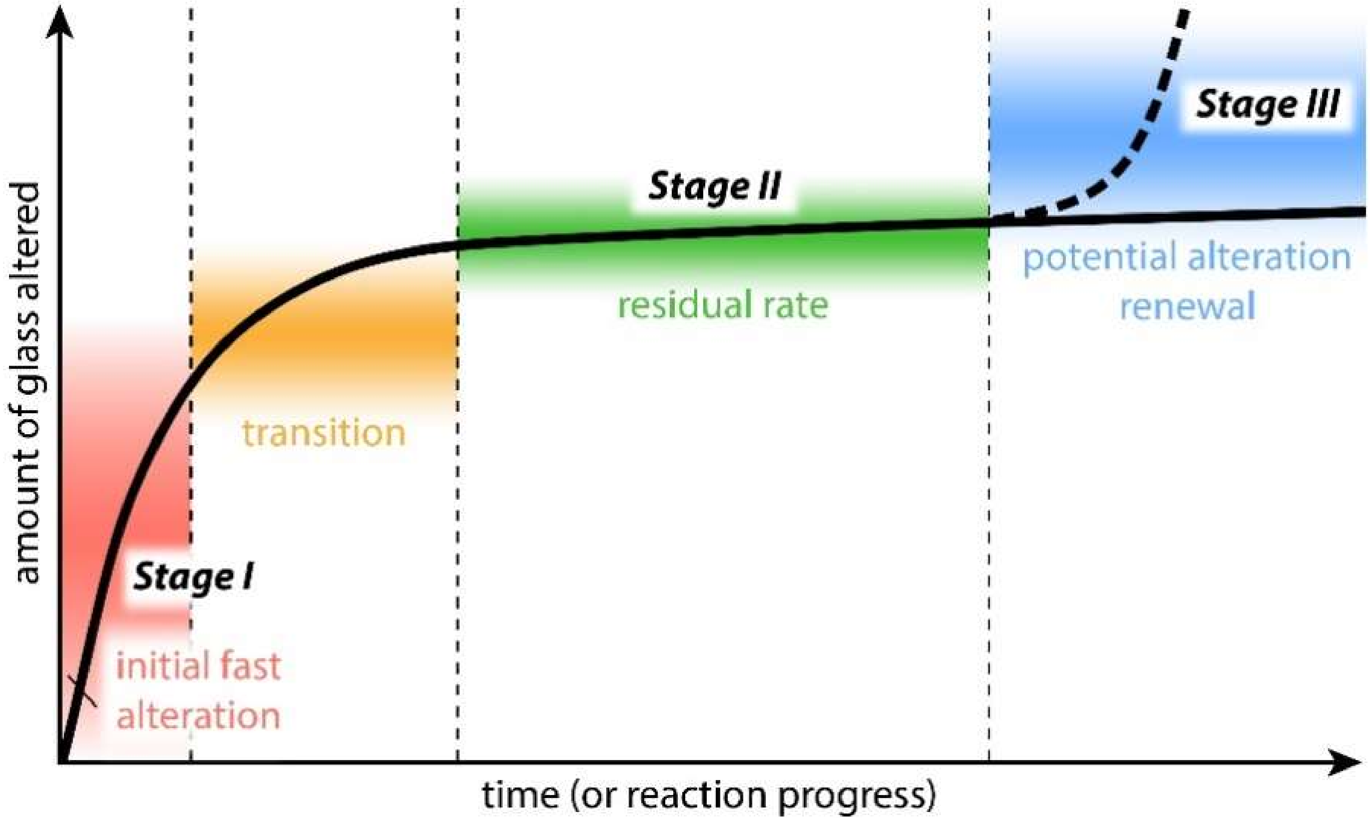
Balance of Mission Treatment Projections

	BNI/WTP Baseline Models	2008 TUA Baseline	2013 TUA Baseline	2013 TUA with Caustic and Oxidative Leaching Eliminated
HLW Canisters	18,400	14,838	8,223	13,534
LAW Containers	145,000	91,400	79,465	65,151
Total Canisters and Containers	163,000	106,238	87,688	78,685

BNI = Bechtel National, Inc.
HLW = high-level waste
LAW = low-activity waste
TUA = tank utilization assessment
WTP = Waste Treatment and Immobilization Plant

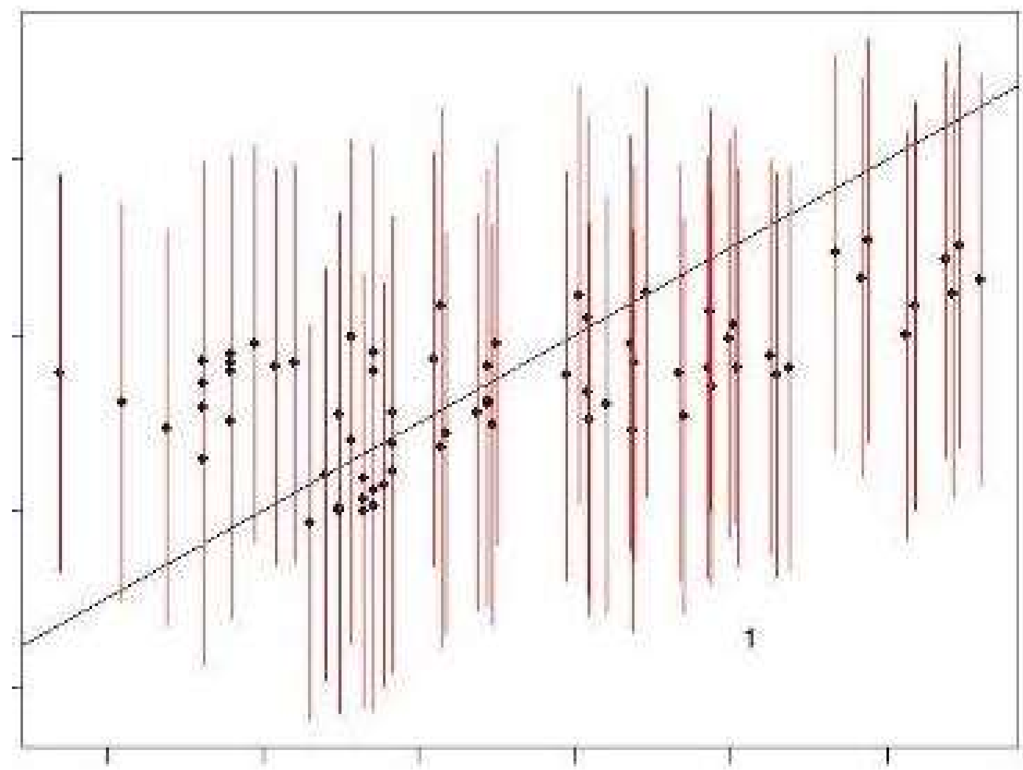
Vitrification Offgas Rig

Glass Durability



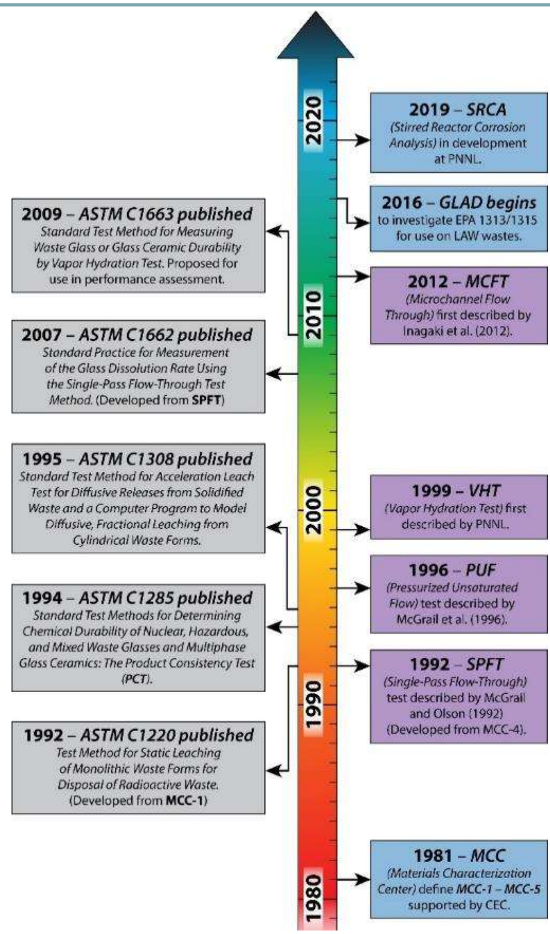
The general behavior of glass dissolution can be described in three major stages.

Vapor Hydration Test



WTP contract Specification 2, Section 2.2.2.17.3: “The glass corrosion rate shall be measured using at least a seven (7)-day vapor hydration test run at 200°C. The measured glass alteration rate shall be less than 50 grams/(m^2 day).”

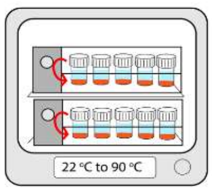
Durability Tests

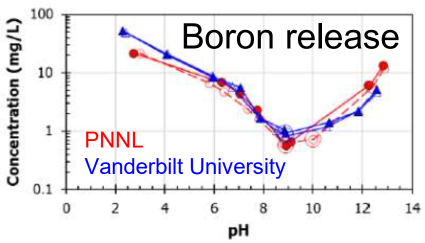


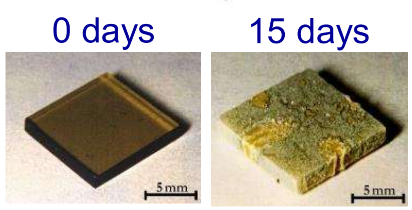
ASTM: *American Society for Testing and Materials International*
CEC: *Commission of European Communities*
MCC: *Materials Characterization Center*

| ASTM proc. | development | documentation

Combined Task Objectives







The Glass Leaching Assessment for Durability Project
Aim: Design a new test for LAW glass using existing EPA test for hazardous component leaching

Develop a low temperature glass corrosion test

↓

Confirm reproducibility between PNNL, Sheffield, and Vanderbilt University

↓

Exchange the high uncertainty vapor hydration test for new test

The Hillfort Project
Aim: Validate the chosen low temperature test against natural analogues from 1,500-year-old Swedish hillforts

Take glass samples from Swedish hillfort

↓

Study corrosion and local environment

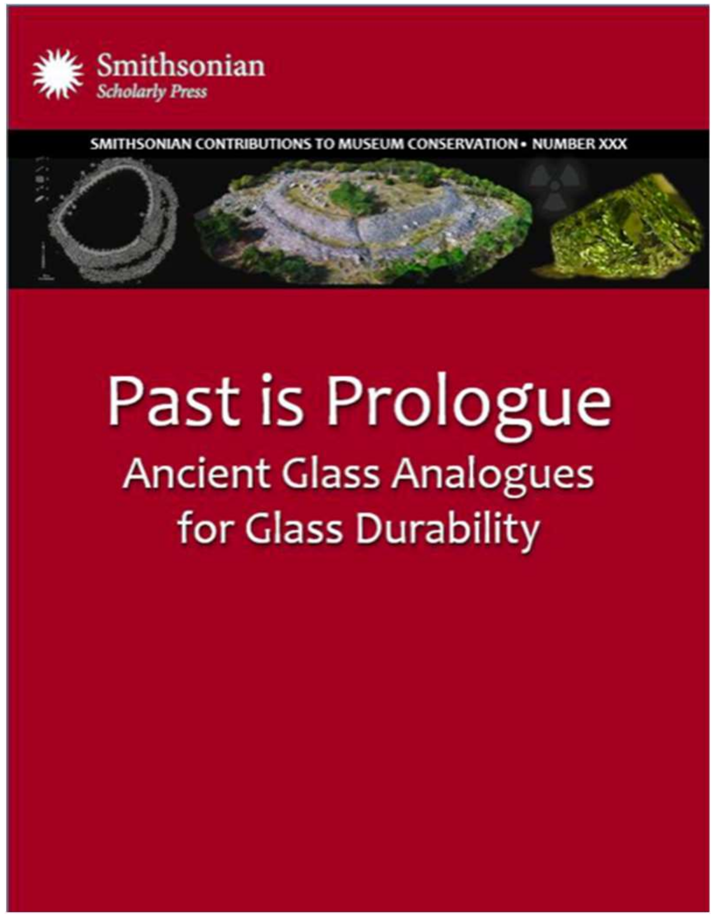
↓

Make glass of identical composition

Apply test to Hillfort glasses and document findings

Effect: Alteration model to replace vapor hydration test in LAW Facility; increases operational windows, provides operations flexibility and direct-link disposal at the IDF.

Glass Leaching Assessment for Durability Success



What if?

Sludge treatment in Pretreatment Facility was primarily driven by the desire to effectively leach and wash the HLW fraction of tank waste

- Caustic leaching to remove, primarily, aluminum
- Oxidative leaching to remove chromium
- Washing to remove, primarily, sodium, sulfur and leached aluminum and chromium

All driven to reduce the amount of glass produced to reduce mission length and cost of HLW glass management

What if? (cont.)

Several recent developments brought into question the need for sludge treatment in the Pretreatment Facility. This could be successful in retiring it as the optimal River Protection Project flowsheet option.

- New glass-development efforts have shown that significant improvements in aluminum, chromium, sodium and sulfur loadings are likely, eliminating the Pretreatment Facility requirements
- Flowsheet models currently project HLW melters idle for large fractions of the mission (balancing throughput between LAW and HLW is the goal)
- Sludge treatment in the Pretreatment Facility was the single largest cause for technical issues and throughput challenges, negatively affecting plant startup schedule

Thank You

"If the reactor blows up, jump in the middle of it and save yourself a lot of trouble."

— Gen. Leslie R. Groves Jr., to Colonel Franklin T. Matthias
Working on the Bomb: An Oral History of WWII Hanford, S.L. Sanger, 1995, p. 77.

1. Goel, A., J.S. McCloy, R. Pokorny, and A.A. Kruger, 2019, "Challenges with vitrification of Hanford High-Level Waste (HLW) to borosilicate glass – An overview," *Journal of Non-Crystalline Solids*: X, Vol. 4, p. 100033, December.
2. Marcial, J., B.J. Riley, A.A. Kruger, C.E. Lonergan, and J.D. Vienna, 2023, "Hanford Low-Activity Waste Vitrification: A Review," *Journal of Hazardous Materials*, September 2, doi.org/10.1016/j.jhazmat.2023.132437
3. Thorpe, C.L., A.J. Fisher, S.A. Walling, R.J. Hand, N.C. Hyatt, C. Pearce, J. Neeway, A.A. Kruger, M. Schweiger, D.S. Kosson, C.L. Arendt, J. Marcial, and C.L. Corkhill, 2021, "Forty years of durability assessment of nuclear waste glass: A review of standard methods," *npj Materials Degradation*, Vol. 5, Article 61, December 20.

Glass Property Constraints, Associated Limits, and Driver for Existing Limit

Property	Limit	Driver
Melt viscosity at 1,150°C (η_{1150})	$2 \leq \eta_{1150} \leq 8$ Pa·s	Process efficiency, mixing, and corrosion
Melt viscosity at 1,100°C (η_{1100})	$\eta_{1100} \leq 15$ Pa·s	Pouring and idle process efficiency
Melt electrical conductivity at 1,100°C (ε_{1100})	$\varepsilon_{1100} \geq 10$ S·m^{-1}	Power delivery to the melt
Melt electrical conductivity at 1,200°C (ε_{1200})	$\varepsilon_{1200} \leq 70$ S·m^{-1}	Current density on electrodes
Melt crystal content at 950°C (C_{950})	$C_{950} \leq 1$ vol%	Melter pour spout pluggage
6-d Monofrax K3 refractory corrosion (k_{1208})	$k_{1208} \leq 0.00102$ m	Melter lifetime
Sulfur solubility/sulfur concentration (S/C)	S/C ≥ 1	Excessive corrosion of melter components
Product consistency test response normalized Na, B, and Si releases ($NL_{[Na,B,Si]}$)	$NL_{[Na,B,Si]} \leq 2$ g·m^{-2}	Reduce risk of excessive corrosion rate in the IDF, Specification 2.2.2.17
Vapor hydration test response (r_a)	$r_a \leq 50$ g·m^{-2}·d^{-1}	Reduce risk of accelerated corrosion in the IDF, Specification 2.2.2.17
Phase changes during slow cooling in the container	No significant impact to performance	Ability to satisfy disposal criteria
Waste classification (W_C)	$W_C \leq$ class C	Demonstrate waste is incidental to reprocessing, Specification 2.2.2.8
^{90}Sr activity	^{90}Sr ≤ 20 Ci·m^{-3}	Demonstrate waste incidental to reprocessing (WIR), Specification 2.2.2.8
^{137}Cs activity[a]	^{137}Cs ≤ 3 Ci·m^{-3}	Demonstrate WIR, Specification 2.2.2.8
^{137}Cs activity[a]	^{137}Cs ≤ 0.3 Ci·m^{-3}	Contact maintenance dose, Section C.7
Container surface dose rate (D_S)	$D_S \leq 500$ mrem·h^{-1}	Container handling, Specification 2.2.2.9
Land disposal restrictions	Satisfy petition	IDF acceptance criteria, Specification 2.2.2.20

[a] There are two ^{137}Cs constraints in the contract. One is required for waste disposal while the other for contact maintenance. The higher limit determines the maximum that can be put in glass while the lower can potentially be exceeded on a case-by-case basis if process safety can otherwise be assured.

Melter Scale Comparison