

FFRDC Team Working Draft Documents – 2017 NDAA 3134 Hanford Supplemental Low Activity Waste Treatment at the Hanford Reservation

The following attached documents have been developed by the FFRDC Team and represent “working draft” information regarding assessment methodologies, technologies, and approaches under consideration and review per the FFRDC Program Plan developed for this study.

The FFRDC Team recognizes that under the NDAA 3134 language, the collaboration with the NAS is critical to achieving the intended goal of the study. As such, working draft information is being shared.

It is important for readers to understand that much of what is presented in these working draft documents has not been peer reviewed or technically edited and is not intended to imply any final conclusions or represent a complete analysis. Peer reviews and subsequent revision and refinement will be completed during the fall of 2018 and spring 2019. Until a final report is issued, all information presented is considered Pre-Decisional DRAFT.

The intent of sharing the working draft documents is to stimulate dialog with the NAS Committee members and to ultimately obtain constructive feedback, comments, and technical ideas to improve on these draft documents and technical concepts as they mature into the ultimate final report(s).

Bill Bates

FFRDC Team Lead



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NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview

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NAS Committee Meeting #3

July 23 and July 24, 2018

Richland, WA

Pre-Decisional

FFRDC Team Review Overview

- **Overview of Team Approach**
 - 6 National Laboratories
 - Evaluate Technologies, Risks, Costs, Regulatory
 - Interface with NAS Committee
- **Base Cases, Variant Cases, Other, Opportunities**
- **Work is Still in Progress**
 - Maturing Cases (and Pre-Treatment)
 - Maturing Risks
 - Maturing Estimates
- **Schedule**
 - Draft Report 7/2018
 - Final Draft Report 10/2018
 - Issuance – Following NAS Committee Report #3
- **Review of Agenda**



FFRDC Team Review Overview

FFRDC Team Overview	Bill Bates
Baseline, Feed Vector, Uncertainties	Michael Stone
Analysis Approach	Tom Brouns
Base & Variant Case Overview	Michael Stone
Pretreatment Approaches	Michael Stone
“Other” Considerations	Tom Brouns
Vitrification Cases	Alex Cozzi
Grout Cases	George Guthrie
Steam Reforming Cases	Nick Soelberg
Transportation & Disposal Site Considerations	Paul Shoemaker
Estimate Methodology & Preliminary Results	Frank Sinclair/William Ramsey
Analysis Results	Sharon Robinson
Summary	Bill Bates





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NDA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Baseline, Feed Vector, Uncertainties

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Overview

- **Definitions**
- **NDAA Scope**
- **One System Integrated Flowsheet Overview**
- **WTP Baseline Process in Integrated Flowsheet**
- **Supplemental LAW Description in Integrated Flowsheet**
- **Feed Vector Overview**
 - Assumptions
 - Data Review
- **Uncertainties**
- **Challenges**



Definitions

- **Supernate waste:** Low Activity Waste (LAW) feed
- **Solids:** High Level Waste (HLW) sludge
- **Treated LAW:** LAW feed with solids and cesium removed (*baseline treatment process for WTP*)
- **LDR Treatment:** Assumed to encapsulation in grout in IDF PA
- **Melter condensate:** Liquid effluent collected from melter offgas systems
 - ALL water fed to melter
 - Entrained feed and Glass Former Chemicals (GFCs) (includes sugar)
 - Water added to offgas system
 - *Film cooler flush*
 - *Wet ElectroStatic Precipitator (WESP) spray*
 - *WESP deluge*
 - *Line flushes*
- **Semi-volatile:** Components that show appreciable vapor pressure at melter temperatures
 - Cl, Cr, Cs, F, I, S, Tc
 - Single pass retention in glass can be lower than 10% (retention of semi-volatiles decreased by bubblers)
 - Vaporize out of the melter glass pool during idling
- **Solids washing:** Dilution of interstitial supernate
- **Solids leaching:** Removal of aluminum by elevated temperature and NaOH
 - Chromium leaching assumed to be performed in TF, if done
- **Flywheel:** A processing loop that concentrates species only partially removed in a single pass
 - Semi-volatiles in LAW melter condensate recycle
 - Selected species may flywheel around HLW filtration/wash loop
 - Magnitude of concentration increase dependent on single pass partitioning and melter idling

NDAA Scope

“Not later than 60 days after the date of the enactment of this Act, the Secretary of Energy shall enter into an arrangement with a federally funded research and development center to conduct an **analysis of approaches for treating the portion of low-activity waste** at the Hanford Nuclear Reservation, Richland, Washington, **that, as of such date of enactment, is intended for supplemental treatment.**”

2017 NDAA, Sec 3134

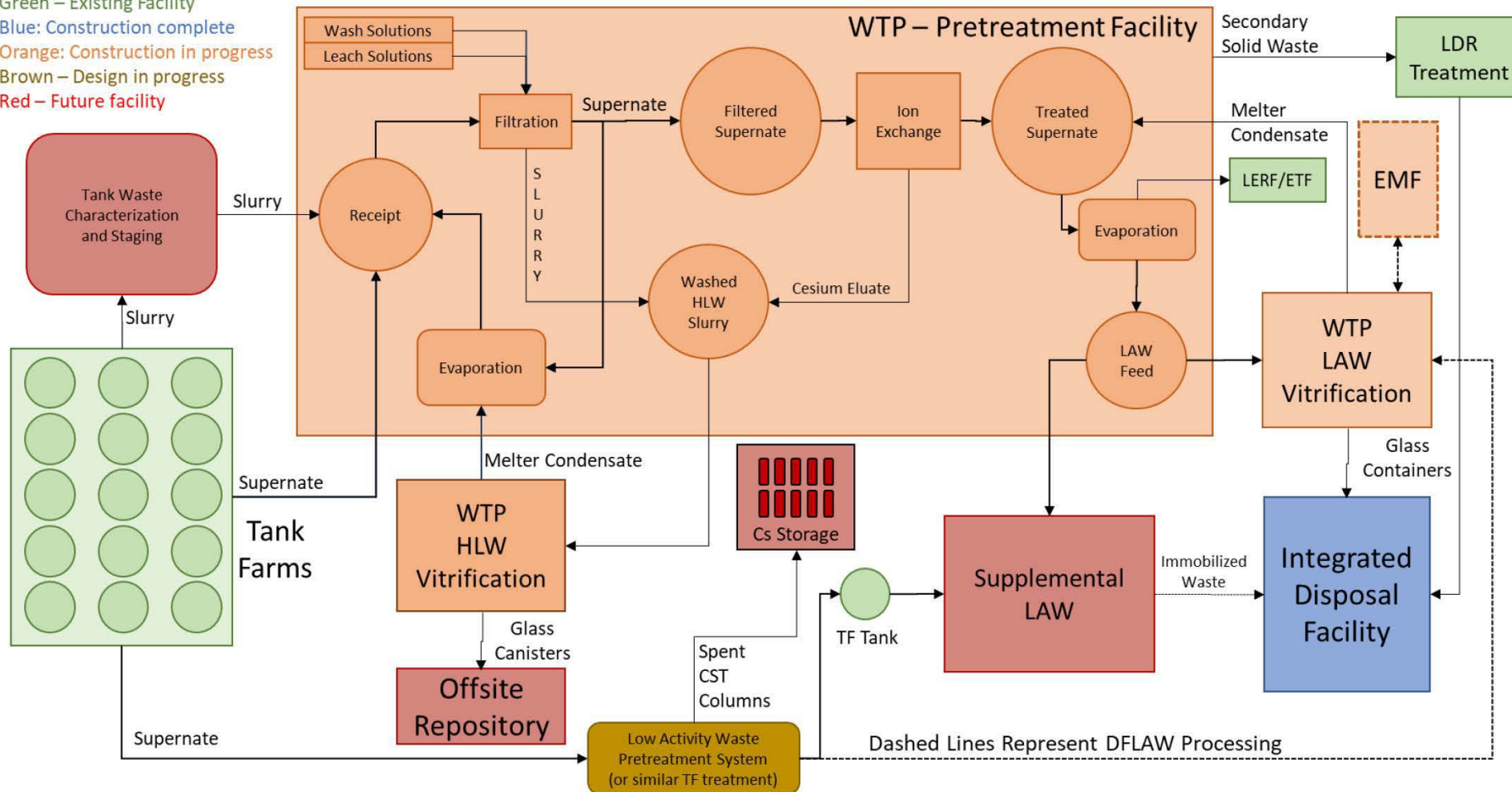
- **System Plan 8** defines the portion of LAW currently intended for supplemental treatment
 - Includes a baseline process and a number of alternatives
 - Detailed calculations are documented in the **One System Integrated Flowsheet, Revision 2** for the baseline process in System Plan 8
 - **Revision 2 was in draft form at time of the NDAA enactment**
 - Revision 1 data for LAW Supplemental LAW feed only available as compiled averages over multiple years
 - The **Best Basis Inventory** is used to define the composition of tank waste at Hanford for flowsheet calculations



WTP Baseline Process

Process flows greatly simplified
 Dilute LAW feed can be sent to evaporation, not shown
 Evaporator condensate is sent to LERF/ETF, not shown for all evaporators
 Solid secondary waste stream only shown for PT, applies to all facilities

Green – Existing Facility
 Blue: Construction complete
 Orange: Construction in progress
 Brown – Design in progress
 Red – Future facility



One System Integrated Flowsheet

- **The Integrated Flowsheet is the only current estimate of the feed vector for Supplemental LAW**
 - System Plan 8 assumptions used for Revision 2 of Integrated Flowsheet
 - “Best Available Data”
 - HTWOS model used for Revision 1 of Integrated Flowsheet does not allow extraction of detailed feed vector for Supplemental LAW
 - *Mission averages are the only data available; not sufficient to evaluate Supplemental LAW processes*
- **Past studies RPP-RPT-55960, Supplemental Immobilization of Hanford Low-Activity Waste: Cast Stone Screening Tests**
 - *Four recipes each at two sodium concentrations (7.8 and 5.0M)*
 - A single-shell tank (SST) blend
 - Overall average LAW feed based on HTWOS modelling
 - High aluminum simulant based on HTWOS modelling
 - High sulfur simulant based on HTWOS modelling
 - SVF-2006 / SVF-2007 determined a Supplemental LAW feed vector for use in RPP-RPT-48333
 - Compositions in these past studies are no longer relevant due to changes in retrieval and processing strategies
- **Use of Best Basis Inventory (BBI) directly would require modeling to separate HLW/LAW fractions in many tanks**
 - Also to account for incidental blending in tank farms during transfer to treatment facility



Integrated Flowsheet: RPP-RPT-57991

- **Entire scope of tank waste immobilization in one flowsheet calculation**
 - Retrievals
 - Tank Farm campaign preparations
 - Treatment Processes
 - Immobilized product estimates
- **Initial compositions based on the Best Basis Inventory – the current “best” estimate of tank compositions**
- **Focused on interfaces between facilities**
- **Revision 1 (2015) assumed Supplemental LAW utilized vitrification**
 - HTWOS program to perform modelling
- **Revision 2 (2017) lists vitrification and grout as options**
 - TOPSim program to perform modelling

Integrated Flowsheet, Rev 1

SLAW Immobilization

- SLAW Immobilization is assumed to be a LAW vitrification facility with 6 melters. Secondary liquid wastes from the facility are assumed to be recycled back to the front end of the facility where they are mixed back into the incoming waste which is then conditioned using an evaporator.
- SLAW Immobilization's primary LAW source is the WTP PT Facility with LAWPS providing supplemental LAW feed as needed to keep the facility at full capacity.
- Integrated Flowsheet assumes that SLAW Immobilization begins operations 3 years after WTP PT Facility begins sending feed to the LAW Facility.

Integrated Flowsheet, Rev 2

2.1.3.1 LAW Supplemental Treatment Facility

The LAW supplemental treatment facility is a future facility. The WTP, as currently scoped, was not intended to process all of the LAW. DOE has pursued a variety of strategies to obtain additional needed LAW treatment capacity. For the purpose of this RPP Integrated Flowsheet, the LAW supplemental treatment facility is assumed to be either a second LAW vitrification facility or a grout facility.

HLW and LAW Processing Closely Coupled in Baseline Process

- **HLW and LAW feed paths are intertwined in PT**
 - Supernate separated from solids in TF for transfer to PT
 - *Solids slurry uses supernate as carrier fluid*
 - *Evaporation of treated LAW stream in PT precipitates some species*
 - Supernate and solids recombined in PT
 - Solids concentrated by filtration, washed, and leached in PT
 - *Generates supernate to be processed as LAW (dilute streams evaporated, then recycled to front end of process)*
 - Cesium removed from LAW combined with HLW solids
 - Recycle streams from many processes combined with HLW/LAW blend at front end of PT
 - *HLW vitrification condensate*
 - *Wash and leach solutions too dilute to process directly as LAW*
 - *HLW canister decontamination solutions*
 - LAW vitrification condensate combined with treated LAW in PT



HLW and LAW Processing Closely Coupled in Baseline Process

- **Impact on LAW stream**

- Enrichment in species washed and leached from solids
 - *Al, Cr, Na (added to prevent aluminum reprecipitation)*
- Enrichment in semi-volatile species from melter condensate recycle flywheel
 - *Supplemental LAW will treat more ^{99}Tc and ^{129}I than LAW vitrification even if volume split is 50-50*
 - *If single pass retention in glass is low for WTP LAW vitrification, the majority of the ^{99}Tc and ^{129}I will be sent to Supplemental LAW*
- Addition of GFC components to LAW stream from melter condensate recycle
- Enrichment in cerium from HLW canister decon (and sodium added to neutralize)

- **Impact on LAW flowrate**

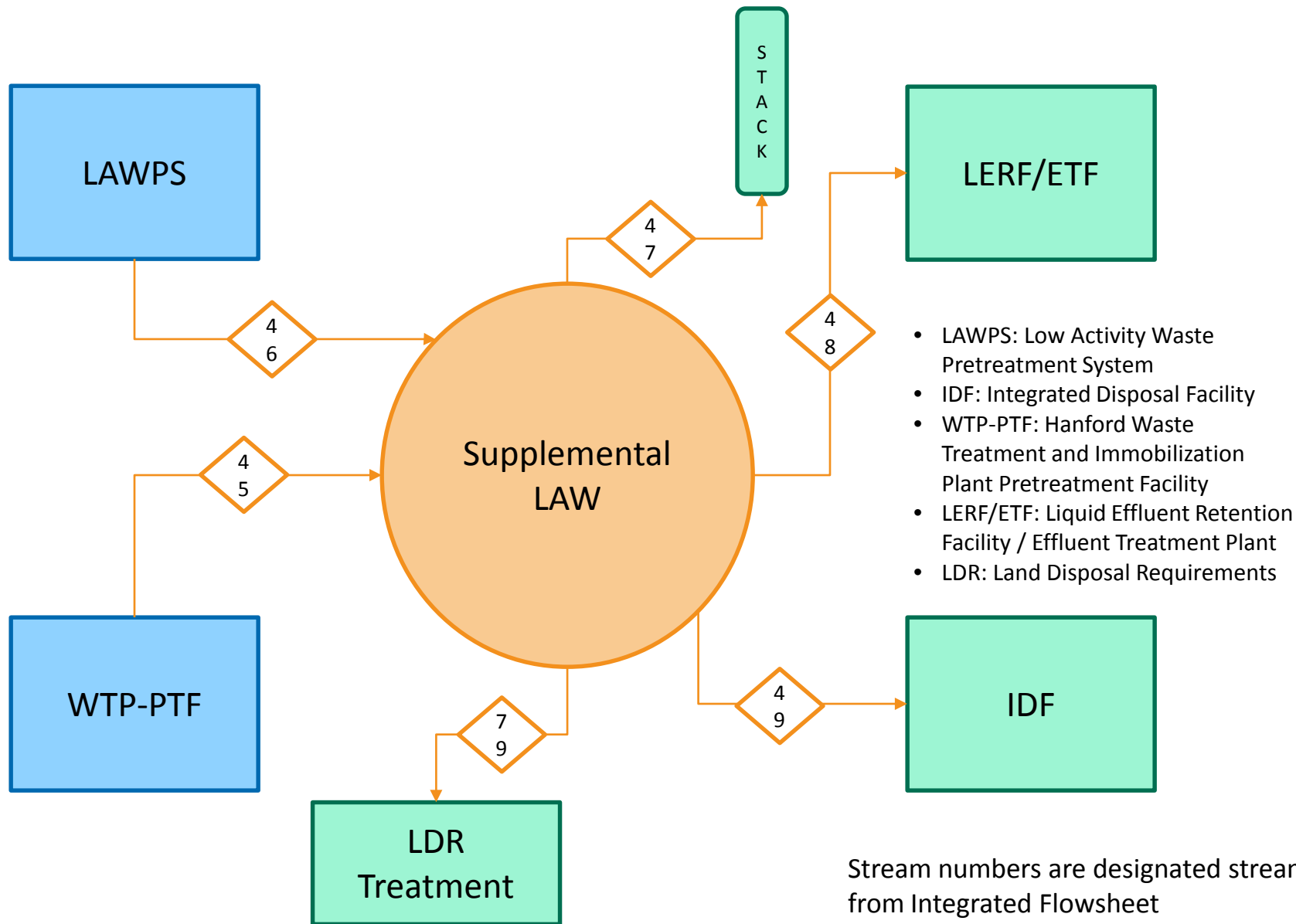
- Integrated flowsheet operates to optimize HLW canister production rate
- LAW generated from HLW processing (concentration, washing, leaching, melter condensate recycle, etc.) is greater than LAW vitrification facility capacity when added to the LAW processed as needed to complete mission at same time as HLW (40 years)
 - *Generates need for supplemental treatment for LAW*

Supplemental LAW in Current Baseline

- **Treatment facility for LAW not processed at WTP LAW facility**
- **Complete treatment facility (no returns to any sending facility)**
 - Any additional pretreatment for Supplemental LAW process is performed internally
 - All condensate from a vitrification process is handled internally
- **Liquid effluents from Supp. LAW are treated to allow disposal through LERF/ETF**
- **Immobilized product sent to IDF**
- **Solid Secondary waste sent to “LDR treatment”**
 - LDR treatment assumed to allow disposal of the solids secondary waste at IDF
- **Purely a conceptual system at the moment**
 - No design in place
 - Some aspects still TBD
 - *Immobilized waste form*
 - *Process sample analysis*
 - *Size*
- **Best data on feed vector to Supplemental LAW is the One System Integrated Flowsheet**
 - Supplemental LAW treated as a “black box” in model

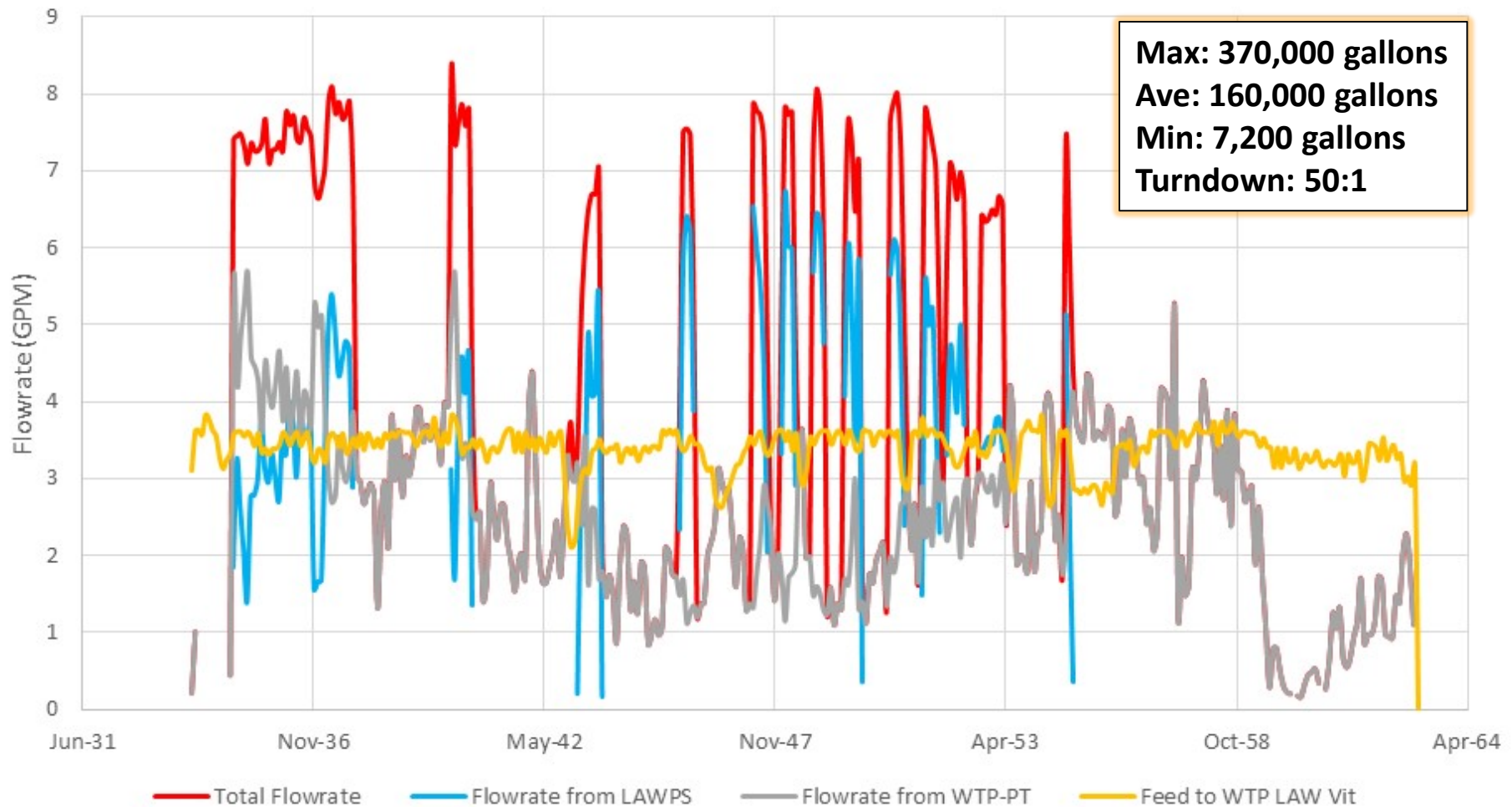


Integrated Flowsheet: Baseline Process Flows to/from Supplemental LAW

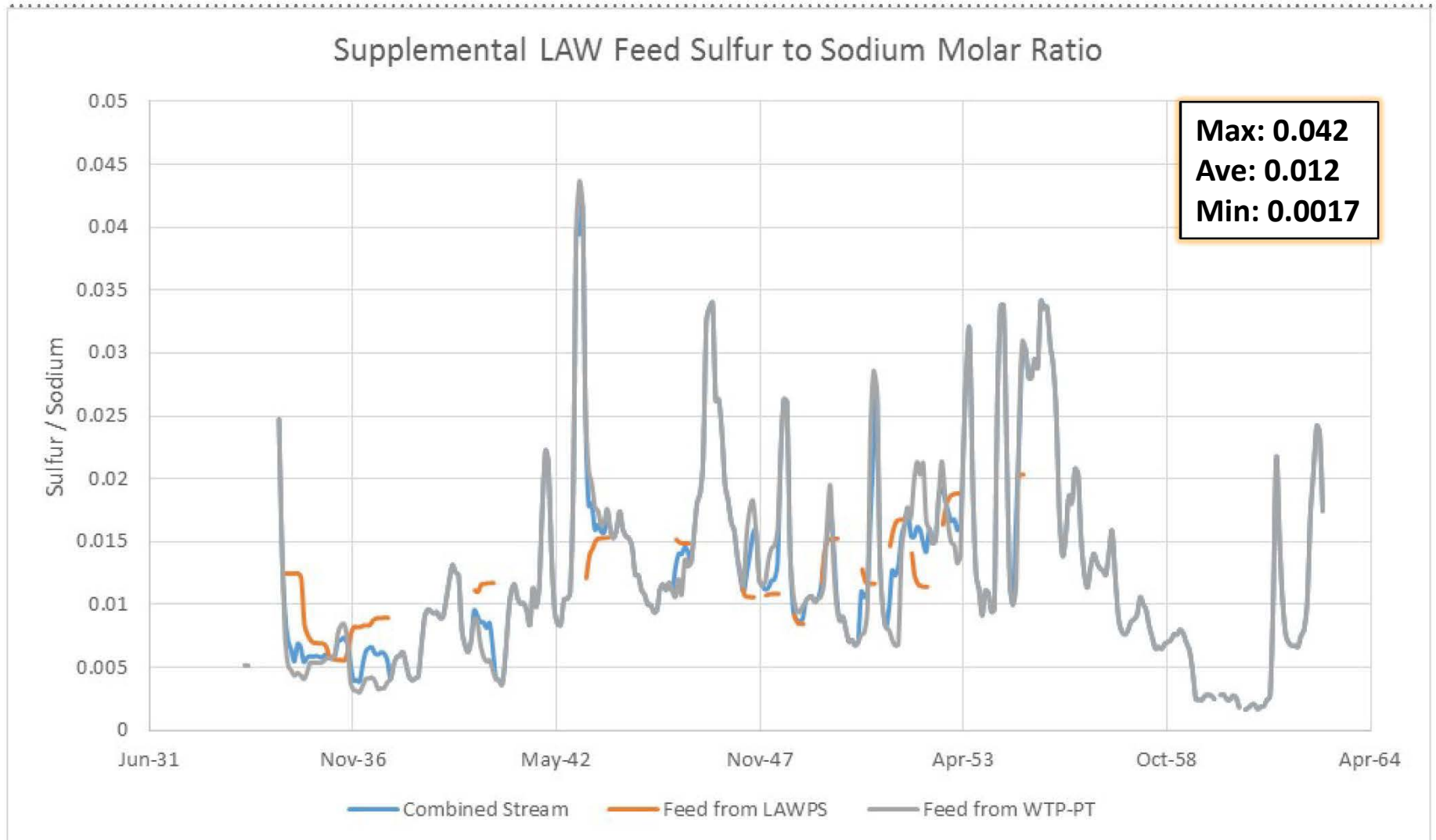


Feed Vector: Flowrates

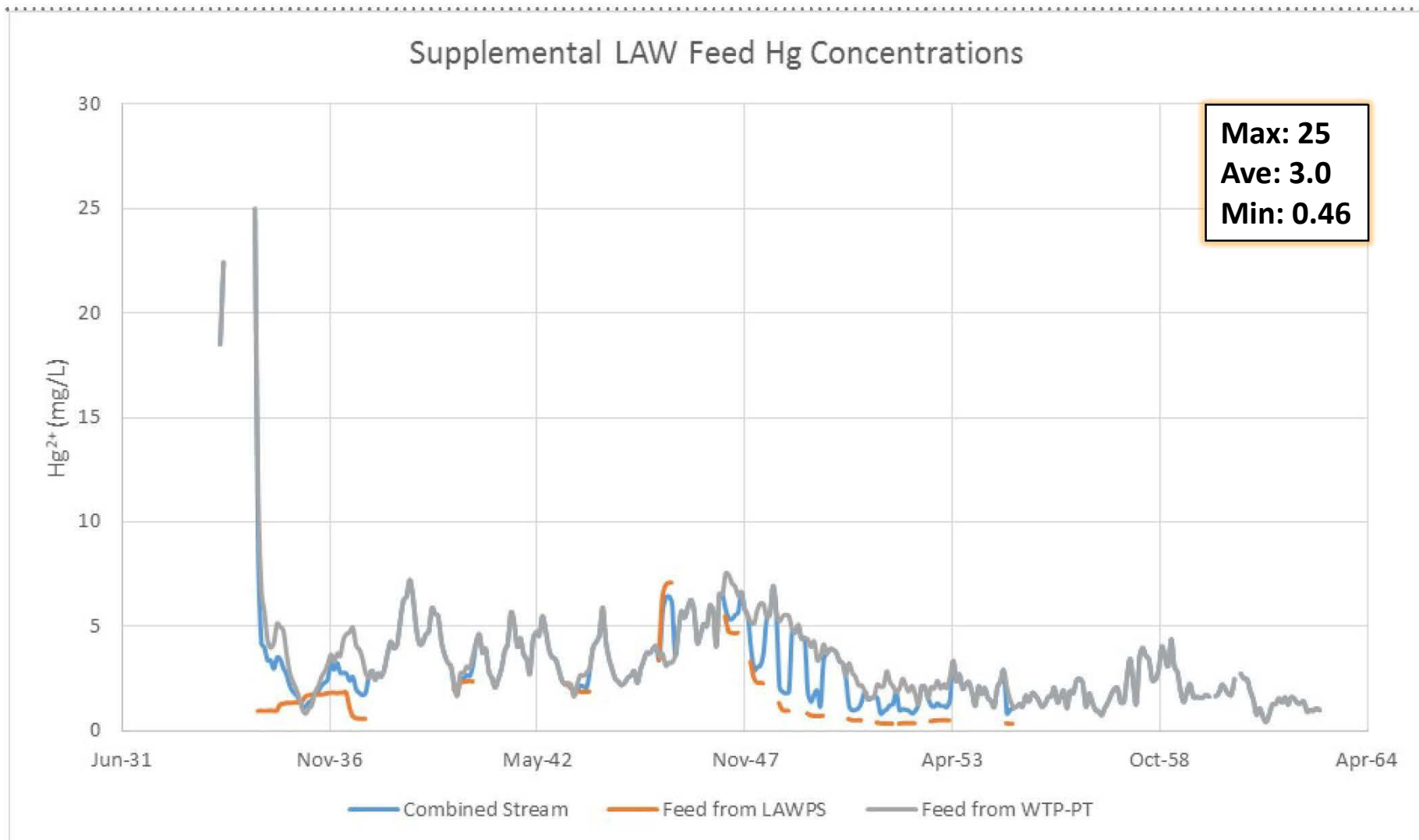
Average Monthly Volumetric Flows to Supplemental LAW



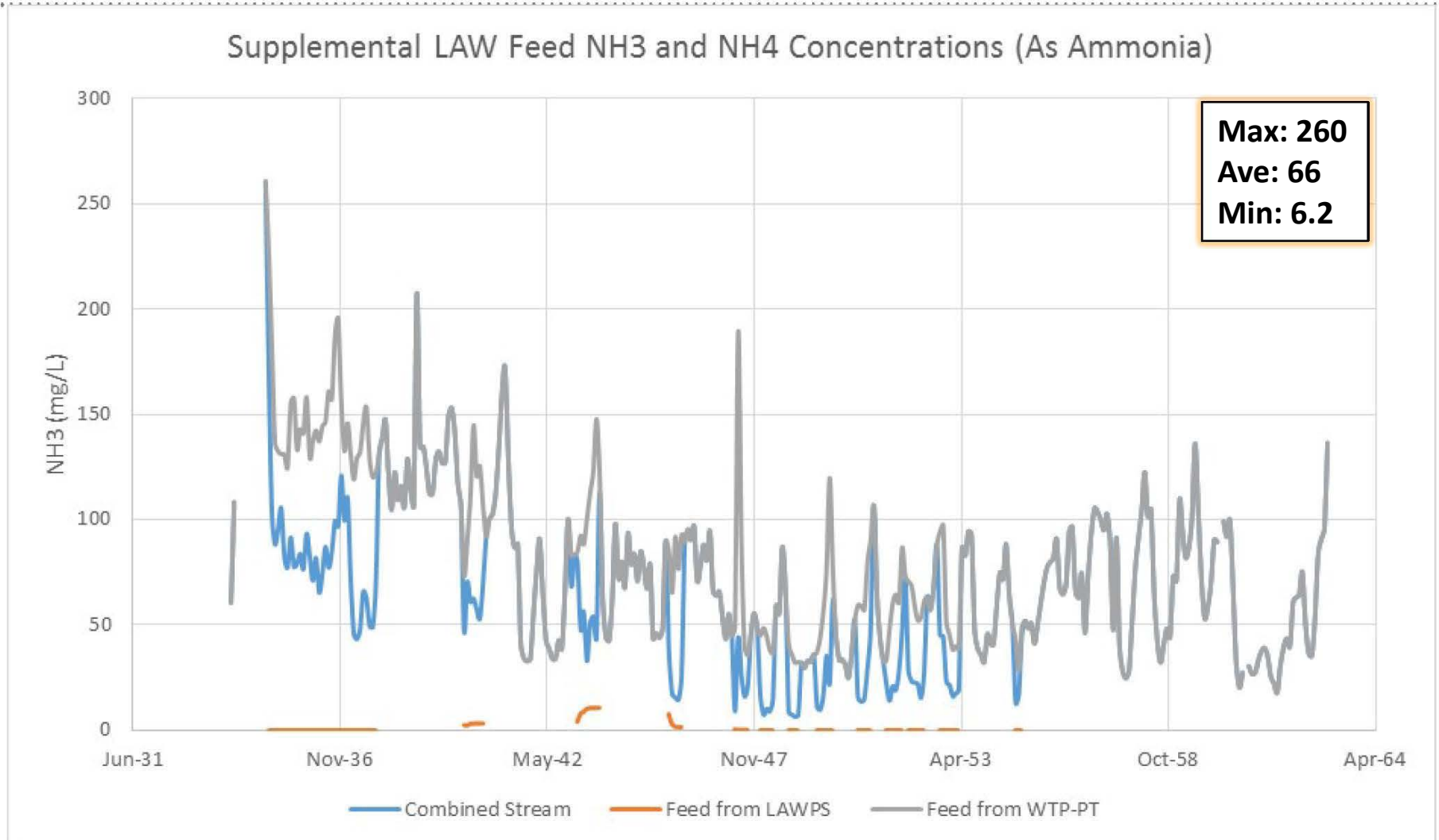
Feed Vector: Sulfur to Sodium Ratio



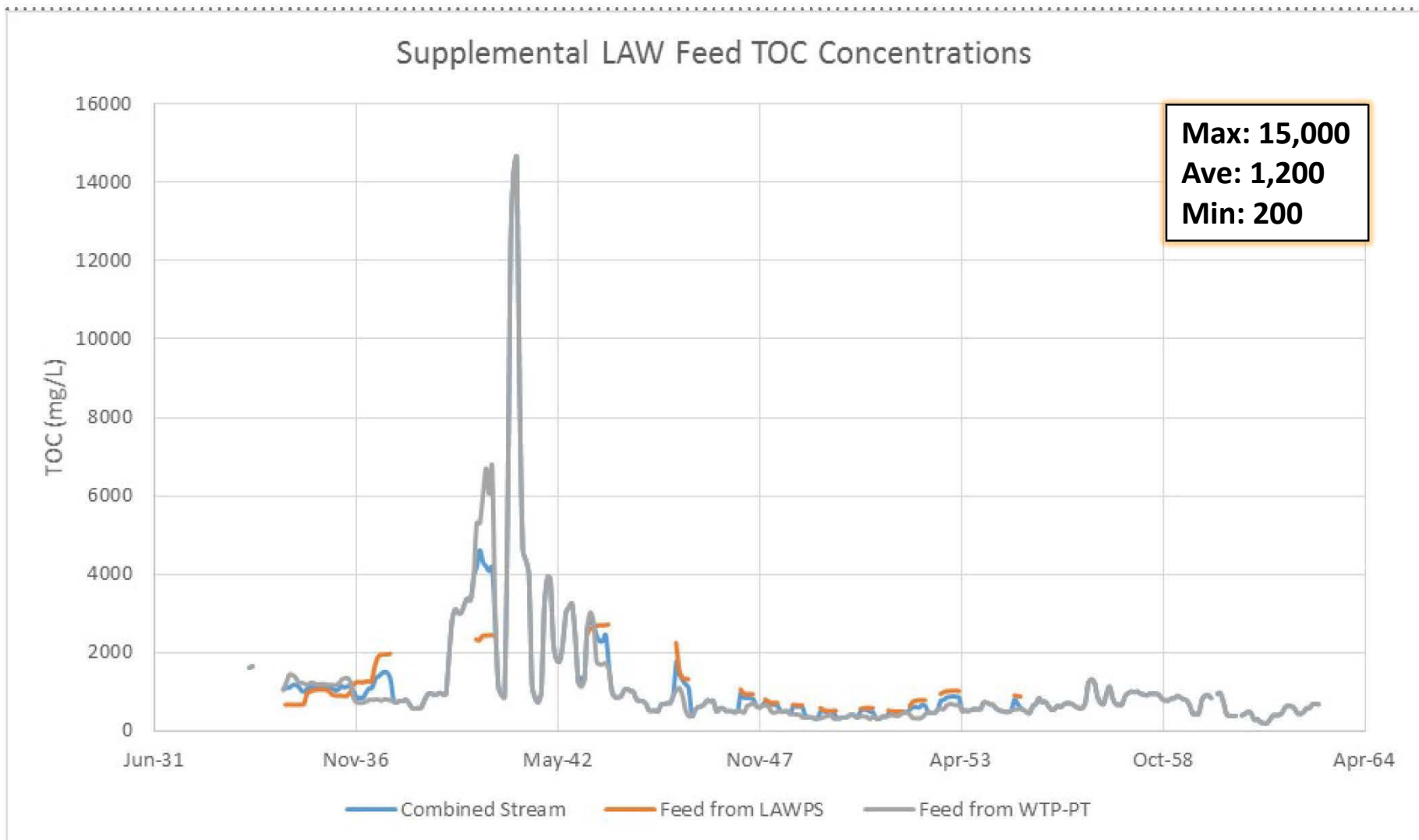
Feed Vector: Mercury Concentrations



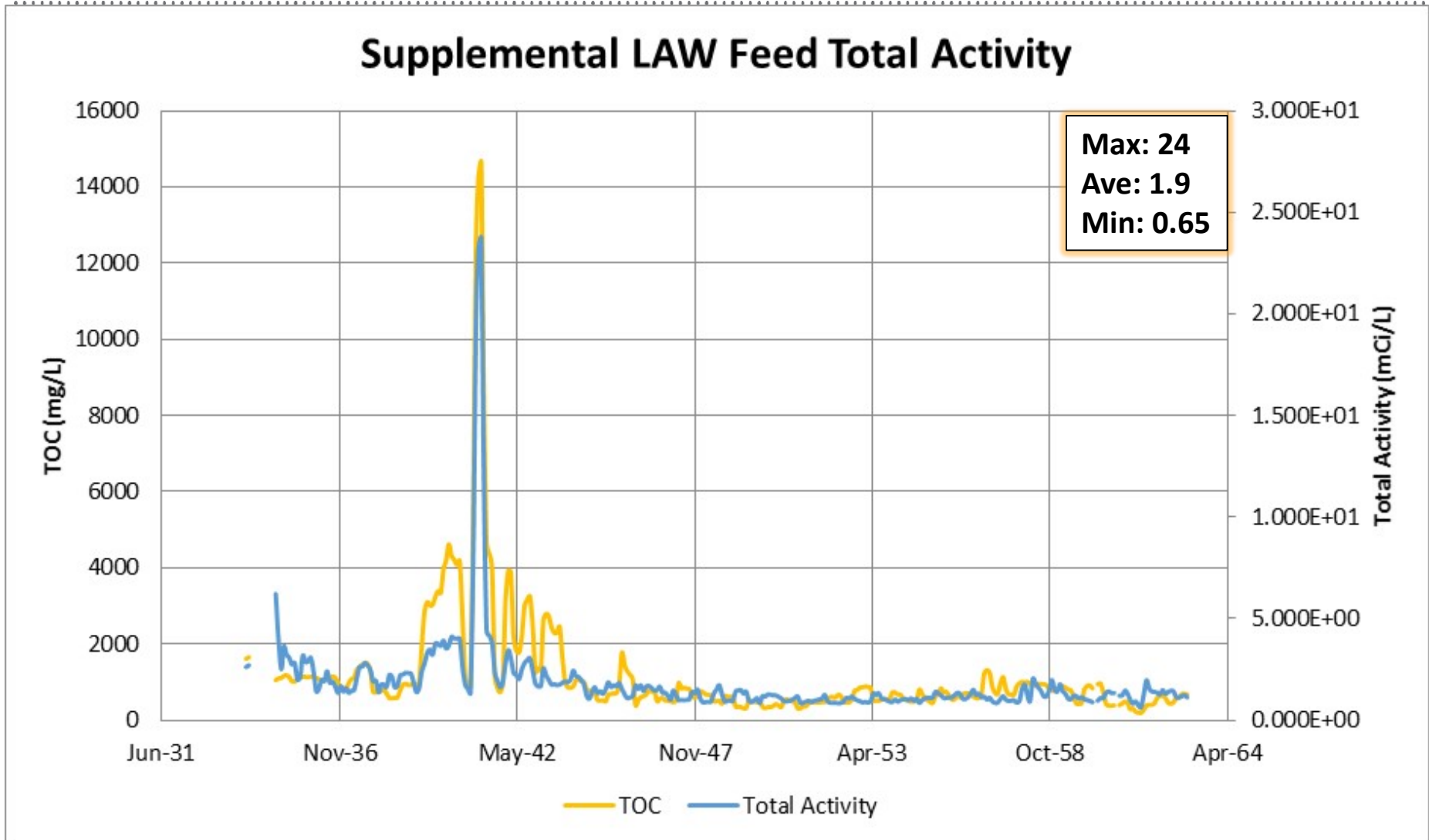
Feed Vector: Ammonia Concentrations



Feed Vector: Total Organic Carbon Concentrations



Feed Vector: Total Activity per Liter



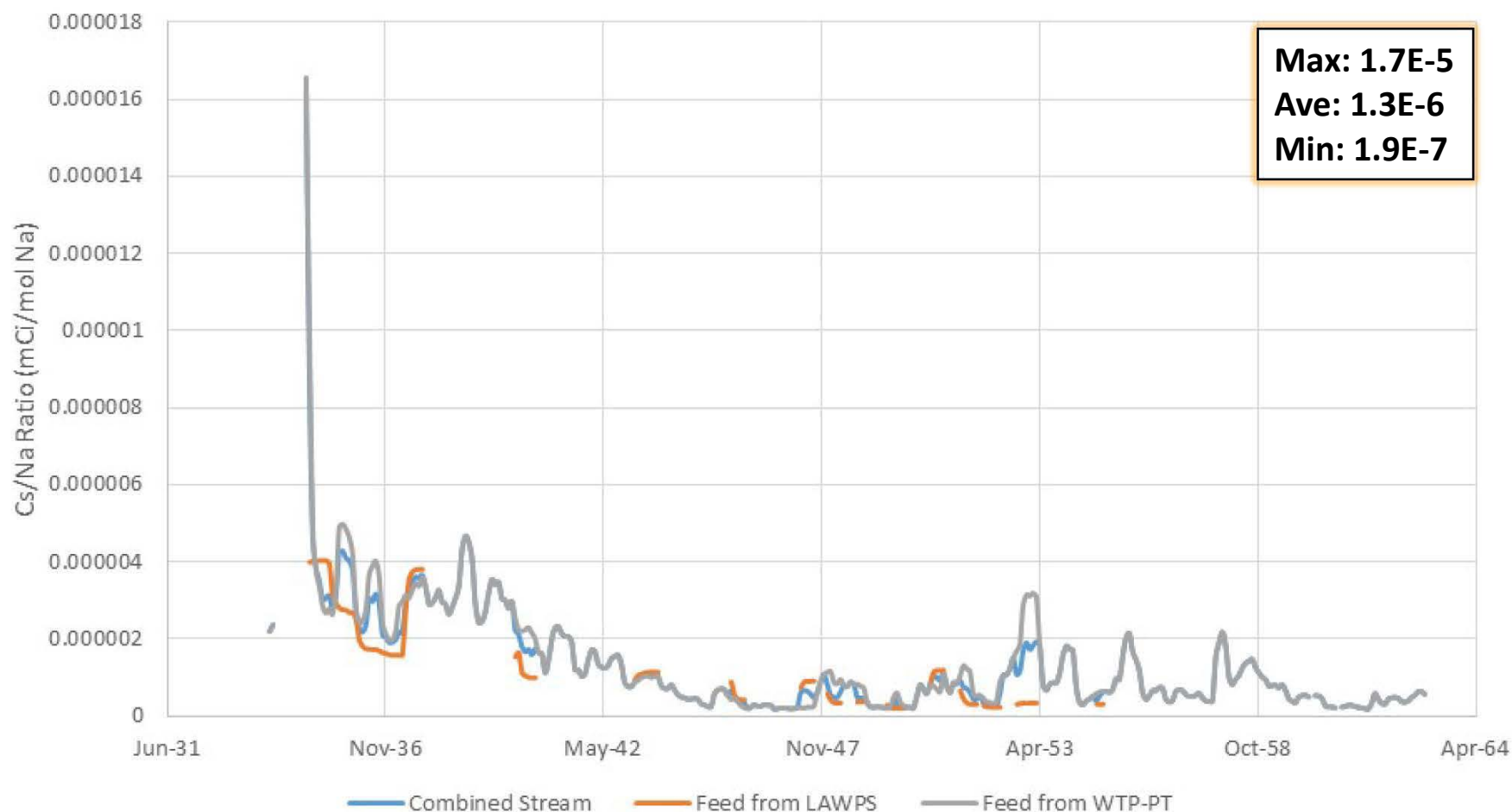
Feed Vector: Technetium-99 Concentrations

Supplemental LAW Feed Tc-99 Concentrations



Feed Vector: Cesium-137 Ratio to Sodium

Supplemental LAW Feed Cs-137 to Na Ratios



Comparison of Supp. LAW to WTP-LAW Production



LAW Facility in June 2009

- **Glass Produced**

- Supplemental ILAW:

- *Revision 1: 576 million kg*
 - *Revision 2: 281 million kg*

- WTP-ILAW:

- *Revision 1: 309 million kg*
 - *Revision 2: 267 million kg*

- **Volume of LAW treated**

- Supplemental LAW:

- *Revision 1: 62.2 million gallons*
 - *Revision 2: 54 million gallons*

- WTP-LAW:

- *Revision 1: 42 million gallons*
 - *Revision 2: 52 million gallons*

Enhanced glass models led to decrease in glass amount estimates from Rev 1 to Rev 2 of the Integrated Flowsheet.



Technical Challenges

- **Immobilization technology viability evaluation**

- Information from previous testing with Hanford waste or simulants along with information from analog facilities will be utilized to perform the evaluation

- *Hanford Waste Testing*

- Vitrification
 - » *Numerous tests with Hanford waste*
 - » *Numerous pilot scale tests with simulants*
 - Grout
 - » *Tests with Hanford waste*
 - » *Pilot scale tests with simulants*
 - Steam Reforming
 - » *Tests with Hanford waste*
 - » *Pilot scale tests with simulants*

- *Technologies in use at other sites*

- Vitrification of HLW at SRS and West Valley
 - Grouting of LLW at SRS in large storage vaults
 - Grouting of LLW at West Valley in containers
 - Fluidized bed steam reforming of sodium bearing waste at INL in final startup testing
 - Long term performance
 - *Identify when compositions are outside the bounds of previous evaluations of the technology*

- **Cost Estimation**

- Significant issues in DOE complex with accuracy of cost estimates for large projects

Uncertainties

- **System Plan 8 Assumptions**

- Funding
- Retrieval Rates

- **Feed Vector**

- Composition Uncertainty
 - *BBI uncertainty and data availability; TOPSim simplifications*
 - *Entire tank farm feed is processed, so feed vector should allow a reasonable comparison between technologies to be made*
- Volume Uncertainty
 - *TOPSim simplifications*
 - *Dependent on funding / policy decisions, other “non-technical” factors*
 - *Results should be scalable, so more important to have consistency between flowsheets versus accuracy in scale of facilities*

- **IDF Performance Assessment**

- Still in draft form, but nearly finalized

- **Cost Estimation**

- Comparison of costs between sites is challenging
 - *Different regulatory environment, etc.*



- **System Plan 8 Issues**

- Assumptions to meet required mission duration

- *Funding profile*

- Flat funding profile is inadequate for WTP PT and HLW completion, TWCSF, Supp. LAW, WRFs, TF upgrades, etc. as described

- Significant changes could be required

- » *WTP-PT not restarted*

- » *DFHLW*

- » *Modular systems for West area treatment*

- *Retrieval rates may not be realistic*

- West-East transfer line availability

- TF evaporator operation

- TF operations culture change

- » *Number of transfers in a year increased by orders of magnitude once processing starts*

- SST tanks at Hanford are out of service and were isolated by cutting piping.



Uncertainties – Details – Best Basis Inventory

- Baseline analytes
 - *Data from sample analysis or process knowledge*
 - *177 tanks in TFs*
 - 32 tanks not sampled
 - 106 tanks have core samples
- Supplemental analytes
 - *Data listed when available*
- “Wash factor” - % of a component that dissolves when sample is diluted 4:1.
- “Leach factors” – similar to wash factors, but from a caustic leach protocol
- Lists amount of components by phase
 - *Kg or curies in solids (sludge and/or saltcake combined)*
 - *Kg or curies in supernate*
- Accuracy of Input data widely variable
- Organic speciation not done for most species
 - *Assumption that all RCRA listed organics are in all tanks*

- **Integrated Flowsheet: TOPSim model**

- Solubility module to split species between solids and liquid
 - *Only selected species included; some species not modelled well*
 - *Wash factors from BBI used to split other analytes during retrieval*
- Speciation of components not changed through high temperature processes
- Split factors for most unit operations versus modelling of systems
 - *Entrainment not included in melter model*
- Melter idling impacts
- WESP deluge not modelled
- Basis, Assumptions, and Requirements Document assumptions versus data for some species
- LAW flushing not modeled



- **Composition**

- Impacts if PT not started
 - *Ammonia decreased*
 - *Semi-volatiles may be decreased if recycles from LAW not sent to Supp. LAW*
- Impacts if at-tank treatment employed
 - *Blending decreased*
- Impacts of changes to HLW mission
 - *Na, Al, etc. may not be washed/leached from HLW*



- **Volume Uncertainty**

- Impacts from uncertainty in overall mission direction
 - *HLW processing: direct feed options*
 - *PT completion*
 - *Localized(tank-side) processing*
- Improvements in LAW glass models could decrease capacity needed
- Incorporation of melter idling in process models would increase capacity needed
- Dependent on funding / policy decisions, other “non-technical” factors
- Results should be scalable, so more important to have consistency between flowsheets versus accuracy in scale of facilities



Conclusions from Feed Vector Evaluation

- **Supplemental LAW feed vector from the Integrated Flowsheet will be used as the basis for the evaluation by the team**
 - Provided by WRPS to the team as monthly averages with two streams
 - *WTP-PT to Supplemental LAW*
 - *LAWPS to Supplemental LAW*
 - Calculations performed during evaluation
 - *Combined stream calculated from the two streams provided*
 - *Unit conversions performed to obtain concentrations*
 - *Average / maximum / minimum determined for each parameter*
- **The use of this feed vector is the major assumption in evaluation of Supplemental LAW.**
 - Defines volumes to be processed, processing rates, feed composition, and variability in process
 - Defines schedule for Supp. LAW processing
 - *NAS comment: Acceleration of LAW processing to decrease risk from waste storage*
 - Not specifically evaluated during review but recognized as a possible consideration for future decisions
 - Assumes processing per System Plan 8



Other Assumptions

- Scaling of processes would not significantly impact “scoring” of options
- Escalation rates for cost estimates
- Cost estimates based on “analog” facilities
- WCS will be able to receive immobilized LAW



Backup Slides



- **Processing strategy tied to System Plan 8**
 - LAW treatment “not accelerated” by Supplemental LAW in System Plan 8
 - *Supplemental LAW already included in System Plan 8 mission life estimate*
- **Process simplifications in TOPSim model include:**
 - Supplemental LAW modeled as a “black box”
 - Single parameter “split factors” to determine partitioning of most species through each unit operation including the melter and melter offgas system
 - Impacts of melter idling not modeled
 - *70% melter utility assumed by model*
 - Flushes of transfer lines in the WTP are not modeled
- **Retrieval sequencing impacts feed compositions due to blending (or lack of blending)**
- **Best Basis Inventory Accuracy**
 - BBI information may be based on sample results or process knowledge
 - *Any approach to a Supplemental LAW feed vector must use this data*



- **Sizing of the Supplemental LAW for maximum throughput provides excess processing capacity that could be used for acceleration of LAW mission**
 - Feed availability
 - *Requires accelerated retrievals from SSTs*
 - *Requires additional Cs removal capability*
 - *Funding availability given other mission needs*



Table 6-1. Conclusions of Each Integrated Solubility Model Component

Good predictions	Poor predictions	Additional data required			
		Trending well	Trending poorly	Varied trending	No trending
⁹⁹ Tc	Al	Plutonium isotopes	Uranium isotopes	Ba	Category 1 (except ⁹⁹ Tc and ¹³⁷ Cs)
¹³⁷ Cs	Cr	Ag	⁵⁹ Ni/ ⁶³ Ni	Bi	¹²⁹ I
⁹⁰ Sr/Sr	F	Nd	Ta	Ca	Te
Cl	PO ₄	Ni		Cd	
C ₂ O ₄		V			
Na		⁹⁰ Y/Y			
NO ₂	⁹⁰ Sr had accurate ISM predictions in all tanks reviewed, but the ISM poorly predicted its concentration in the saltcake dissolution studies. However, since ⁹⁰ Sr is a Category 2 component, the ISM should predict the correct dominant phase not necessarily the correct concentration to a factor of 2. ⁹⁰ Sr is highly insoluble and it is easy for the liquid concentration to change dramatically when the major phase is still picked accurately. In addition, ⁹⁰ Sr is subject to the carbonate concentration, which could be subject to assumption made during mass balancing and experimental data reconciliation. The ISM ⁹⁰ Sr concentration predictions in saltcake dissolution may not be within a factor of 2, but the dominant phase is accurately predicted.				
NO ₃					
OH					
SO ₄					
CO ₃					
Fe					

Concentration values predicted within a factor of 2 were considered good



NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Analysis Approach

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NAS Committee Meeting #2

July 23-24, 2018

Pre-Decisional

- **“(2) An analysis of the following:**
 - (A) The risks of the approaches described in paragraph (1) relating to treatment and final disposition.*
 - (B) The benefits and costs of such approaches.*
 - (C) Anticipated schedules for such approaches, including the time needed to complete necessary construction and to begin treatment operations.*
 - (D) The compliance of such approaches with applicable technical standards associated with and contained in regulations prescribed pursuant to ...(CERCLA, RCRA, CWA)*
 - (E) Any obstacles that would inhibit the ability of the Department of Energy to pursue such approaches.”*
- **In response, the FFRDC Team defined in the program plan a high level analysis approach to:**
 - Consider the “...ability of supplemental treatment alternatives to meet the waste acceptance criteria of potential disposal sites, ... their major risks, regulatory impacts, and costs and schedules.”
 - The approach was based on lessons learned and guidance from:
 - *DOE Guidance on “Assessment of Alternatives (AOAs)” DOE O 413.3B, Appendix C*
 - *GAO Recommendations on “DOE and NNSA Project Management: Analysis of Alternatives Could Be Improved by Incorporating Best Practices.” GAO-15-37*



Approach to Assess Technologies

- Developed Lines of Inquiry (LOI), criteria, and semi-quantitative metrics for analysis of alternatives
- Expert elicitation from Team members, supported by documentation of assumptions, supporting studies, and analysis.
- Decision Analysis software to aid in documenting and assessing sensitivity of evaluation

Supplemental LAW Options and Areas of Consideration

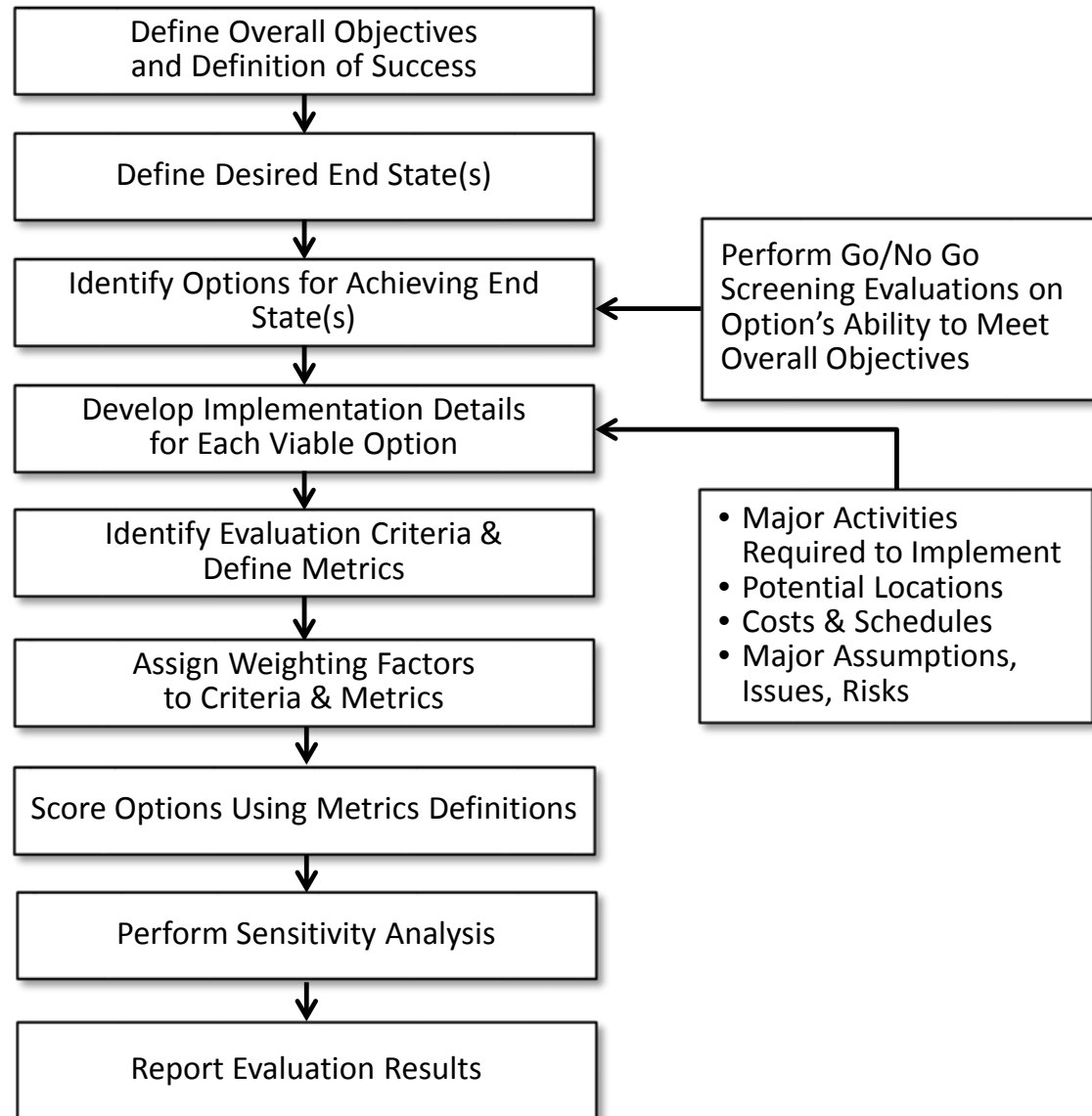
OPTIONS Pre-Treatment Waste, Disposition Technology, & Disposal Location	TRL & Complexity	Safety	Robust Operational Flexibility (ability to handle wide variety of waste feed streams)	Cost LC & Annual	Schedule	Risks and Opportunities	Waste form Performance	Secondary Wastes	Regulatory Considerations (Includes waste form & packaging)			End State Decommissioning
									Processing	Shipment	Disposal	
- Option Description - High Level Flowsheet a. Sub-option 1 b. Sub-option 2 c. _____	- TRL - Review prior documents assessing TRL - Assess qualitatively as a team - Use EM TRL guide - Complexity - Number of unit ops - Type unit ops - Secondary wastes generated (minimal, moderate, high) - Difficulty handling off-spec waste products - Major equipment replacement challenges (i.e. melters, etc.)	- Nuclear Safety - Chemical Safety - Accident/Hazard Analysis - Number of Hazards requiring controls (evaluate qualitatively, focus on active controls) - Address - Pretreatment - Immobilization - Packaging - Transport - Disposal	- Number of challenging feed streams or constituents - Impact to Pretreatment Needs - Fraction of feed streams not compatible	- Project Cost - Operations Cost - Annual Cost - Pedigree & method/reference for estimate - Comparison to "baseline" EM liability cost profile - Include Disposal & Transport Costs - Use Net Present Value or consistent "Dollars"	- Comparison to "baseline" - Options for Acceleration	- Project Risks - Operational Execution Risks - TRL related risks with technology maturation - Opportunities to accelerate schedule or reduce LC cost	- Comparison to Disposal Site WACs - Physical Performance Summary - Max Release Rate per radionuclide - TCLP Leaching - Compressive Strength - Rad Tolerance - Thermal Tolerance - Other	- Quantity - Contribution to the Environment Assessment (EA) - Disposal Pathways - Evaluation against LAW criteria	- NEPA - Long Term Environmental Impacts - Env. Permits	- DOT & NRC shipping compliance - Road vs. Rail considerations - Onsite shipping compliance - NEPA - Long Term Environmental Impacts - Env. Permits - Address concentration (Ci/cm ²) - Total volume - Inventory per container	- NEPA - Long Term Environmental Impacts - Env. Permits - Address concentration (Ci/cm ²) - Total volume - Inventory per container - PA compliance	- Decon - Removal - Entombment



- **Goal: Use a structured evaluation approach to evaluate options for alternative treatment of SLAW**
 - Used Analytical Hierarchy Process (AHP) decision modeling method developed at the Wharton School of Business at the University of Pennsylvania and used by many Fortune 500 companies and the federal government for project planning
 - It is ideal for evaluating qualitative, quantitative, and potentially conflicting criteria
 - It uses pairwise comparisons to measure the relative importance of criteria and metrics
 - It provides a documentable structured process for selecting a preferred implementation option
- **Approach: Considered 22 options for alternative treatment of SLAW**
 - Twelve options were evaluated and ranked using 10 criteria defined by the FFRDC team
 - The FFRDC team assessed that 10 were bounded by the other criteria and were not evaluated in detail



AHP Options Analysis Process



Evaluation Criteria & Metrics

Criteria	Metrics
Technical Maturity and Process Simplicity & Reliability	TRL
	Maturation of TRL
	Number of unit operations
	Simplicity of feed start-up/shut down
	Simplicity of control of unit operations
Safety	Nuclear and radiological hazards
	Chemical hazards
	Physical hazards
	Transportation hazards
Operational Flexibility	Ability to handle range of feed vector compositions
	Ability to handle range of feed vector flowrates
	Ability to prevent/rework off-spec product
	Analytical requirements

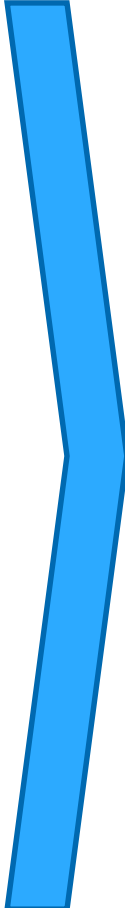


Evaluation Criteria & Metrics Continued

Criteria	Metrics
Economy	Development cost
	Capital cost (includes permits & D&D etc.)
	Operational / annual cost
Schedule (Speed)	Development time prior to design
	Time to complete design, construction, and hot startup
Imperviousness to Risks	Project risks
	Operational execution risks
	TRL related risks
Primary Waste Form Compliance	Primary waste form compliance
Secondary Waste	Quantity
	Compatible with existing / draft disposal site WAC
Regulatory Considerations	Permitting/licensing complexity for new facilities & processes
	Compliance with shipping regulations
	Permitting/licensing complexity for disposal
End State Decommissioning	Complexity (includes residual inventory)
	Waste volume



Assessing Risks

- **Risk Assessment:** Application of a systematic process for evaluating the potential risks involved in a project activity or enterprise
 - **Risk Domains**
 - Project risks
 - Environmental risks
 - Safety risks
 - **Risk Assessment Methods**
 - Probabilistic Risk Assessment (PRA)
 - Semi-quantitative risk assessment
 - Qualitative risk or hazards analysis
 - **Applications Areas (examples)**
 - Alternatives analysis
 - Risk acceptance analysis
 - Cost-benefit or cost-effectiveness analysis
- 
- **NDA 3134 Study**
 - Domains: Project, Environmental, and Safety Risks
 - Methods: Semi-quantitative
 - Application: Alternatives analysis
 - **LOIs and Expert Elicitation**
 - Significant risks identified where applicable for each LOI and Option/Variant
 - Risk Analysis SME to support Team's elicitation and evaluation process (threat scenario, consequence, probability or likelihood)
 - Explicit consideration of scope/schedule/budget, environmental, and safety risks
 - Assumptions and considerations documented for each alternative's evaluation



Assessing Risks – Progress to Date

- **Significant Risks – Identification of risks in progress**
 - Initial identification of scenarios that will be basis for risk assessment.
 - Examples:
 - *Vitrification Baseline 1 – Operational Flexibility: Current assumptions for WTP LAW facility availability and throughput may be higher than achievable in actual operation*
 - *Cast Stone Base-Case 2 – Primary Waste Form Performance: Certain organics and metals may not be adequately immobilized to meet LDR requirements.*
 - *System-Level – Feed Vector: Uncertainty in the compositions to be processed could result in the feed vector being non-conservative for selected analytes.*
- **Next Steps (with Risk Assessment SME facilitation)**
 - Identify and refine scenarios as a basis for risk assessment
 - Team assessment of each risk scenario to assign consequence and likelihood
 - Further evaluate each risks in the context of the priorities set by the AHP option evaluation results



Waste Form Performance for On-Site Disposal

Hanford Integrated Disposal Facility (IDF)

- **IDF RCRA Permit and WAC**

- WAC are defined in the current IDF Permit
(Hanford Dangerous Waste Permit Rev. 8C, WA7890008967, IDF Operating Unit Group 11)
- IDF is currently limited to ILAW from WTP ILAW glass canisters and 50 Bulk Vit test boxes
 - *Permit specifies process to propose additional wastes for disposal (including secondary wastes)*
- Requires a “risk budget tool” to assess impacts to groundwater of disposed wastes and expected to be disposed wastes; restricts disposal if results indicate impacts >75% of any performance standard, including federal drinking water standards.
- Specifies that HLVIT BDAT applies to ILAW for 8 LDR metals
- Requires DOE submit “**all waste acceptance criteria**” prior to IDF operations

- **DOE Draft “all” WAC**

- similar requirements as offsite commercial WAC, but
- contains a “release rate limit (Ci/yr)” for LAW waste forms informed by past IDF performance assessment (PA) analysis



IDF Disposal Performance – Analysis Approach

- **Study will employ a disposal risk assessment approach (“mini” PA) to directly compare alternative waste forms**
 - Verify waste form meets long-term performance objectives (groundwater benchmarks)
 - Waste form-specific radionuclide release mechanisms, rates, and transport to groundwater
 - Reference analysis
 - *2003 Supplemental Treatment Risk Assessment*
 - *2012 Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington (TC & WM EIS) (DOE/EIS-0391)*
 - *2017 DRAFT Integrated Disposal Facility Performance Assessment*
- **Disposal Risk Assessment Approach – in progress**
 - Document waste form release mechanisms, parameters, disposal site and waste form assumptions, inventory, recharge/infiltration, and assessment tools (models)
 - Compare and contrast study assumptions, mechanisms, and parameters with those of prior analysis. Document basis for differences.
 - Model each waste form option to the extent necessary to obtain release rate information for key contaminants of concern (CoCs).
 - *Priority on Steam Reforming mineral product, and cementitious waste forms (ILAW and secondary wastes) because they were not considered in the 2017 IDF PA, or need to be evaluated with new or broader waste form performance data*
 - Bounding assumptions and parameter values will be considered, to the extent practical, to assess uncertainty



Backup Slides



Highlights of GAO Recommended 24 Best Practices

- **General Principles**

- includes members with diverse areas of expertise including, at a minimum, subject matter expertise, project management, cost estimating, and risk management.
- creates a plan, including proposed methodologies, for identifying, analyzing, and selecting alternatives, before beginning the AOA process.
- conducts the analysis without a predetermined solution.

- **Identifying Alternatives**

- includes one alternative representing the status quo to provide a basis of comparison among alternatives.
- screens the list of alternatives before proceeding, eliminates those that are not viable, and documents the reasons for eliminating any alternatives.

- **Assessing Alternatives**

- uses a standard process to quantify the benefits/effectiveness of each alternative and documents this process.
- identifies and documents the significant risks and mitigation strategies for each alternative.
- tests and documents the sensitivity of both the cost and benefit/effectiveness estimates for each alternative to risks and changes in key assumptions.

- **Selecting a Preferred Alternative – *not in FFRDC Team's Scope***

NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Base and Variant Case Overview

Michael Stone

FFRDC Team Sr. Technical Advisor

Senior Fellow Engineer

SRNL Environmental Stewardship Directorate

NAS Committee Meeting #3

July 23 – 24, 2018

Pre-Decisional

Base Cases

Option Title	Attributes	Assumptions	Pathways	Notes
1 - Vitrification - Base Case	Primary Waste Disposition: IDF Primary Container: LAW Canister Pretreatment: None Pretreatment Waste Disposition: N/A Scrubber liquid, etc: LERF/ETF Secondary Solid Waste Disposition: IDF	Four additional melters - same as LAW melters, Glass formulation from System Plan 8; idling is not considered but will increase size; secondary waste stays on site	Supplemental LAW feed vector -> Vit plant near WTP, SLAW waste pumped to Feed Tank, Melter Feed prep tank, Melter feed tank, melter, Container filling, Container Decon, Lag Storage Facility, Disposal at IDF; SBS concentrate, HEME and scrubber got to EMF for evaporation; bottoms are recycled, overheads sent to LERF/ETF	Add GFC silos, share control room, new EMF;
2 - Grout - Base Case	Primary Waste Disposition: IDF Primary Container: 8.4m ³ bag in box Pretreatment: None Pretreatment Waste Disposition: N/A Secondary Solid Waste Disposition: IDF	Hanford Cast Stone Mixture, Volume increase is assumed to be 1.8, no pretreatment beyond WTP-PT/LAWPS; all equipment will be contact handleable	Supplemental LAW feed vector -> Grout plant near WTP, SLAW waste pumped to Feed Tank, Batch mixer, Container filling, Container Decon, Lag Storage Facility, Disposal at IDF	May consider variants with pretreatment to remove Tc, I or Sr. Getters may be added to tie-up Tc and/or iodine.
3 - Steam Reforming - Base Case	Primary Waste Disposition: IDF Primary Container: 8.4m ³ Pretreatment: None Pretreatment Waste Disposition: N/A Secondary Solid Waste Disposition: IDF	Two complete FBSR systems, Grout or geopolymer monolith system to encapsulate the granular product before storage, Caustic scrub goes back to FBSR system	Supplemental LAW feed vector -> FBSR plant near WTP, SLAW waste pumped to Feed Tank, Waste Staging tank, FBSR system, waste product handling system, Container filling, Lag Storage Facility, Disposal at IDF; off-gas system (Thermal oxidation, Carbon bed for Hg, Caustic scrub for I, HEPA)	HIC or encapsulate the powder needed to go to IDF

Pre-Decisional



Vitrification Variant Cases

Option Title	Attributes	Assumptions	Pathways	Notes
1c - Vit to IDF, Secondary to WCS	Primary Waste Disposition: IDF Primary Container: LAW Canister Pretreatment: None Pretreatment Waste Disposition: N/A Scrubber liquid, etc: LERF/ETF Secondary Solid Waste Disposition: WCS	Same as base Vit case (1) but with secondary waste to WCS	See Case 1	
1d - Bulk Vitrification	Primary Waste Disposition: IDF Primary Container: 44 MT container Pretreatment: None Pretreatment Waste Disposition: N/A Scrubber liquid, etc: LERF/ETF Secondary Solid Waste: IDF	Two 44 MT melters; secondary waste stays on site;	Supplemental LAW feed vector -> Vit plant near WTP, SLAW waste pumped to Feed Tank, Waste drier, Dried waste handling system, melter, Bulk Vit Container (44MT) filling, Container Decon, Lag Storage Facility, Disposal at IDF; SBS concentrate, HEME and scrubber go to LERF/EFF	5 silos; May need to add EMF
1g - Bulk vit in large container to IDF, Secondary to WCS	Primary Waste Disposition: IDF Primary Container: Large (10m ³) container Pretreatment: None Pretreatment Waste Disposition: N/A Secondary Solid Waste Disposition: WCS	Two 44 MT melters; secondary waste goes off-site;		

Pre-Decisional



Grout Variant Cases

Option Title	Attributes	Assumptions	Pathways	Notes
2d - Grout with LDR pretreatment, Primary & Secondary waste to IDF	Primary Waste Disposition: IDF Primary Container: 8.4m ³ bag in box Pretreatment: LDR Pretreatment Waste Disposition: N/A Secondary Solid Waste Disposition: IDF	Grout base case with pretreatment for LDR, Primary to IDF, Secondary to IDF	See Case 2	
2e1 - Grout with LDR and Tc & I Pretreatment to HLvit Primary & Secondary waste to IDF	Primary Waste Disposition: IDF Primary Container: 8.4m ³ bag in box Pretreatment: LDR, Tc, I Pretreatment Waste Disposition: Tc, I to HLvit Secondary Solid Waste Disposition: IDF	Grout base case with pretreatment for LDR, Tc, I sent to HLvit, Secondary to IDF	See Case 2	
2e2 - Grout with LDR and Tc & I Pretreatment to WCS Primary & Secondary waste to IDF	Primary Waste Disposition: IDF Primary Container: 8.4m ³ bag in box Pretreatment: LDR, Tc, I Pretreatment Waste Disposition: Tc, I to WCS Secondary Solid Waste Disposition: IDF	Grout base case with pretreatment for LDR, Tc, I grouted and sent to WCS, Secondary to IDF	See Case 2	
2f - Grout with LDR and Sr pretreatment; Primary waste to WCS	Primary Waste Disposition: WCS Primary Container: 8.4m ³ bag in box Pretreatment: LDR, Sr Pretreatment Waste Disposition: Sr to HLvit Secondary Solid Waste Disposition: IDF	Grout base case with pretreatment for LDR, Sr to HLvit, Secondary to IDF	See Case 2	
2g2 - Grout with LDR pretreatment; Primary waste to WCS	Primary Waste Disposition: WCS Primary Container: 8.4m ³ bag in box Pretreatment: LDR Pretreatment Waste Disposition: N/A Secondary Solid Waste Disposition: IDF	Grout base case with pretreatment for LDR; grouted secondary to IDF	See Case 2	

Pre-Decisional



Steam Reforming Variant Case

Option Title	Attributes	Assumptions	Pathways	Notes
3b - Steam Reforming to WCS, Secondary to WCS	Primary Waste Disposition: WCS Primary Container: 8.4m ³ Pretreatment: None Pretreatment Waste Disposition: N/A Secondary Solid Waste Disposition: WCS	Not macroencapsulated in containers to WCS. Dried, packaged secondary solid waste to WCS	See Case 3	

Pre-Decisional



NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Pretreatment Approaches

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Pre-Decisional

Sec. 3134 “Further Processing”

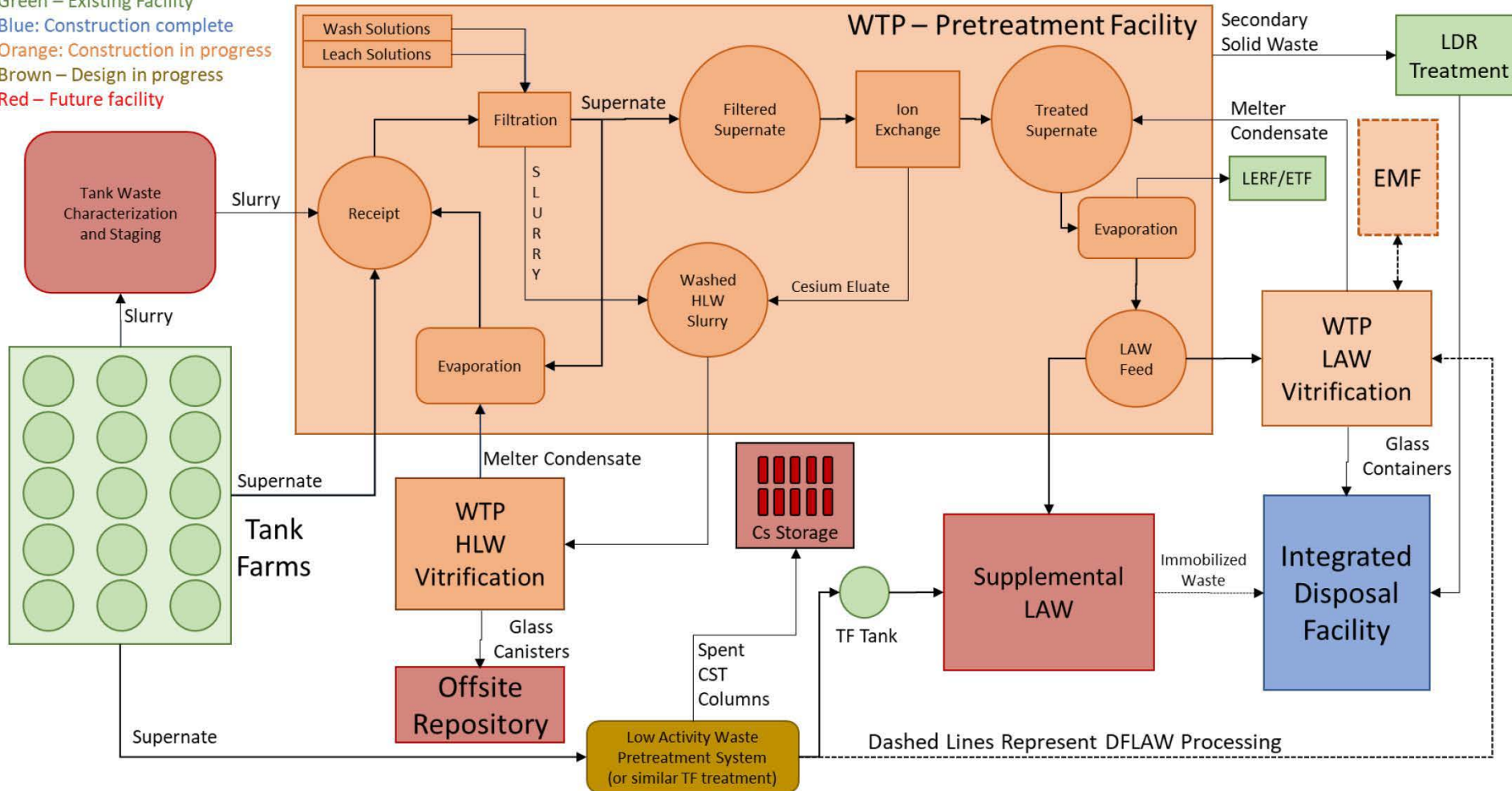
- “(1) An analysis of at a minimum, the following approaches for treating the low-activity waste ...:
 - (A) Further processing of the low-activity waste to remove long-lived radioactive constituents, particularly technetium-99 and iodine-129, for immobilization with high-level waste.
- In response, the FFRDC Team is identifying and analyzing:
 - Further processing alternatives that reduce the levels of:
 - *Iodine*
 - *Technetium*
 - *Could change the waste class (strontium)*
 - *Could address Land Disposal Restrictions*



WTP Baseline Process as Defined in Integrated Flowsheet

Process flows greatly simplified
 Dilute LAW feed can be sent to evaporation, not shown
 Evaporator condensate is sent to LERF/ETF, not shown for all evaporators
 Solid secondary waste stream only shown for PT, applies to all facilities

Green – Existing Facility
 Blue: Construction complete
 Orange: Construction in progress
 Brown – Design in progress
 Red – Future facility



Pre-Decisional

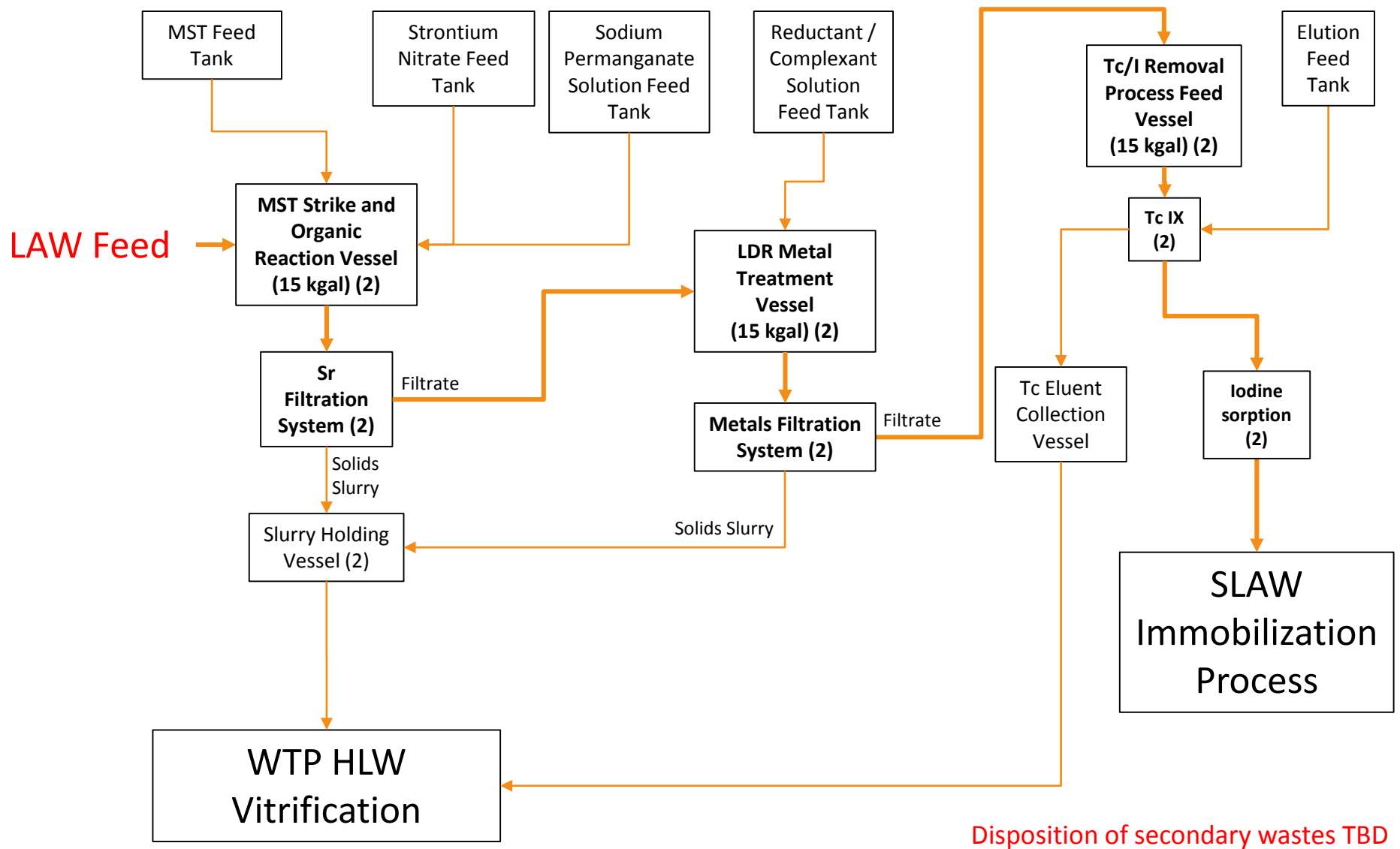


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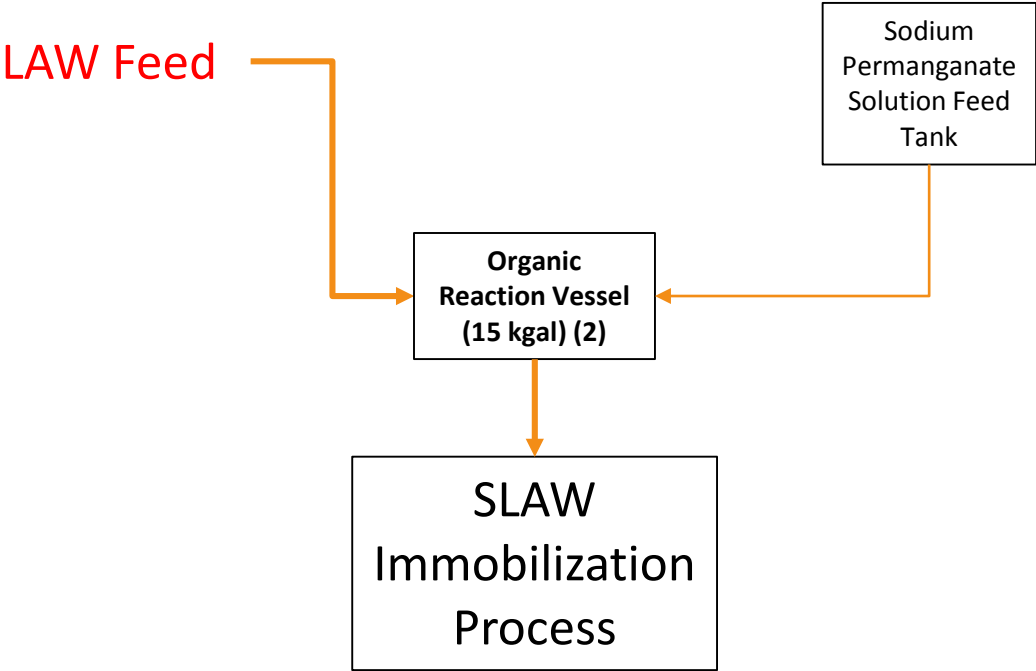
Pre-Decisional

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Supplemental LAW Pretreatment Concept



Supplemental LAW Pretreatment Concept: LDR Organic Treatment Only



Methodology for Identification and Analysis of Further Processing Approaches

- **Further processing of the LAW stream may provide benefits in:**
 - addressing potential limitations in processing of the waste into a stable waste form,
 - improving disposal performance, or
 - meeting other regulatory requirements
- **FFRDC Team Approach**
 - Identify potential limitations of each primary waste processing technology flowsheet (vitrification, grouting, steam reforming)
 - *to the extent possible, includes evaluation of each major process step to identify any limiting constituents in the stream and determine if their removal could have significant benefits.*
 - Identify potential areas of opportunity for each flowsheet, from waste processing through transportation and disposal, where further processing could provide substantial cost or risk reduction.
 - Assess process performance requirements necessary to address the limitation or opportunity. For example, how much Tc-99 removal would be required to meet a disposal WAC or other performance requirement?
 - Identify and evaluate further processing technologies and flowsheets that may have the potential to meet the process performance requirements.
 - Document the assessment and recommendations for each option considered.



Preliminary Identification of “Other” Options for Review

Process Category	Technology Option	Key Attributes	Source
Immobilization	Vitrification with Phosphate Glass	Increased sulfate and chromium loading in glass, increased vitrification throughput	DOE, 2014
Immobilization	Active-metal reduction	Destroys nitrate and nitrites, produces a ceramic waste form	Choho and Gasper, 2002 Gasper et al., 2002 DOE, 2014
Immobilization	Alternative low-temperature waste forms such as phosphate-bonded ceramics and alkali-aluminosilicate geopolymers	Potential increased durability over cement-based waste forms at low temperature processing	Cantrell and Westsik, 2011 Gong et al., 2011
Pretreatment	Fractional crystallization	Separate Cs, Tc, I from a high sodium fraction of the LAW	DOE, 2014 Herting, 2007
Pretreatment	Clean salt (with or without sulfate removal)	Separate a “clean” sodium (and optional sulfate) fraction for immobilization in ceramic, grout, or polymer	Choho and Gasper, 2002 Gasper et al., 2002 DOE, 2014
Pretreatment	Plasma mass separator	Physical separation of elements by atomic mass to produce heavy and light fractions for treatment	DOE, 2014
Pretreatment	Caustic recycle	Electrochemical separation of sodium hydroxide for recycle, reducing LAW volume	DOE, 1999
Pretreatment	Technetium removal	Reduce Tc in LAW fraction or secondary waste	DOE, 2014 (or 2012???)
Pretreatment or Off-gas Treatment	Iodine removal	Reduce I in LAW fraction or secondary waste	DOE, 2014
Pretreatment	Strontium removal	Reduce soluble Sr-90 in specific LAW feeds	n/a ¹
Pretreatment	Treatment of RCRA LDR Constituents	Oxidation or reduction to destroy organics or reduce metal mobility in LAW waste form (e.g., grout)	n/a ¹
Pretreatment	Ammonia removal	Reduce emissions and safety concerns during waste processing	n/a ¹

¹ NDAA 3134 FFRDC Team Assessment. Analysis of specific technology options in progress



Removal Requirements

- **Tc Removal Target:**

- *Primary Basis - 2017 IDF PA, Extracted summary plots from WRPS presentation to NAS committee, 2/27/18*
- *Assumptions:*
 - *LSW grout is conservative relative to performance of ILAW grout*
 - *LSW performance extrapolation linear to much higher Tc inventories*
 - *Fraction of Tc inventory for SLAW is 50%*
- *Based on these assumptions and a maximum ground water limit of 900 pCi/l to meet regulatory requirement an overall Tc removal of 92% is required*
- *To limit the ground water concentration to 100 pCi/l an overall Tc removal of 99% is required*

- **Iodine Removal Target:**

- *Primary Basis - 2017 IDF PA, Extracted summary plots from WRPS presentation to NAS committee, 2/27/18*
- *Assumptions*
 - *LSW grout is conservative relative to performance of ILAW grout*
 - *LSW performance extrapolation linear to iodine inventories*
 - *Fraction of iodine inventory for SLAW is 50-60%*
- *Based on these assumptions and a maximum ground water limit of 1 pCi/l to meet regulatory requirement an overall iodine removal of 48 – 57% is required*
- *To limit the ground water concentration to 0.05 pCi/l an overall iodine removal of 97 to 98% is required*



Removal Requirements (Cont.)

- Strontium Removal Targets

Grout (1770 kg/m ³ , all nuclides retained and 1.8 multiplier)					
% Sr-90 removal	GTCC (months)	Class C (months)	Class B (months)	Class A (months)	Notes
None	0	33	408	0	TRU's from WTP PT cause Class C
90% removal	0	33	338	70	
95% removal	0	33	314	94	
99% removal	0	33	2	406	

Glass (or Steam Reformed) (2600 kg/m ³ , all nuclides and 1.0 multiplier)					
% Sr-90 removal	GTCC (months)	Class C (months)	Class B (months)	Class A (months)	Notes
None	0	42	399	0	TRU's from WTP PT cause Class C
90% removal	0	42	399	0	
99% removal	0	42	1	398	



Removal Requirements (Cont.)

- **LDR Organics Removal Target:**

- Organic content indeterminant based Feed Vector / Tank chemical analysis.
- Cast stone (CS) process does not meet the definition of HLWIT to address suspected organics.
- As a stabilization technology, CS is a less likely candidate for a determination of equivalent treatment (DET), and is generally not an acceptable treatment technology for organics
- *Assumptions:*
 - *Some organic treatment / destruction will be required.*
 - *Organic removal / destruction of 50 to 90% required for selected tanks*

- **LDR Metals Removal Targets:**

- RCRA metal content indeterminant based Feed Vector / Tank chemical analysis.
- Tank specific waste form TCLP results needs
- *Assumptions:*
 - *Some metal removal / complexation may be required.*
 - *Selected RCRA metal removal / complexation of TBD required for selected tanks*

- **No-Migration Variance**

- Waste handlers can land dispose hazardous wastes subject to LDR in a land-based unit without meeting treatment standards, if a petitioner can demonstrate that there will be no migration of hazardous constituents from the unit for as long as the waste remains hazardous.



Sr Removal Options

- **A number of options have been identified and developed to various degrees:**
 - *Precipitation with strontium nitrite*
 - *Solvent Extraction*
 - *D2EHPA*
 - *Modified Caustic Side Solvent Extraction*
 - *Ion-Exchange*
 - *Sodium nonatitanate*
 - *Sodium titanate*
 - *Monosodium titanate (MST)*
 - *Crystalline Silico-titanate (CST): Some Sr removal will occur; not primary purpose*
- **Notes:**
 - The actinide elements, plutonium and americium, present in some of the Hanford tanks, e.g., 241-AN-102 and 241-AN-107 are held in solution by complexing agents used during ^{90}Sr recovery efforts conducted at the Hanford B Plant.
 - These complexed species do not readily sorb to monosodium titanate; therefore, a different separation method is required in some cases.
 - A precipitation process has been and demonstrated at multi-liter scale for separating the ^{90}Sr and TRU components from complexant concentrate waste
 - *^{90}Sr is removed by adding strontium nitrate to precipitate strontium carbonate following a caustic adjustment step*
 - *The strontium addition imparts an isotopic dilution for the radioactive strontium.*
 - *This is followed a sodium permanganate strike that forms a precipitate of manganese oxides or hydroxides.*
 - *TRU components of the waste follow the precipitated manganese phase.*
 - *System Plan 8 assumes this process is performed in the tank farms for 241-AN-102 and 241-AN-107*



Tc Removal Options

- **A number of options have been identified and developed to various degrees:**

- *Solvent Extraction*

- *SrTALK (DI+butylcyclohexano)-18-crown-6) in TBP:Isopar*

- Moyer's group developed a process (SrTalk) for removing Sr and Tc from wastewater in the late '90s. The Sr part doesn't work in high alkalinity, but the Tc part worked well.

- *Ion-Exchange*

- *Numerous materials tested as part of Tank Waste Remediation System (TWRS) program (see table below)*

- *SuperLig-639[®], (a polystyrene matrix resin with a crown-ether based organic linker covalently attached), has the best adsorption separation capacity under realistic conditions. (DF of ~100 for wastes without significant amounts of organic complexants)*

- **Complications**

- *Batch contact and laboratory-scale ion exchange column tests have indicated that 1 to 5 percent of the technetium present in samples of non-complexed tank wastes is not present as the pertechnetate anion and cannot be extracted using SuperLig 639 resin.*

Ion exchanger	Description	Kd, mL/g ^a
Purolite A-520E	Macroporous anion exchanger with triethylamine groups	1,300
Ionac SR-6	Macroporous anion exchanger with tributylamine groups	1,170
Reillex HPQ	Copolymer of 1-methyl-4-vinylpyridine and divinylbenzene	670
n-butyl-Reillex HP	n-butyl derivative of poly-4-vinylpyridine/divinylbenzene (Reillex [™] HP)	1,405
iso-butyl-Reillex HP	iso-butyl derivative of Reillex [™] HP	810
n-hexyl-Reillex HP	n-hexyl derivative of Reillex [™] HP	1,405
n-octyl-HP	n-octyl derivative of Reillex [™] HP	780
TEVA•Spec	Methyltricaprylammonium chloride (Aliquat [™] 336) sorbed onto an acrylic ester nonionic polymer	1,280
Aliquat 336 beads	Aliquat [™] 336 sorbed onto porous carbon beads (Ambersorb [™] 563)	1,420

William R. Wilmarth , Gregg J. Lumetta , Michael E. Johnson , Michael R. Poirier , Major C. Thompson , Patricia C. Suggs & Nicholas P. Machara (2011) Review: Waste-Pretreatment Technologies for Remediation of Legacy Defense Nuclear Wastes, Solvent Extraction and Ion Exchange, 29:1, 1-48, DOI: 10.1080/07366299.2011.539134



Iodine Removal Options

- A very limited number of options have been identified and only limited development on these:
 - *Solvent Extraction*
 - *SrTALK (DI+butylcyclohexano)-18-crown-6) in TBP:Isopar*
 - As noted for Tc SrTalk was developed for removing Sr and Tc from wastewater in the late '90s. The Tc portion worked well. Moyer thinks that IO_3^- might also be removed, but this has not been experimental verified
 - *Ion Exchange*
 - *Several macroreticular resins have been studied for iodine removal from aqueous streams*
 - *But predominately from neutral to acidic conditions*
 - *Adsorption*
 - *Separation of radioactive iodine from alkaline solutions was achieved using alumina doped with silver nanoparticles (Ag NPs) has been developed in S. Korea*
 - achieved iodine removal and recovery efficiencies of 99.7%
- **Complications:**
 - The amount of iodine in the tanks is dwarfed by the other halogens.



LDR Organics and Metals Management Options

- **Organic Management**

- *Chemical Oxidation (CHOXD)*

- *Permanganate*

- *Peroxides*

- *Recovery of Organics (RORGs)*

- *Carbon adsorption*

- *Liquid / Liquid Extraction*

- *Physical phase separation / centrifugation*

- **Metals Management**

- *Chemical Reduction*

- *Additives to admix to waste form*





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NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview - “Other Considerations”

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NAS Committee Meeting #3

July 23-24, 2018

Pre-Decisional

Sec. 3134 “Further Processing” and “Alternative Approaches”

- “(1) An analysis of at a minimum, the following approaches for treating the low-activity waste ...:
 - (A) Further processing of the low-activity waste to remove long-lived radioactive constituents, particularly technetium-99 and iodine-129, for immobilization with high-level waste.
 - (B) Vitrification, grouting, and steam reforming, and other alternative approaches identified by the Department of Energy for immobilizing the low-activity waste.”
- In response, the FFRDC Team is identifying and analyzing:
 - The three primary immobilization options – vitrification, grouting, and steam reforming,
 - Other alternative approaches, and
 - Further processing alternatives



Identification of “Other” Options for Review

Process Category	Technology Option	Key Attributes	Source
Immobilization	Vitrification with Phosphate Glass	Increased sulfate and chromium loading in glass, increased vitrification throughput	DOE, 2014
Immobilization	Active-metal reduction	Destroys nitrate and nitrites, produces a ceramic waste form	Choho and Gasper, 2002 Gasper et al., 2002 DOE, 2014
Immobilization	Alternative low-temperature waste forms such as phosphate-bonded ceramics and alkali-aluminosilicate geopolymers	Potential increased durability over cement-based waste forms at low temperature processing	Cantrell and Westsik, 2011 Gong et al., 2011
Pretreatment	Fractional crystallization	Separate Cs, Tc, I from a high sodium fraction of the LAW	DOE, 2014 Herting, 2007
Pretreatment	Clean salt (with or without sulfate removal)	Separate a “clean” sodium (and optional sulfate) fraction for immobilization in ceramic, grout, or polymer	Choho and Gasper, 2002 Gasper et al., 2002 DOE, 2014
Pretreatment	Plasma mass separator	Physical separation of elements by atomic mass to produce heavy and light fractions for treatment	DOE, 2014
Pretreatment	Caustic recycle	Electrochemical separation of sodium hydroxide for recycle, reducing LAW volume	DOE, 1999
Pretreatment	Ammonia removal	Reduce emissions and safety concerns during waste processing	n/a ¹

Pretreatment	Technetium removal	Reduce Tc in LAW fraction or secondary waste	DOE, 2014
Pretreatment or Off-gas Treatment	Iodine removal		
Pretreatment	Strontium removal		
Pretreatment	Treatment of RCRA LDR Constituents	Reduce metal mobility in LAW waste form (e.g., grout)	n/a ¹

Identified as further processing options to be evaluated within specific variants in this assessment

¹ NDAA 3134 FFRDC Team Assessment. Analysis of specific technology options in progress

Assessment of “Other” Options

Other Option NDAA Category	Technology Option	Major Alt., Variation, or Supplemental to Primary Options	Preliminary Disposition
1(B) Other Alternative Approach	Vitrification with Phosphate Glass	Variation of vitrification base case and variants	Iron phosphate glasses offer several potential benefits over borosilicate glasses such as sulfate tolerance, but with some tradeoffs including lower technical maturity (e.g., testing at scale and melter corrosion performance) than the vitrification base case.
1(B) Other Alternative Approach	Active-metal reduction with phosphate-bonded ceramic or aluminosilicate waste form.	Major alternative	Low technical maturity with higher technical and safety risk than current approaches. No evidence of development/maturation since 2002 assessment.
1(B) Other Alternative Approach	Alternative low-temperature waste forms such as phosphate-bonded ceramics and alkali-aluminosilicate geopolymers	Variation of low-temperature grout base case ¹	Benefits not deemed significant relative to grout base case based on secondary waste treatment evaluation results. Lower technical maturity than grout base case.

¹ Could be considered major alternative, but both waste forms were evaluated alongside grout as low-temperature alternatives for Hanford secondary waste applicability.



Assessment of “Other” Options

Other Option NDAA Category	Technology Option	Major Alt., Variation, or Supplemental to Primary Options	Preliminary Disposition
1(A) Further Processing	Fractional crystallization	Supplemental to base cases and variants	Benefits limited to medium to low-curie tanks in lieu of baseline Cs pretreatment, with potential added benefit of Tc removal (e.g., early 200-West tank treatment). Alternative Cs removal considered outside NDAA scope.
1(A) Further Processing	Clean salt (with or without sulfate removal)	Supplemental to base cases and variants	Alternative to baseline Cs pretreatment, with potential added benefit of Tc removal. Alternative Cs removal considered outside NDAA scope. Technical risk of immobilized salt increasing waste volume or not meeting WAC for disposal.
1(A) Further Processing	Caustic recycle	Supplemental to base cases and variants	Reduction in need for sodium addition to support HLW processing reduces LAW volume. Technical and economic assessments in 2007-2009 were favorable. Technology not core to NDAA scope.



Assessment of “Other” Options

Other Option NDAA Category	Technology Option	Major Alt., Variation, or Supplemental to Primary Options	Preliminary Disposition
1(A) Further Processing	Plasma mass separator	Major Alternative for improved separations prior to immobilization	Low technical maturity and high technical risk. Principally focused on reducing HLW volume, with modest reduction in LAW volume. Commercial development ceased in 2006.
1(A) Further Processing	Ammonia removal	Supplemental to grout base case and variants	Need for ammonia mitigation not confirmed at this stage of pre-conceptual design. Deferred to detailed project definition.



Backup Slides



Methodology for Identification and Analysis of Other Processing Alternatives

- **Wide range of options previously identified and considered:**

- *Initial Supplemental Treatment, Mission Acceleration Initiative (Choho and Gasper, 2002)*
- *Tank Closure and Waste Management EIS (DOE, 2012)*
- *DOE-sponsored development and testing since 2003*

- **FFRDC Team Approach**

- Identify options previously considered as part of supplemental treatment selection processes,
- Review rationale for the options' earlier disposition (e.g., screened out, or further consideration recommended),
- Assess subsequent development or evaluation of the technology option (since its previous evaluation).
- Evaluate the current relevance of the option to:
 - *scope of the study*
 - *potential benefits to the supplemental treatment mission, and*
 - *likelihood that benefits could be realized if pursued.*
- Document the assessment and recommendations for each option considered.



Methodology for Identification and Analysis of Further Processing Approaches

- **Further processing of the LAW stream may provide benefits in:**
 - addressing potential limitations in processing of the waste into a stable waste form,
 - improving disposal performance, or
 - meeting other regulatory requirements
- **FFRDC Team Approach**
 - Identify potential limitations of each primary waste processing technology flowsheet (vitrification, grouting, steam reforming)
 - *to the extent possible, includes evaluation of each major process step to identify any limiting constituents in the stream and determine if their removal could have significant benefits.*
 - Identify potential areas of opportunity for each flowsheet, from waste processing through transportation and disposal, where further processing could provide substantial cost or risk reduction.
 - Assess process performance requirements necessary to address the limitation or opportunity. For example, how much Tc-99 removal would be required to meet a disposal WAC or other performance requirement?
 - Identify and evaluate further processing technologies and flowsheets that may have the potential to meet the process performance requirements.
 - Document the assessment and recommendations for each option considered.



NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Vitrification Cases

Alex Cozzi

FFRDC Team Vitrification Lead

Manager, Immobilization Technology Group
SRNL Environmental Stewardship Directorate

*NAS Committee Meeting #3
July 23 -24, 2018*

Pre-Decisional

Vitrification Baselines and Options

WTP LAW (First LAW) – Two-melter facility used as framework for baseline and options

- Baseline 1: Vitrification
 - Four WTP LAW melters based on ORP-11242 Revision 8
 - “Traditional” Joule-heated, ceramic-lined glass melter
 - Resized vessels and modified primary offgas system
 - Additional EMF (2x WTP size)
- Option 1c: Vitrification with secondary waste disposed of off-site
 - Break recycle loop for contaminants with poor retention in glass
 - Reduce IDF inventory/source term

In-Container Vitrification™ used as framework for baseline and options

- Baseline 1d: Bulk Vitrification
 - Based on RPP-24544 Revision 1D
 - Waste dried, placed into container, and melted via inserted electrodes
 - Offgas treatment system
 - 44 metric ton container capacity
- Option 1g: Bulk Vitrification in large container; solidified secondary waste off-site
 - 10 m³ bag in box
 - Secondary solid waste shipped to off-site disposal facility

WTP - From Hanford Vit Plant website

<https://www.hanfordvitplant.com/low-activity-waste-law-vitrification-facility>



LAW VIT: Footprint – 330 ft x 240 ft x 90 ft
Concrete – 28,500 cubic yards
Structural Steel – 6,200 tons
Craft hours to build: 2,337,000



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Pre-Decisional

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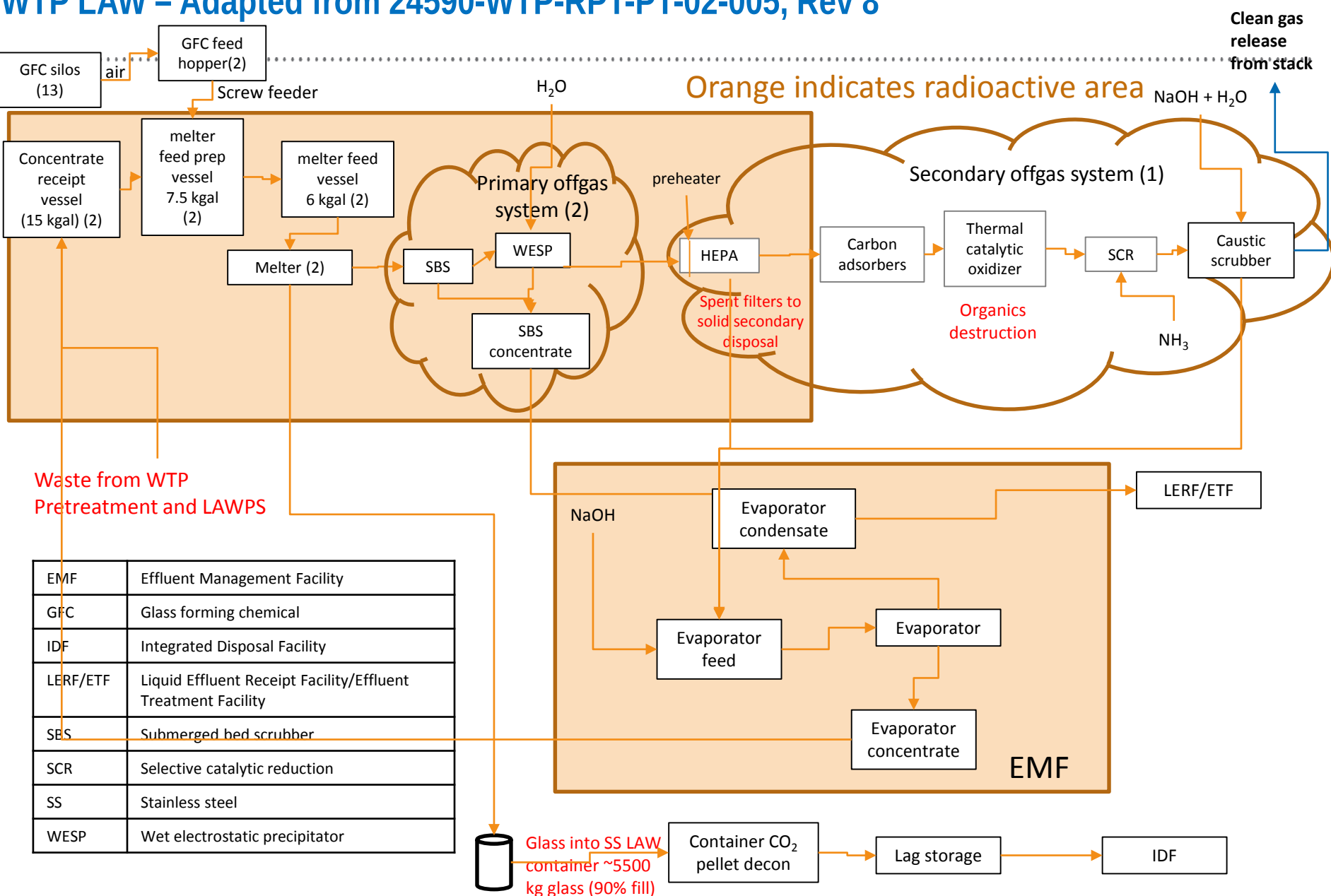
Vitrification - Basis

WTP LAW (First LAW) – Two-melter facility used as framework for baseline and options

- Waste concentrate received from LAWPS or WTP PT (88 gpm)
- Waste is analyzed (time for sample collection, transport, and analysis is 10.5 hr) to select and add GFCs
 - LAW Glass Shells perform the following steps:
 1. Take stream data and convert it to glass oxide values that are usable in the calculations
 2. Estimate a probable mass and glass chemistry for a batch
 3. Determine the glass properties for the batch using glass property models
 4. Adjust the glass additives, as necessary, to bring the glass properties to within prescribed limits
 5. Determine the amounts of glass former minerals to supply glass additives
 6. Determine impurities and their amounts that accompany the glass additives in the glass forming minerals
- Blended feed (concentrate plus GFCs) are fed to the Melter Feed Vessel (50 gpm)
 - Feed rate to the two melters is determined by composition and properties of the waste.
- Glass is poured into containers that are then cooled and decontaminated
 - Containers are disposed of in IDF
- Melter offgas treated via primary and secondary unit operations
 - Contaminated portion of offgas condensate is returned to front end
 - Liquid secondary wastes treated at LERF/ETF
 - Solid secondary wastes are disposed of in IDF



WTP LAW – Adapted from 24590-WTP-RPT-PT-02-005, Rev 8



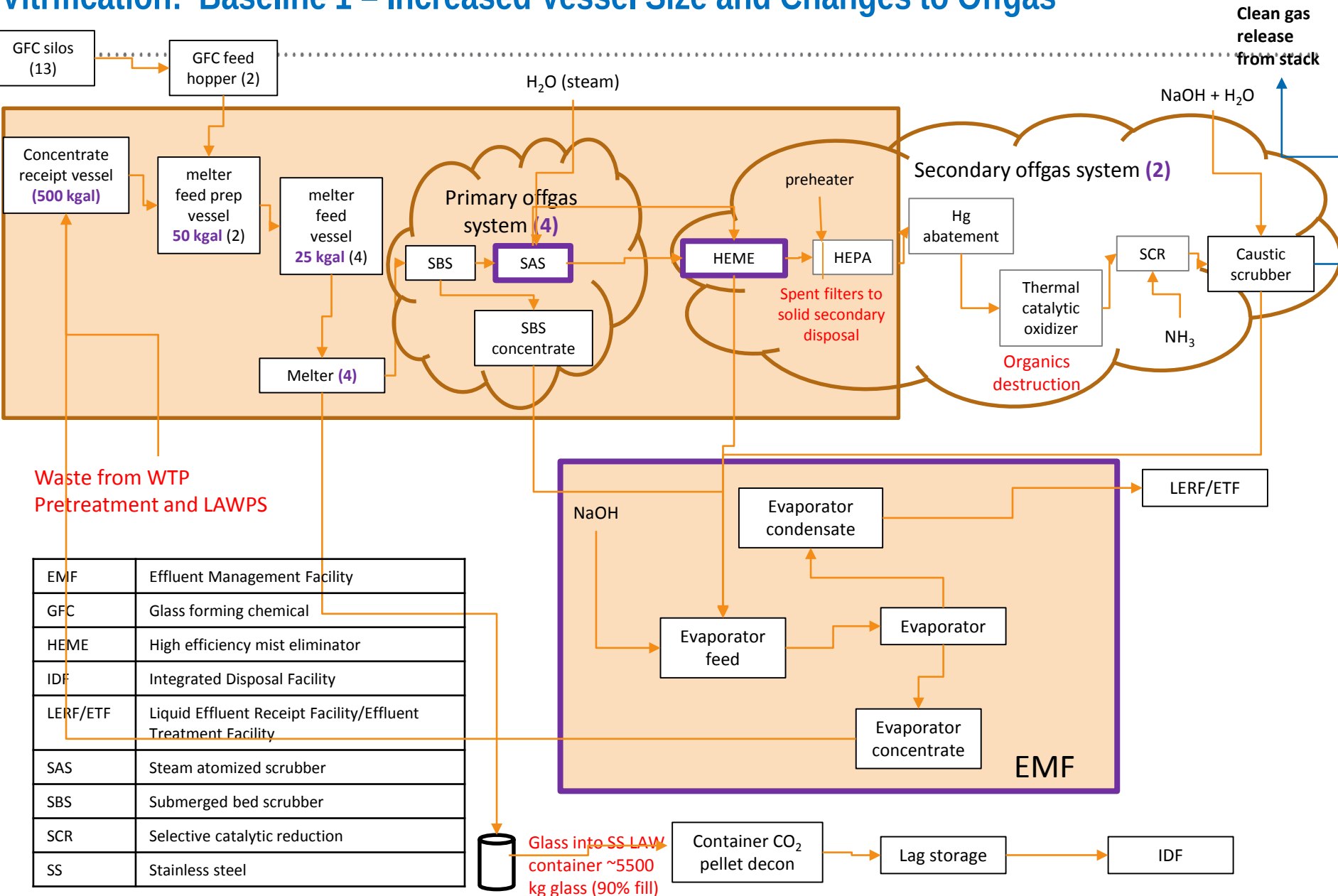
SLAW Vitrification – Baseline 1

WTP LAW (First LAW) – Two-melter facility used as framework for baseline

Modifications to WTP LAW flowsheet for SLAW baseline:

- Increased volume of concentrate receipt, melter feed preparation, and melter feed vessels
 - Improve lag storage capacity and reduce stress on sample analysis points
- Four melter systems, each with primary offgas treatment systems
 - Provide adequate waste throughput for SLAW mission
- Steam Atomized Scrubber (SAS) in place of Wet Electrostatic Precipitator (WESP)
 - Avoid downtime for flushing required for WESP operation
 - Reduce pass through of technetium
- Addition of High Efficiency Mist Eliminator
 - Remove soluble contaminants and prevent condensation in HEPA filters
- Addition of larger Effluent Management Facility
 - Double the scale currently planned for EMF construction to support WTP

Vitrification: Baseline 1 – Increased Vessel Size and Changes to Offgas



EMF	Effluent Management Facility
GFC	Glass forming chemical
HEME	High efficiency mist eliminator
IDF	Integrated Disposal Facility
LERF/ETF	Liquid Effluent Receipt Facility/Effluent Treatment Facility
SAS	Steam atomized scrubber
SBS	Submerged bed scrubber
SCR	Selective catalytic reduction
SS	Stainless steel



SLAW Vitrification – Baseline 1

Assumptions:

- Tank waste retrieval and pretreatment can maintain continuous feed to four SLAW vitrification lines
 - Melter operation requires that a cold cap of feed be maintained in order to reduce volatility
- Existing WTP LAB and control room can support four SLAW vitrification lines
- IDF has sufficient capacity for
 - Disposal of the ILAW containers produced by SLAW vitrification
 - Disposal of encapsulated HEPA filters from SLAW vitrification, including those from the offgas trains and from container decontamination
 - Spent carbon beds, spent catalyst from the TCO, and spent catalyst from the SCR (as solid secondary waste)
- Plant availability and maintenance times are assumed equivalent to those assumed for WTP LAW vitrification
- The EMF to support LAWPS is successfully designed, operated, and constructed, to serve as a basis for the larger EMF assumed for SLAW vitrification
- The Hanford LERF/ETF has sufficient capability to process condensate from the SLAW EMF

SLAW Vitrification – Baseline 1

Risks:

- Significant changes to the WTP LAW unit operations (from feed preparation through offgas treatment) during startup and initial hot operations would directly impact SLAW vitrification
- Current assumptions for WTP LAW facility availability and throughput may be higher than achievable in actual operation
- Availability of the specified GFCs may change before facility operation begins
- The radionuclide DFs of the full scale melter may be lower than expected, increasing the burden on EMF and recycle
- The impact of melter idling on secondary waste volume generation is not considered
- The current WTP LAW flowsheet may underestimate the volume of liquid secondary waste that will be produced

SLAW Vitrification – Option 1c

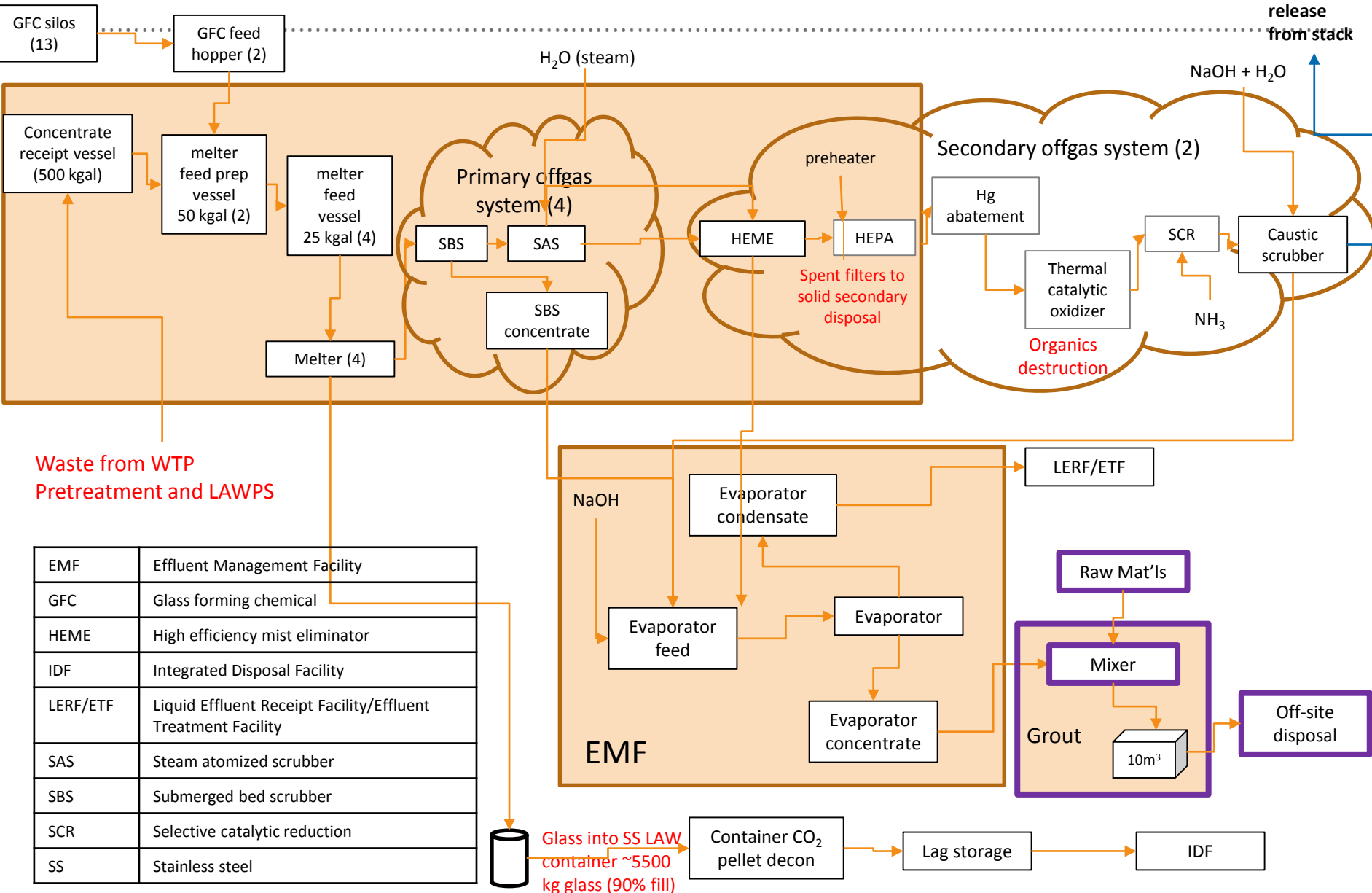
Option would send immobilized secondary waste to off-site facility for disposal

Modifications for Option 1c:

- EMF evaporator concentrate immobilized in grout waste form
 - Break recycle loop to frontend of vitrification process
 - Reduce concentration of contaminants that are difficult to retain in glass and contribute to corrosion of WTP components
- Directing contaminants away from IDF reduces source term
- Would require addition of grout production facility
 - Relatively simple unit operations:
 - Raw materials receipt, storage, and blending; mixing of raw materials with liquid waste; pouring of grout slurry into containers; and curing
 - Leverage DOE experience with similar operating facilities
- Shipped off-site for disposal
 - Assumes shipping regulations for transportation to disposal site are met



Vitrification: Option 1c – secondary waste disposed of off-site



EMF	Effluent Management Facility
GFC	Glass forming chemical
HEME	High efficiency mist eliminator
IDF	Integrated Disposal Facility
LERF/ETF	Liquid Effluent Receipt Facility/Effluent Treatment Facility
SAS	Steam atomized scrubber
SBS	Submerged bed scrubber
SCR	Selective catalytic reduction
SS	Stainless steel



SLAW Vitrification – Option 1c

Additional assumptions associated with Option 1c:

- Appropriate raw materials available in the Hanford area for producing grout waste form
- Approvals are obtained for transportation and offsite disposal of secondary waste immobilized in grout

Additional risks associated with Option 1c:

- Appropriate raw materials are not available in the Hanford area
- Approval is not obtained for offsite transportation of secondary waste immobilized in grout
- An offsite disposal facility is no longer available

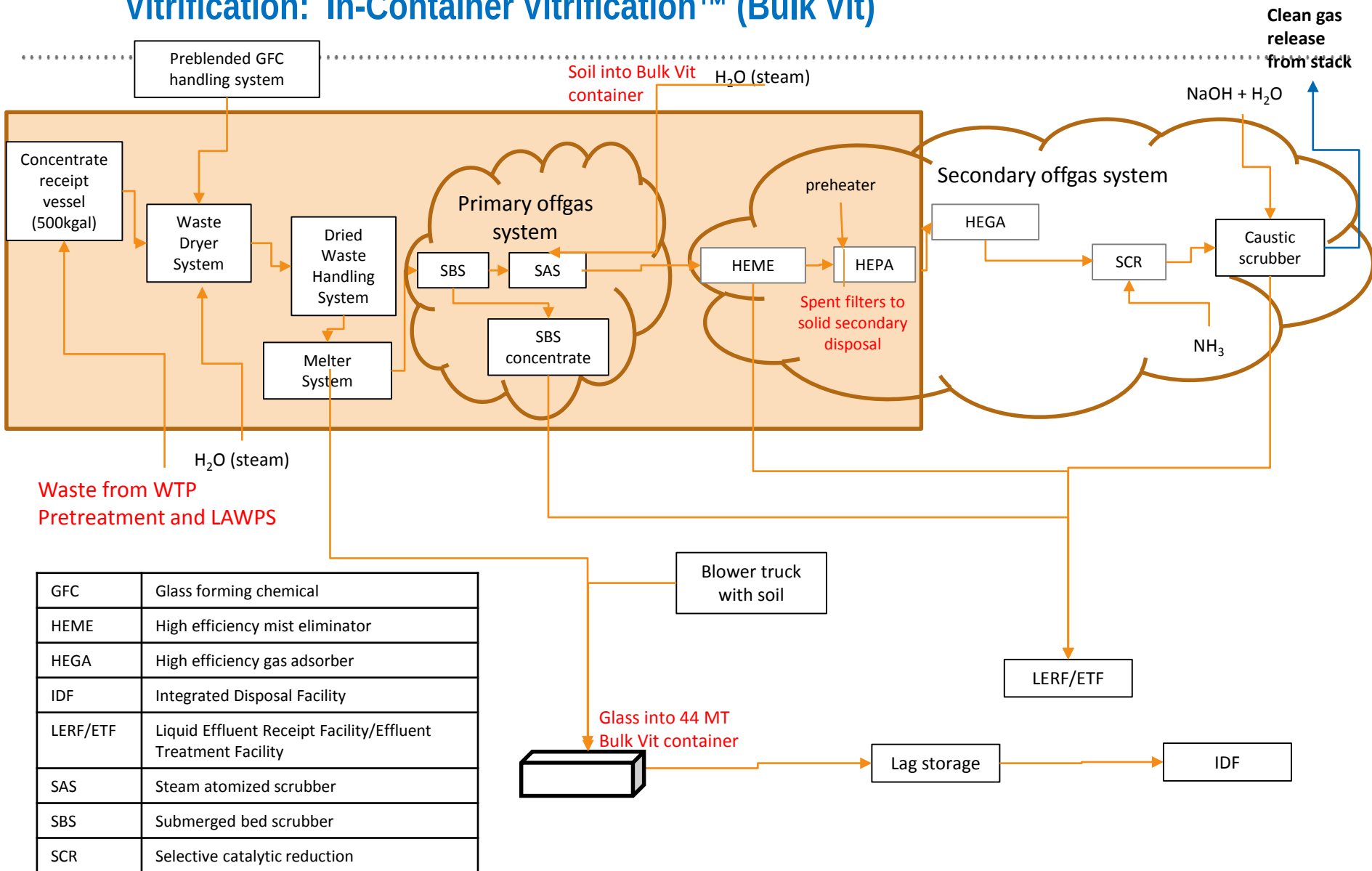


SLAW In-Container Vitrification – Baseline 1d

In-Container Vitrification– Two-melter facility used as framework for baseline and options

- Waste concentrate received from LAWPS or WTP PT
- Waste is analyzed to select and add GFCs
- Plow-mixed vacuum waste dryer (steam jacketed) is inventoried with glass formers
- Waste concentrate is added to waste dryer at rate < evaporation rate to maintain dry bed
- Dryer periodically discharges 20% to dried waste handling system
- Container is a steel box with a sand liner and refractory panel
 - Two graphite electrodes and a conducting starter path for initiation
- Container is inventoried with two piles of dried waste
 - As batch to glass conversion progresses, additional dried waste is conveyed to the melter
- When melter is full, container is disconnected from the system and allowed to cool
 - Clean soil layer is blown over surface
 - Another container is moved into place
 - Containers are disposed of in IDF
- Melter offgas treated via primary and secondary unit operations
 - Liquid secondary wastes treated at LERF/ETF
 - Solid secondary wastes are disposed of in IDF

Vitrification: In-Container Vitrification™ (Bulk Vit)



SLAW Bulk Vitrification – Baseline 1d

Assumptions:

- Glass formulations prepared with five premixed forming chemical can meet all requirements
- Plant availability and maintenance times are assumed equivalent to those assumed for WTP LAW vitrification
- Testing and design changes are sufficient to address the 19 technical issues and 26 area of concern identified by the Expert Review Panel (ERP)
- The offgas system can treat off-normal amounts of carryover associated with process upsets



SLAW Bulk Vitrification – Baseline 1d

Risks:

- ERP issues and concerns not resolved
 - Associated cost to resolve makes process less viable wrt traditional waste melters
- Product CoC release exceeds values input to IDF-PA



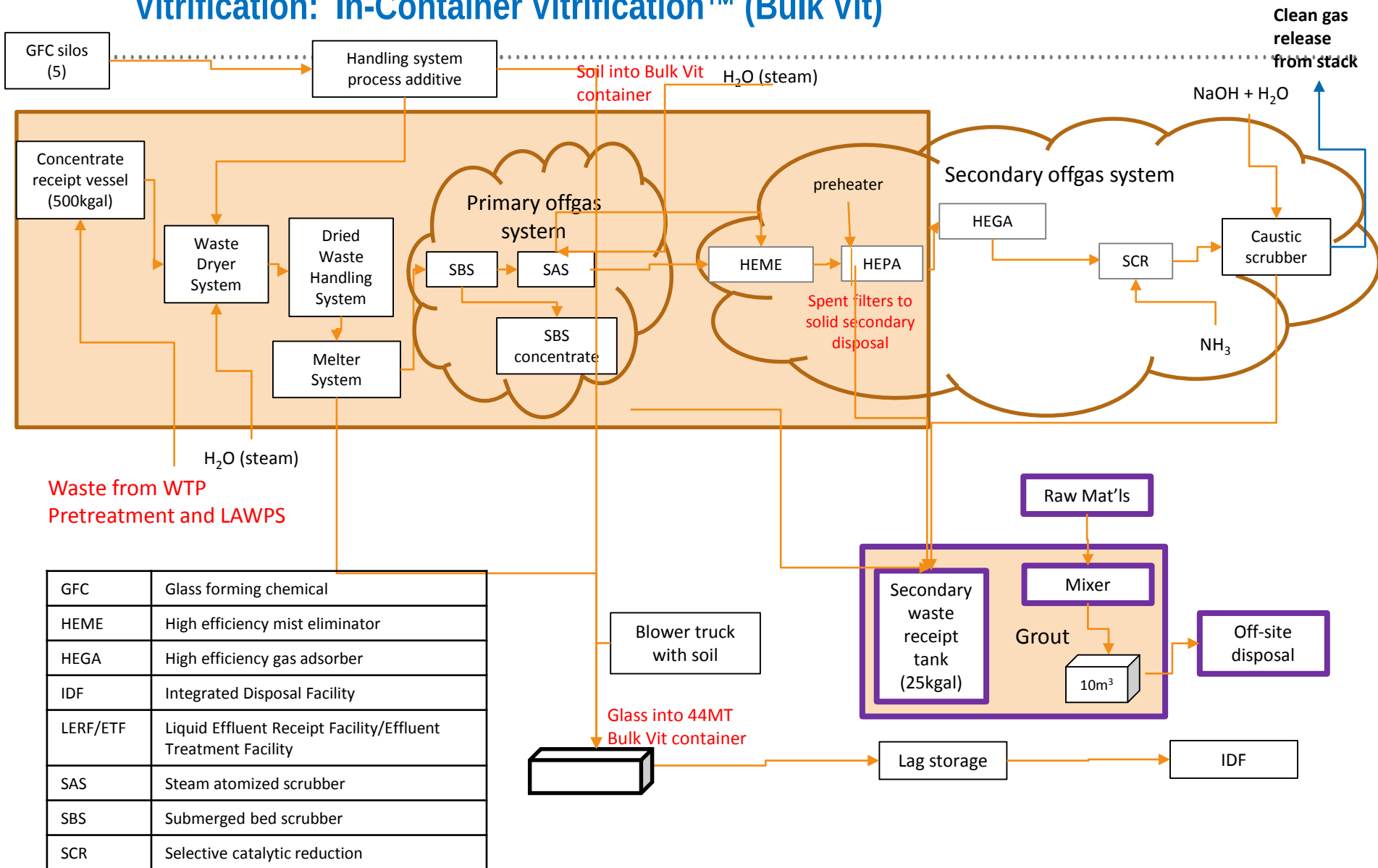
SLAW Bulk Vitrification – Option 1g

Option would send immobilized secondary waste to off-site facility for disposal

Modifications for Option 1g:

- Secondary waste immobilized in grout waste form
 - Directing contaminants away from IDF reduces source term
- Would require addition of grout production facility
 - Relatively simple unit operations:
 - Raw materials receipt, storage, and blending; mixing of raw materials with liquid waste; pouring of grout slurry into containers; and curing
 - Leverage DOE experience with similar operating facilities
- Shipped off-site for disposal
 - Assumes shipping regulations for transportation to disposal site are met

Vitrification: In-Container Vitrification™ (Bulk Vit)



SLAW Bulk Vitrification – Option 1g

Additional assumptions associated with Option 1g:

- Appropriate raw materials available in the Hanford area for producing grout waste form
- Approvals are obtained for transportation and offsite disposal of secondary waste immobilized in grout

Additional risks associated with Option 1g:

- Appropriate raw materials are not available in the Hanford area
- Approval is not obtained for offsite transportation of secondary waste immobilized in grout
- An offsite disposal facility is no longer available

Vitrification: Technology Readiness Level Estimates

Estimated Technology Readiness Level, assumptions

Common to all flowsheets

- waste feed systems TRL high
- Balance of facilities TRL high
- Not unique, common commercial equipment

Common to all flowsheets

- GFC's batching blending feed system TRL Medium
- Common commercial equipment, more complicated than most dry material blending/transfer operations

- LAW-Vit type melter TRL High
- SLAW Construction would begin after LAW-Vit initiated
- Needs to incorporate modifications
- ICV™ TRL Medium
- Demonstrated in limited testing

Common to all flowsheets

- Off-gas system TRL med
- Baseline incorporates offgas train in operation at Defense Waste Processing Facility

- Product store, transport - TRL med/high
- Containers of both designs have been produced in limited quantity





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NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Grout Cases

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Program Manager for Fossil & Geothermal Energies

Los Alamos National Laboratory

NAS Committee Meeting #3

July 23 and July 24, 2018

Richland, WA

Pre-Decisional

Outline

- Grout Waste Forms Overview
- Updated process flow diagrams
 - Base case
 - 5 variants (2d, 2e1, 2e2, 2g2, 2f)—LDR treatment; Tc/I treatment; Sr treatment; IDF vs. WCS
 - 1 opportunity (2h)—pumped to large disposal unit in IDF
- Potential Risks



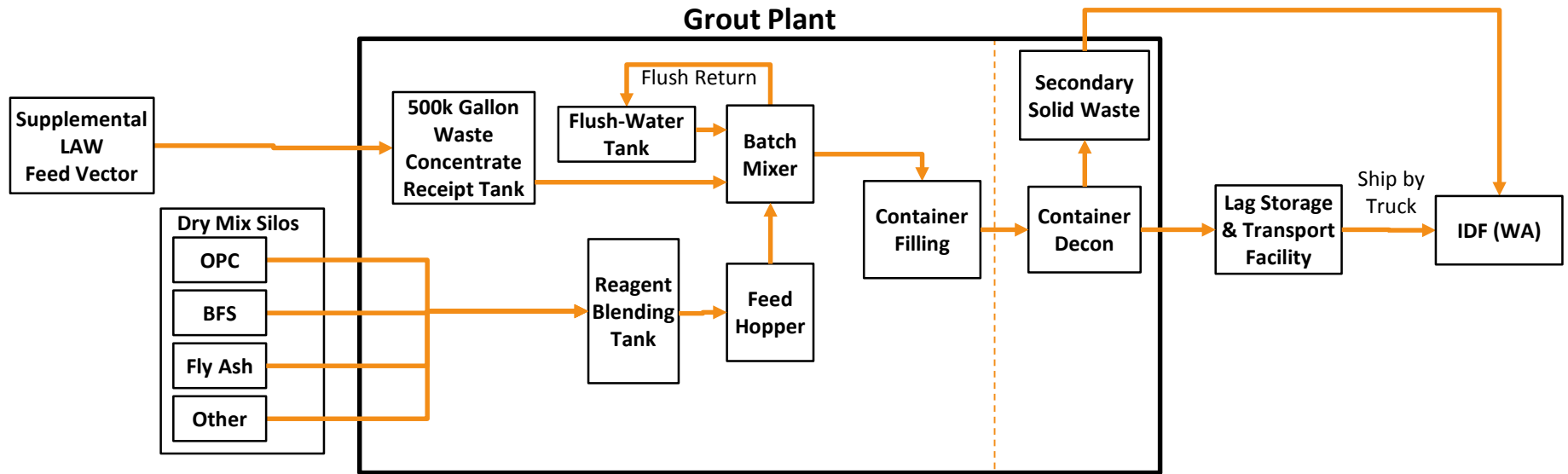
Grout Waste Forms

- Cement-based waste forms are used for: (1) Solidifying aqueous waste, (2) Stabilizing selected RCRA and metal contaminants, (3) Micro-encapsulating particulate waste and (4) Macro-encapsulating hazardous and mixed debris.
- Grout technology is BDAT for selected RCRA hazardous/mixed contaminants & debris
- Grout waste forms—
 - Ambient Temperature processing (minimal off gas treatment; no organic destruction)
 - Treats water for disposal
 - Volume increase from liquid waste to grouted waste ~1.7 to 2X (TBD based on final mix); very limited secondary waste
 - Robust formulation design (ingredients and proportioning)
 - Operational flexibility (quick start up and shut down, one to three shifts/day, easily scaled)
 - Commercially available reagents
 - DOE, commercial, and international experience (UK, France, Spain, EU utilities, Russia, South Korea) (IAEA, 2018)
- Cast stone—adapted from SRS Saltstone—tailored for high pH sodium-salt wastes; new data on performance since 2003 EIS
- Recent demonstration of grout stabilization with legacy Hanford waste
 - Perma-Fix used proprietary treatment to stabilize 2.5 gallons into a solid; passed TCLP
 - Containers sent to WCS for disposal, along with 1 container of secondary waste



Base-Case SLAW Cast Stone Flowsheet

Grout plant located close to WTP; no pretreatment beyond WTP-PT/LAWPS; disposal at IDF



- Assumed no pre-treatment needed beyond WTP-PT/LAWPS

- Semi continuous batch processing
- Grout formulation based on Cast Stone mix design

- TRL estimated “medium to high”

- *Container*: Grout cast in an 8.4 m³ steel box.
(Note: size of box scaled to be compatible with WCS option (variant 2g2))

- TRL estimated to be “medium”

Note: TRLs are preliminary/qualitative; final report will have quantitative ranges

- Regulatory consideration/risks estimated to be “medium to high”

- Waterless decon
- TRL estimated to be “high”

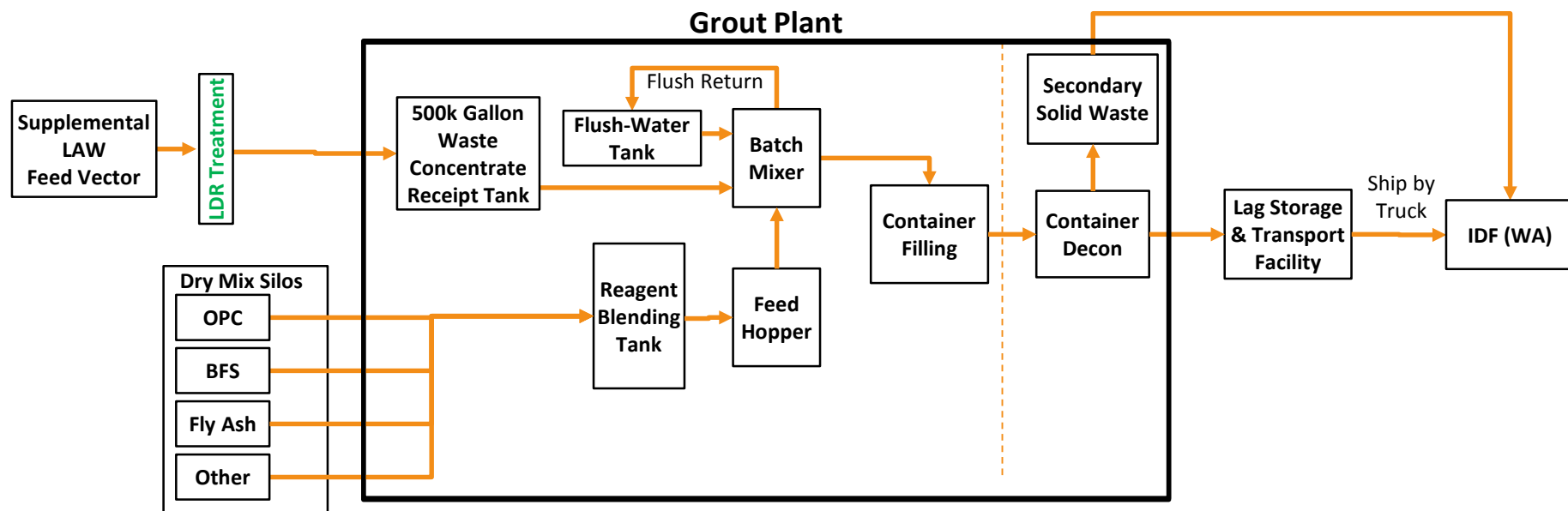
- TRL for conveying, curing, and lag storage estimated to be “medium to high”

- Transportation TRL estimated to be “high”



Variant 2d for SLAW Cast Stone Flowsheet

Grout plant located close to WTP; disposal at IDF; **pre-treatment to comply with LDR**



- Additional pre-treatment prior to entering grout plant to remove **organics** &/or metals to comply with land disposal restrictions (LDR)

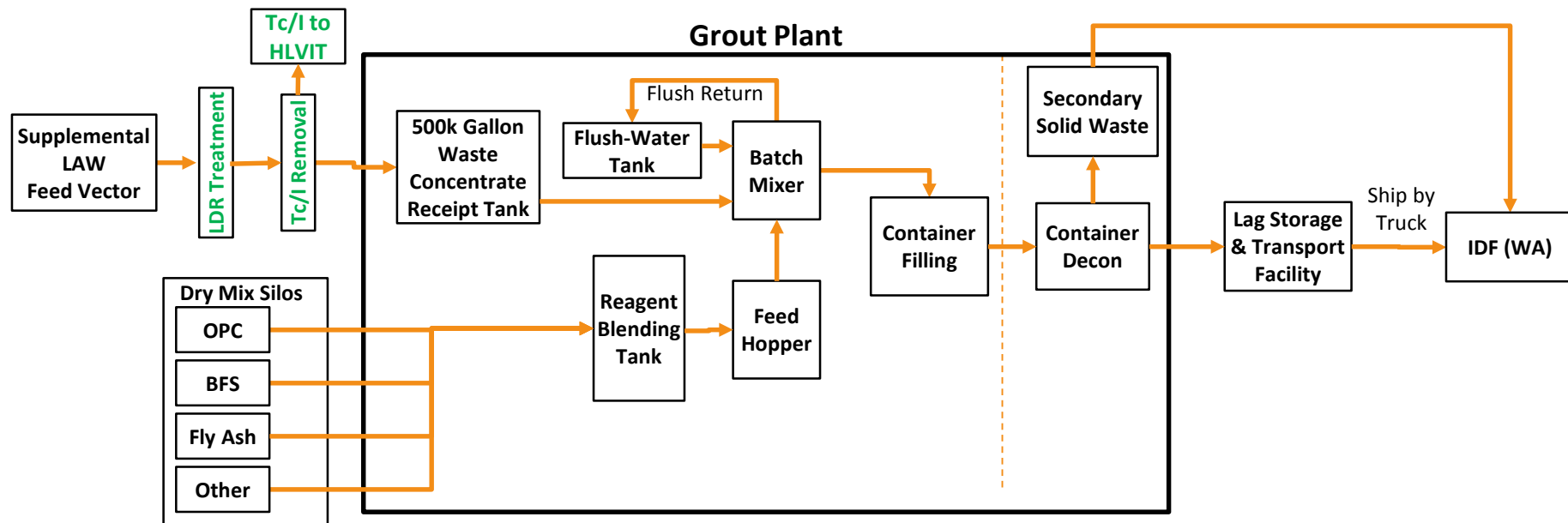
- Regulatory consideration/risks estimated to be “medium to high”
 - Risk slightly lower than base case assuming LDR issues are adequately addressed
 - Risk of Tc/I remains

*Note: TRLs are preliminary/qualitative;
final report will have quantitative ranges*



Variant 2e1 for SLAW Cast Stone Flowsheet

Grout plant located close to WTP; disposal at IDF; pre-treatment to comply with LDR;
pre-treatment for Tc/I to reduce groundwater risk



- Additional pre-treatment prior to entering grout plant to remove **organics** & metals to comply with land disposal restrictions (LDR)

- Additional pre-treatment to remove Tc/I, which are then sent to high level Vit facility

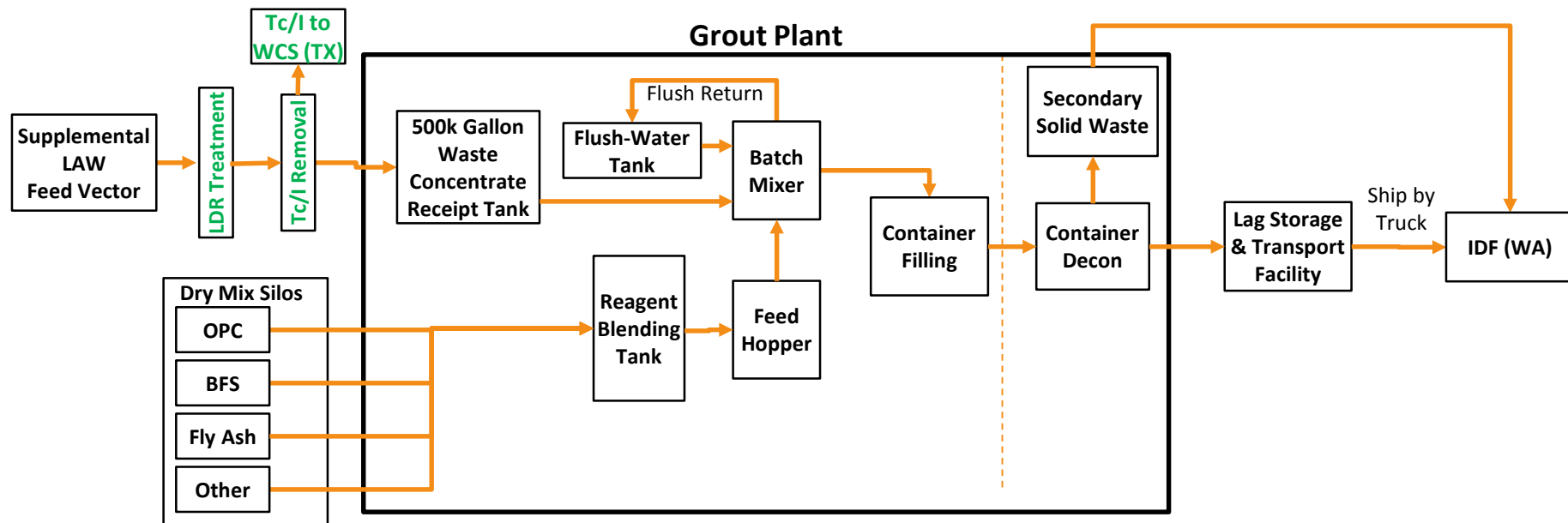
- Regulatory consideration/risks estimated to be “medium”
 - Risk significantly lower than base case assuming LDR issues are adequately addressed and assuming Tc/I is adequately reduced

Note: TRLs are preliminary/qualitative; final report will have quantitative ranges



Variant 2e2 for SLAW Cast Stone Flowsheet

Grout plant located close to WTP; disposal at IDF; pre-treatment to comply with LDR;
pre-treatment for Tc/I to reduce groundwater risk



- Additional pre-treatment prior to entering grout plant to remove **organics** & metals to comply with land disposal restrictions (LDR)
- Additional pre-treatment to remove Tc/I, which are then grouted and sent to WCS facility (TX) in B-25 boxes

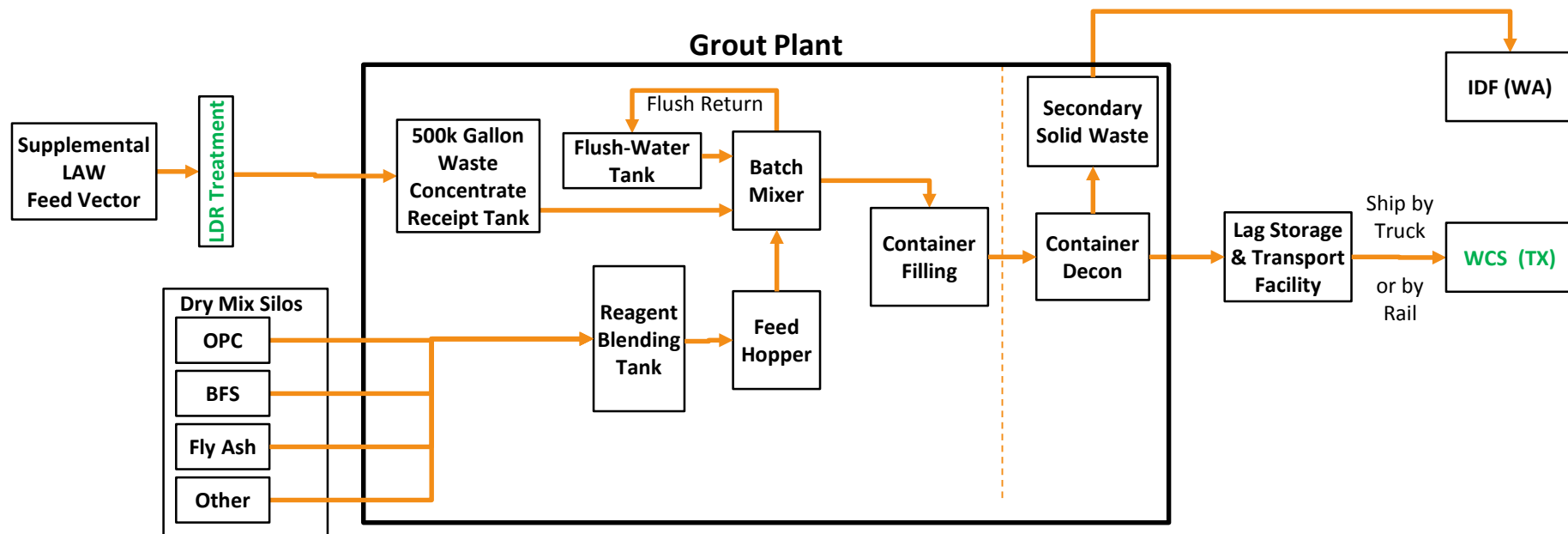
- Regulatory consideration/risks estimated to be “medium”
 - Significantly lower than base case due to removal of potential LDR issues and due to removal of Tc and I
 - But grout waste forms remain unpermitted at IDF

*Note: TRLs are preliminary/qualitative;
final report will have quantitative ranges*



Variant 2g2 for SLAW Cast Stone Flowsheet

Grout plant located close to WTP; **cast stone disposal at WCS; pre-treatment to comply with LDR**



- Additional pre-treatment prior to entering grout plant to remove **organics** & metals to comply with land disposal restrictions (LDR)
- Tc/I removal not required

- **Container:** Grout cast in an 8.4 m³ bag in a steel box/form; heavy-duty woven & non-woven polypropylene bags certified to meet Industrial Package type 1 (IP-1) for transport
- Bag+grout-monolith removed at storage facility for disposal in modular concrete containers (MCCs)
- Steel box/form returned to grout plant for re-use
- TRL estimated to be “medium”

- Regulatory consideration/risks estimated to be “low to medium”
 - Significantly lower than base case because WCS facility is permitted to accept waste containing Tc/I
 - Added risk for transportation (could include class A, B, & C wastes)

Note: TRLs are preliminary/qualitative; final report will have quantitative ranges



Polypropylene bags for disposal at WCS



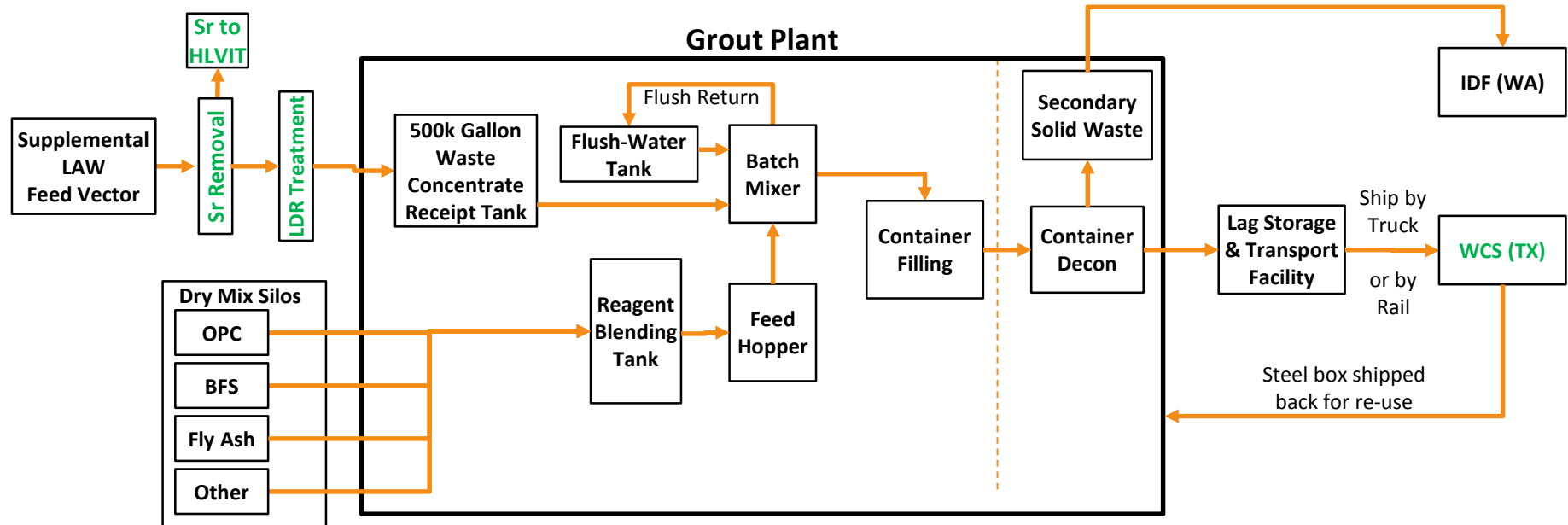
Photo of example commercial bag (LiftPac)

- Use of polypropylene bags offer cost saving over conventional steel boxes
- Commercially available heavy-duty woven & non-woven polypropylene bags certified to meet Industrial Package type 1 (IP-1) for transport
- Grout would be cast directly into bag, which would be placed inside a steel box used as a form and during shipping
- Bagged grouted monolith would be removed from steel box at WCS prior to disposal, and steel box would be returned for re-use at grout plant



Variant 2f for SLAW Cast Stone Flowsheet

Grout plant located close to WTP; **cast stone disposal at WCS**; **pre-treatment to comply with LDR**;
pre-treatment for Sr to reduce ship/store costs



- Additional pre-treatment prior to entering grout plant to remove **organics** & metals to comply with land disposal requirements (LDR)

- Pre-treatment to remove Sr, which is then sent to HLVT
- Ensures all waste is class A to lower transportation & disposal cost

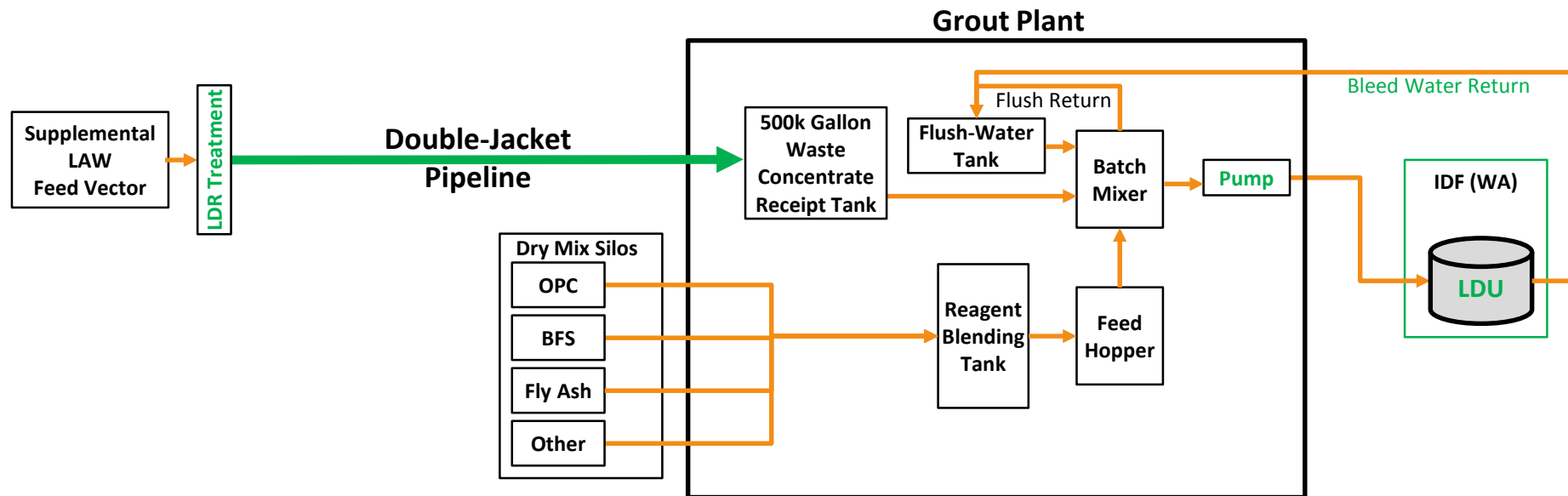
- **Container:** Grout cast in an 8.4 m³ bag in a steel box/form; heavy-duty woven & non-woven polypropylene bags certified to meet Industrial Package type 1 (IP-1) for transport
- Bag+grout-monolith removed at storage facility for disposal in modular concrete containers (MCCs)
- Steel box/form returned to grout plant for re-use
- TRL estimated to be “medium”

- Regulatory consideration/risks estimated to be “low to medium”
 - Significantly lower than base case because WCS facility is permitted to accept waste containing Tc/I
 - Added risk for transportation (class A wastes)

Note: TRLs are preliminary/qualitative; final report will have quantitative ranges

Opportunity 2h for SLAW Cast Stone Flowsheet

Grout plant located close to IDF; pre-treatment for LDR; disposal in large disposal units (LDUs) at/near IDF



- Process similar to variant 2d, except that grout facility is located near IDF, allowing ability to cast waste in place in large disposal units.
- Relocation of grout facility requires additional double jacketed pipeline to deliver supplemental LAW.
- Facility would **not** require some processes from base case (e.g., container filling, container decon, and lag storage)
- Facility **would** require additional processes from base case (e.g., pumping of grout; bleed water return)
- Large disposal units (LDUs) would be significantly larger than transportable units (i.e., comparable to saltstone disposal units or SDUs).

SRS uses containerization in place, transferring grout to SDUs at disposal site.

- **Saltstone Disposal Units (SDU)**
 - Rectangular and circular cross sections
 - Engineered Barriers
 - Stabilize redox sensitive contaminants: Cr(VI) and Tc(VII)
 - Low K_h
 - Large volume containment structures



Potential Risks of Grout as an Option

- **Waste acceptability**

- Grout waste forms have not been permitted for disposal at the IDF, and the State of Washington has explicitly questioned the use of a grout waste form
- Risk could potentially be mitigated by:
 - A demonstrated performance for a grouted waste form that is comparable to that for glass (which is permitted for disposal in the IDF)
 - The use of the WCS facility in Texas for the disposition of the grouted SLAW waste form
 - The removal (by pre-treatment) of radionuclides of concern (Tc and I)
- All grout waste forms (both primary SLAW and grouted secondary wastes from any process) will require altering existing IDF permit

- **LDR Constituents**

- Any acceptable pathway for grout as a waste form (either at IDF or WCS) will require addressing the potential presence of organics and metals associated with LDR under RCRA
- Risk could be mitigated by:
 - The inclusions of additional pre-treatment steps prior to the introduction of SLAW into the grout facility



Potential Risks of Grout as an Option (cont'd)

- **Future unavailability of reagents**

- Risk is estimated to be low—reagent needs are <1% of current domestic production
- Risk could potentially be mitigated by:
 - Stockpiling of reagents
 - R&D to assess potential substitute reagents (e.g., hydrated lime or pozzolans)
- All grout was forms (both primary SLAW and grouted secondary wastes from any process) will require altering existing IDF permit

- **Inability of a specific batch to meet waste acceptance criteria**

- Risk is estimated to be low; includes failure to set, failure of TCLP, poor strength, bleeding, etc.
- Existing technology and processes are available to address poor batches

- **Construction and shakedown of a facility will not be met within budget or timeline**

- Risk is estimated to be low based on extensive prior experience with similar facilities

- **Inability to mature a specific aspect of the process to a high TRL within time**

- Risk is estimated to be low based on extensive prior experience with similar facilities
- Risk for incorporation of new formulations (such as the use of getters for Tc and I) may be higher but requires relatively simple modifications to overall process

NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Steam Reforming Cases

Nick Soelberg

FFRDC Team Steam Reforming Lead

Chemical Engineer Level 5, Environmental &
Geological Engineering
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*NAS Committee Meeting
July 23-24, 2018*

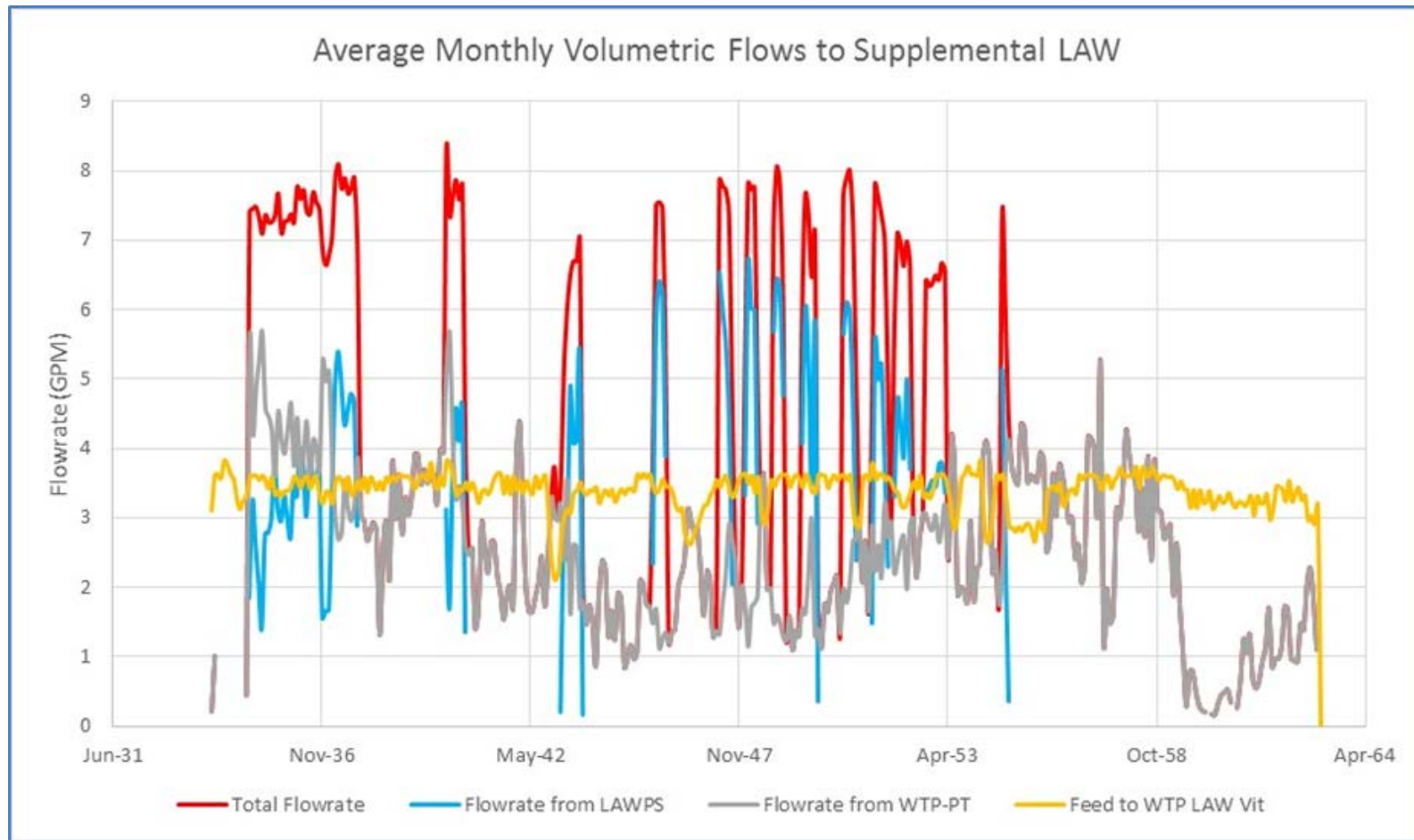
Pre-Decisional

The Supplemental LAW treatment system feed vector is expected to vary widely and presents flowrate and composition challenges for the SLAW treatment process

Parameter	Monthly average	Monthly turndown ratio (max/min)	Comments
SLAW feedrate, gpm	3.6	51	High turndown ratio; lag tank needed to achieve turndown ratio of ~2 per FBSR
WTP LAW vit feedrate, gpm	3.4	1.8	Steady flowrate presumably by design
Solids conc., wt%	3.3	126	Not relevant to FBSR which has much more added clay per L waste
Na conc., g/L	180	2	Vary clay as needed
NO3 conc., g/L	110	6	Destroyed by FBSR system
NO2 conc., g/L	30	11	
Hg conc., mg/L	3.0	55	Need Hg control but necessary DF decreases after ~2035
Tc-99 conc., mg/L	3.2	36	Captured in product due to their relatively high capture efficiencies and recycle of scrub solution to the DMR; no liquid secondary wastes
I-129 conc., mg/L	0.3	16	
S conc., mg/L	56	470	
Organics, NH4 conc.	Not relevant		Destroyed by FBSR system



The total SLAW feedrate varies from month-month by 51x

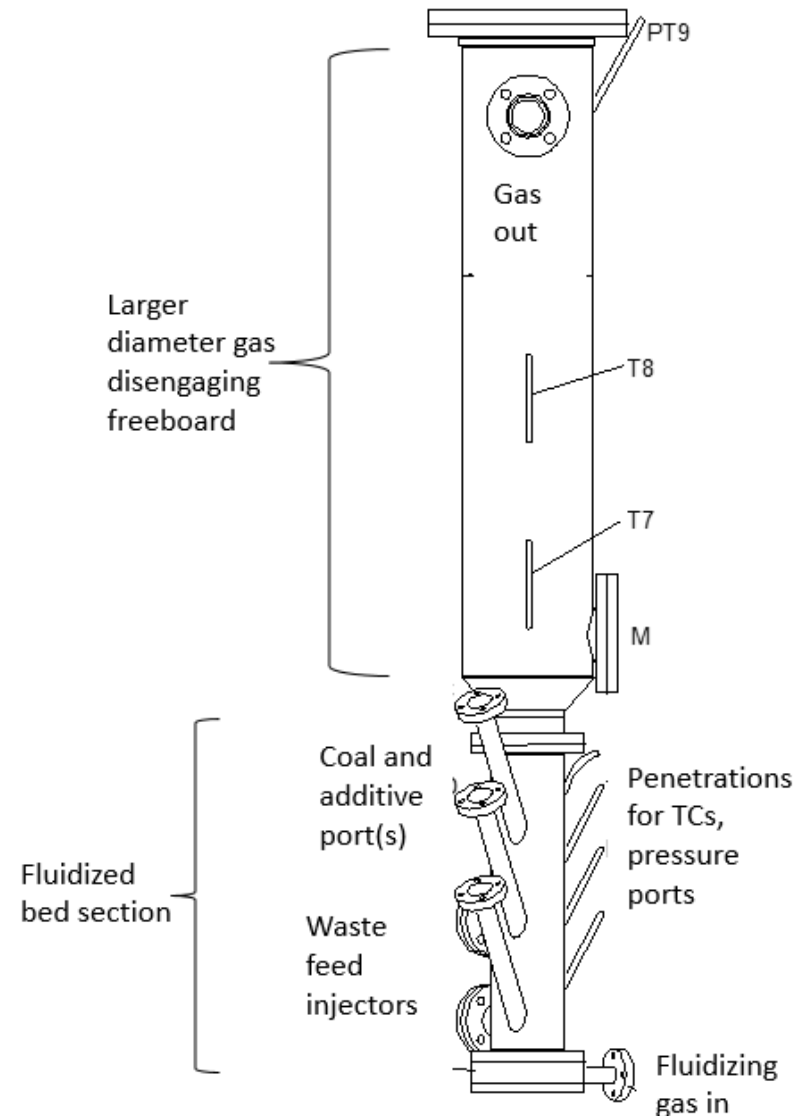


- The WTP LAW vit flowrate is much more consistent and appropriate for steady state WTP LAW vit operation
- The 500,000 gal tank farm delivery tank should considerably normalize month-month feed and concentration variations



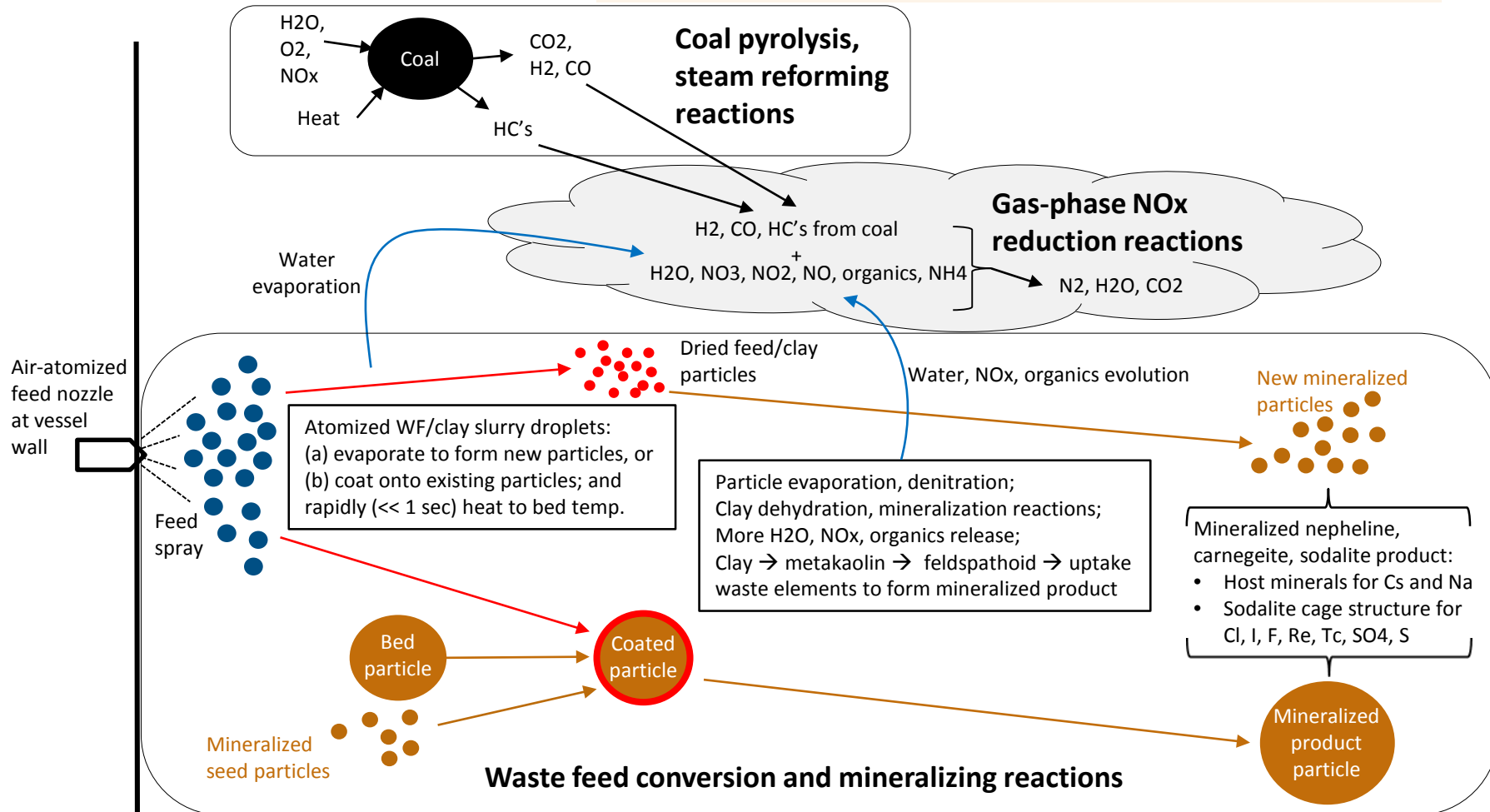
Features expected in the fluidized bed vessel (Denitration Mineralizing Reformer, DMR)

- Haynes 556 alloy or equivalent for strength and corrosion tolerance at temperatures ~750 C (no refractory)
- Steam, O₂, and N₂ fluidizing gas flows up from bottom
- Heated by coal oxidation
- O₂-deficient pyrolysis destroys both organics and NO_x
- N₂, O₂, or air – atomized liquid/slurry waste feed nozzles
- Granular solid product removed from bottom
- Gas discharge out the top
- Sealed thermocouple ports
- Pressure-monitoring ports penetrate through vessel wall and are N₂-purged to keep clear of bed particles and prevent moisture condensation
- Exterior is insulated (not shown) as needed for heat retention



High FBSR mass transfer rates convert the waste feed to a durable aluminosilicate mineralized product and destroys nitrates/NOx and organics

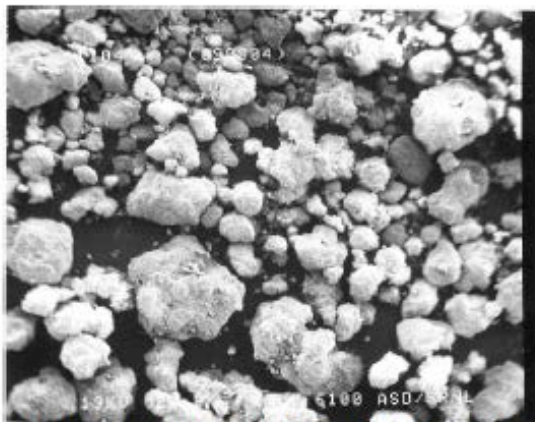
3- part DMR chemistry model: Coal reactions, gas-phase reactions, and waste feed conversion and mineralizing reactions



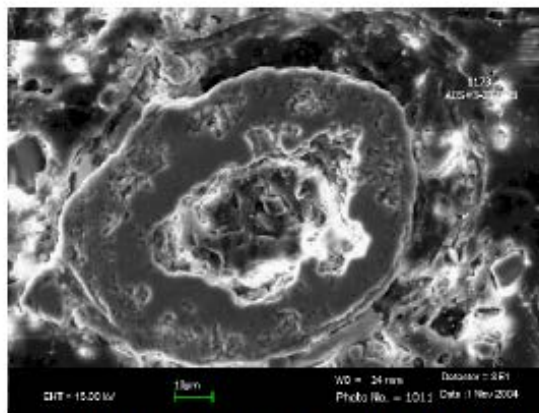
Demonstrated in 3.5-in. to 15-in. tests at INL SAIC STAR Center and up to 24-in. at the Hazen Engineering Scale Test Demonstration (ESTD)



Example granular solid product and geopolymer monolith



(a) 1123 Bed product from 2004 Pilot Scale Testing



(b) 1173 Bed product (sectioned) from 2004 Pilot Scale Testing

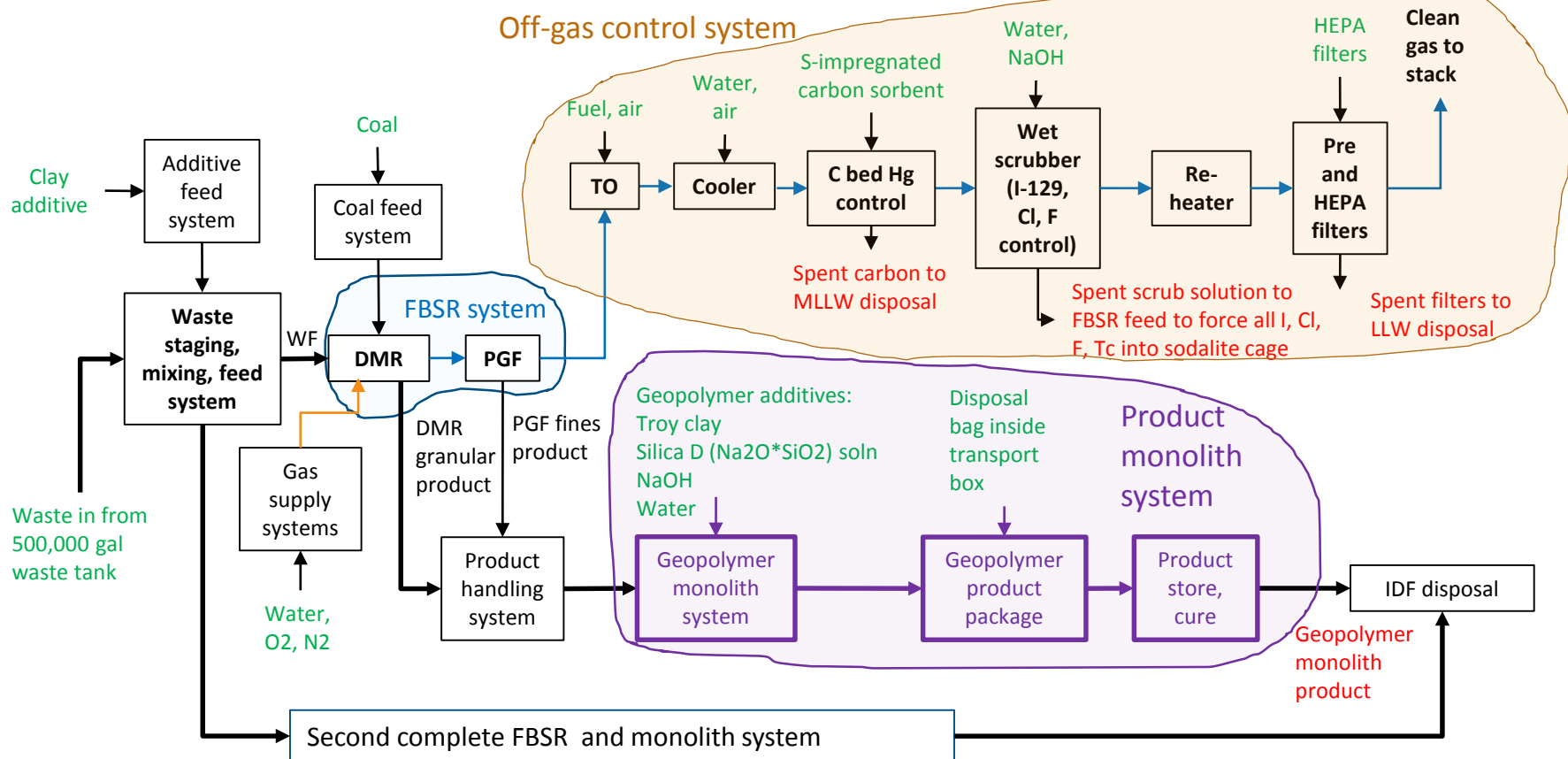
Figure 2-2. Scanning electron microscopy (SEM) photos of FBSR bed product from INL SBW; (SRNL-ORNL-PNNL-WRPS down-select).



Troy clay geopolymer monolith of Hanford LAW 60% FBSR product (SRNL-ORNL-PNNL-WRPS down-select)



Base Case Mineralizing FBSR (Treatment Option 3): Two DMR systems; solid monolith product to IDF

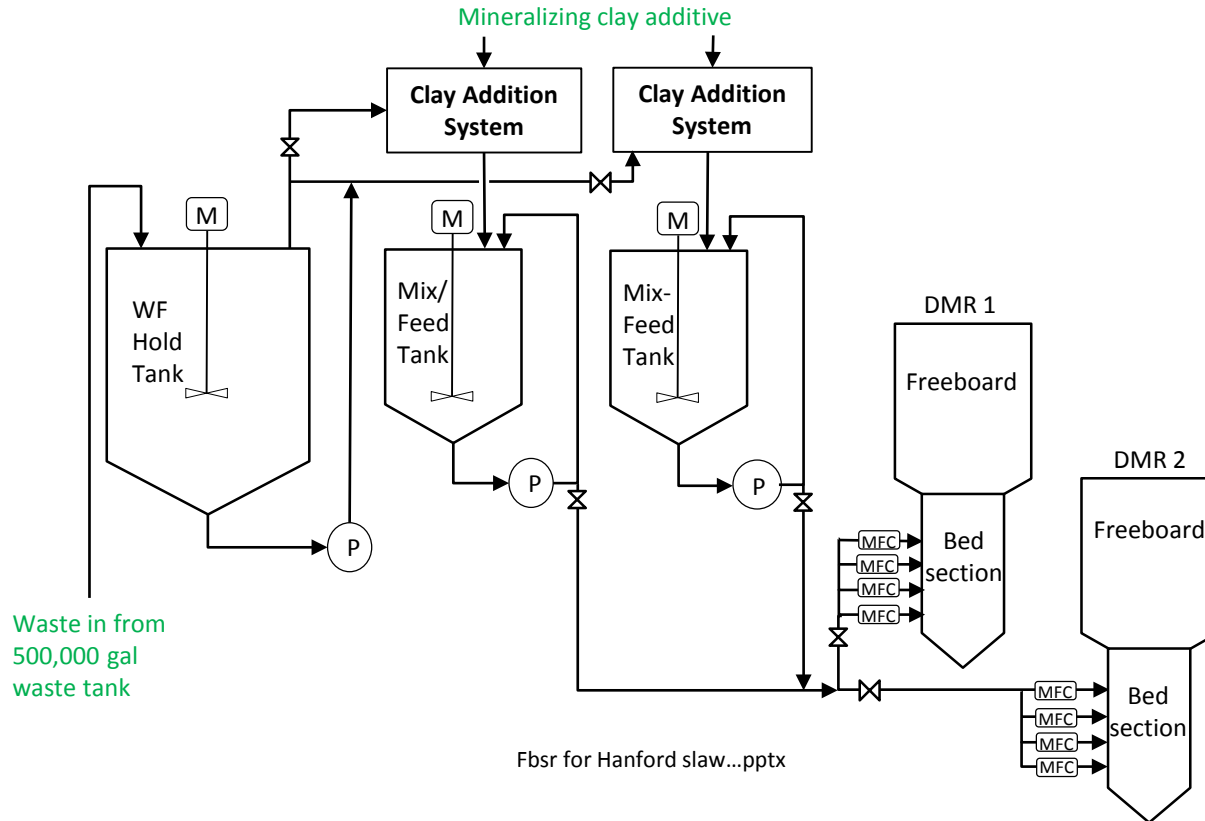


- Two identical FBSR systems to maximize available capacity in first ~3 yrs
- Shared waste staging, mixing, feed system
- Eliminates dust, provides more compression strength compared to granular product
- Secondary wastes (spent HEPAs, equipment, filters, PPE, etc.) in B-25s to IDF

DMR Denitration Mineralizing Reformer
 FBSR Fluidized bed steam reforming
 HEPA High efficiency particulate air (filter)
 PGF Process Gas Filter
 TO Thermal oxidizer
 WF Waste feed



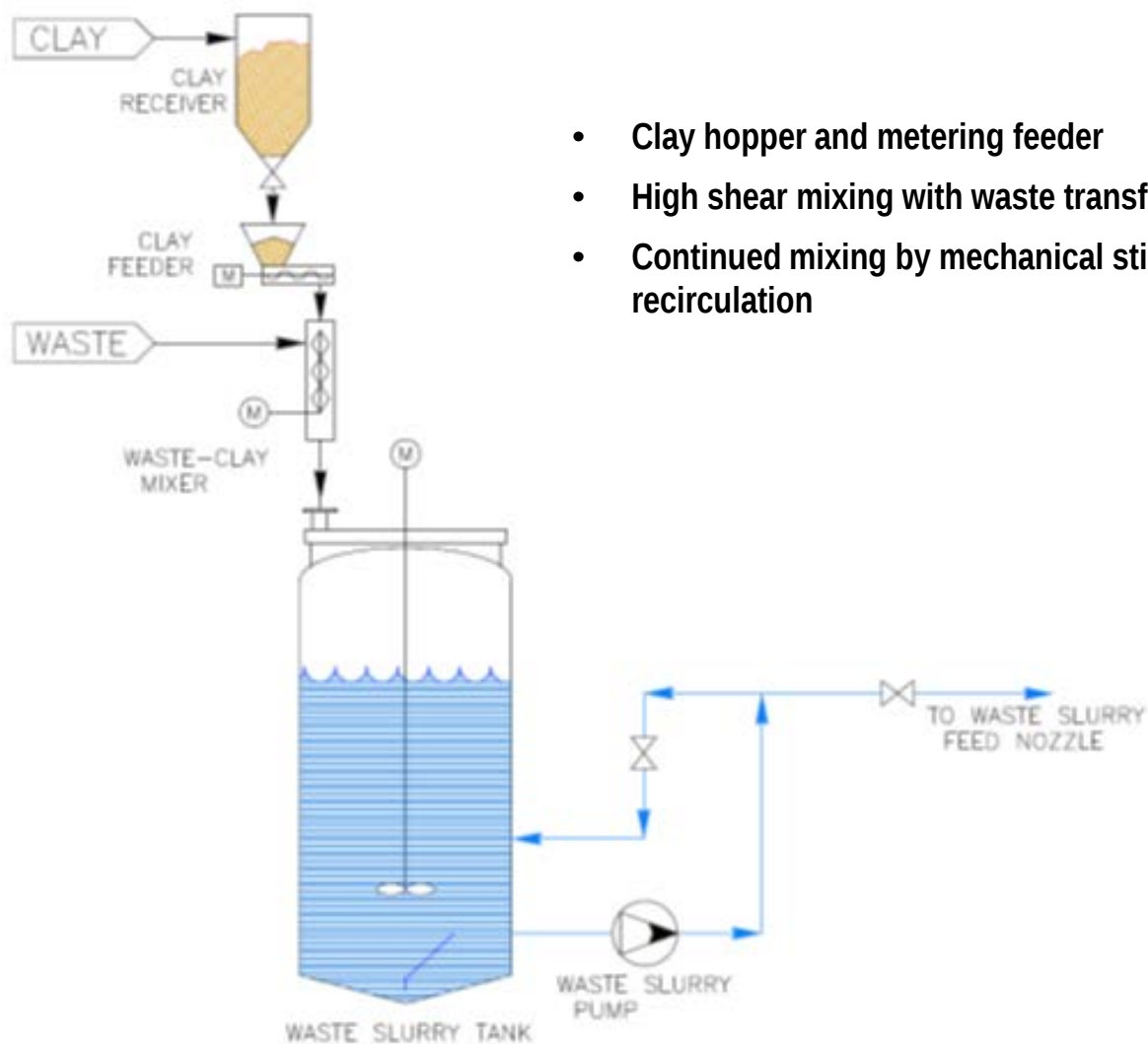
Waste staging, mixing feed system concept design



- Two 50,000 gal WF hold tanks provides delay storage and staging for sample analysis (only 1 shown for simplicity). Reduced from earlier estimates of larger tanks, due to change in estimated on-line availability from 50% to 70%.
- Two 30,000 gal mix/feed tanks provide batch addition and mixing of clay/WF slurry and can feed to either or both FBSR systems.



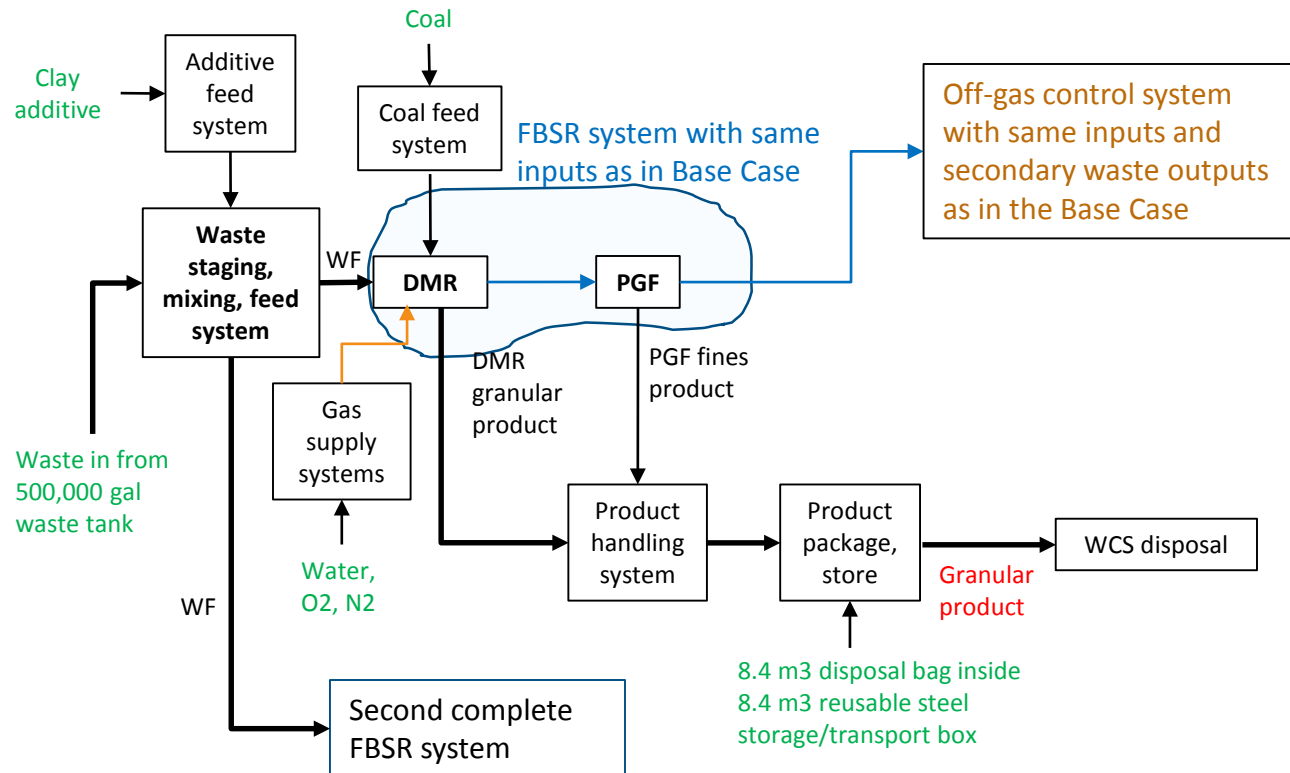
Clay and Waste high shear in-line mixing system concept design



- Clay hopper and metering feeder
- High shear mixing with waste transfer
- Continued mixing by mechanical stirring and waste recirculation



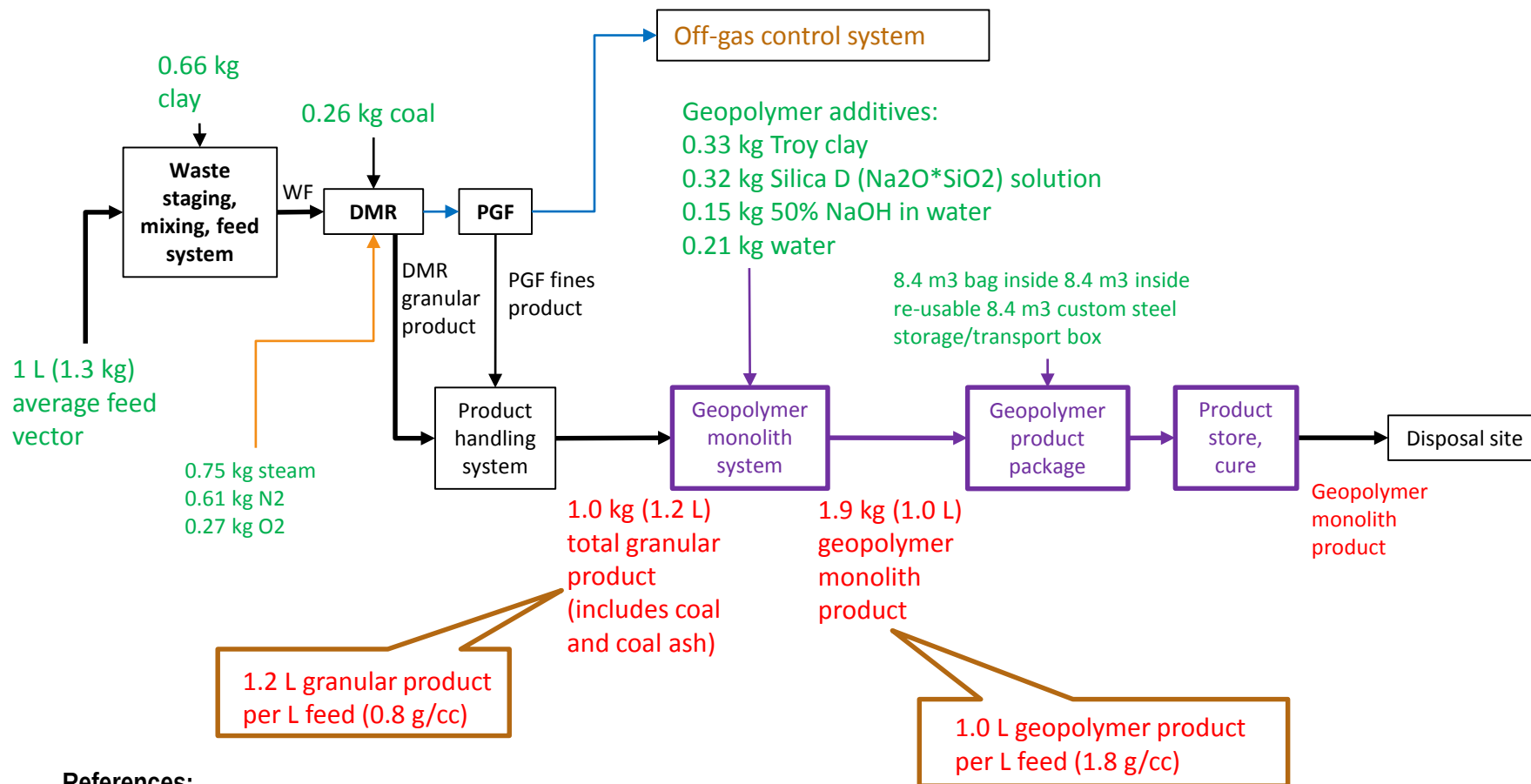
Mineralizing FBSR (Treatment Option 3b): Two DMR systems; solid granular product, disposal at WCF



- Same two identical FBSR systems
- Same shared waste staging, mixing, feed system, and same off-gas control system
- No product monolith system
- Secondary wastes (spent HEPAs, equipment, filters, PPE, etc.) in B-25s to WCF



FBSR preliminary mass balance



References:

- FBSR mass balance for average SLAW feed vector (February 15, 2018)
- SRNL-ORNL-PNNL-WRPS down-select (Jantzen 2015) and 2014 Waste Management paper. The downselect report culminated a ~4-yr SRNL-ORNL-PNNL-WRPS program focused on the FBSR capture of radionuclides in a durable waste form. Five other reports and many other presentations of work done over several years at SRNL, ORNL, PNNL, and WRPS are summarized in the downselect report.



Target granular product phases

Table 2-1. Similarity of Mineral Phases in FBSR Waste Forms to HLW Waste Forms Previously Studied (SRNL-ORNL-PNNL-WRPS 2015 downselect).

Mineral Phases Formed in FBSR at ~700°C [60,61]	Mineral Phases Formed in HLW Ceramic Waste Forms [13,15-17,20-26]	Mineral Phases in Glass Bonded Sodalite Waste Forms [18,19,27,28]
Nosean-Sodalite (NaAlSiO ₄) ₆ (Na ₂ SO ₄)	Sodalite (NaAlSiO ₄) ₆ (NaMoO ₄) ₂	Sodalite (NaAlSiO ₄) ₆ (NaI,NaCl) ₂
Nepheline NaAlSiO ₄	Nepheline NaAlSiO ₄	Nepheline NaAlSiO ₄
Cubic Nepheline NaAlSiO ₄		NaCl
Corundum Al ₂ O ₃	Corundum Al ₂ O ₃	PuO ₂
Hematite Fe ₂ O ₃		
Magnetite Fe ₃ O ₄		



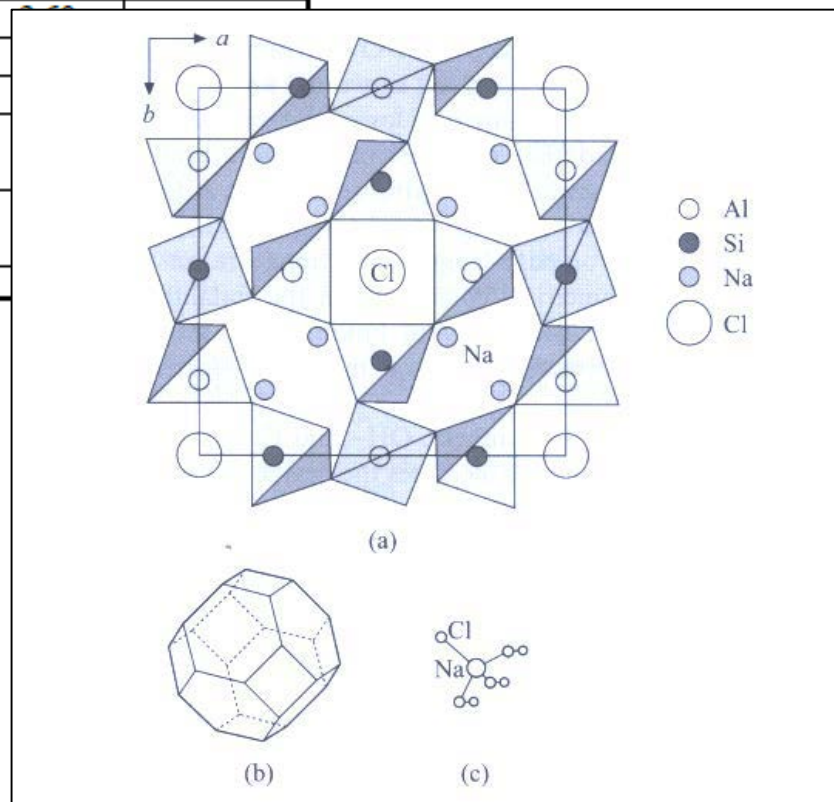
Halogens, S, and Tc-99 can be captured in sodalite and nosean phases in durable “cages”

Element	Mineral Name	Oxidation State	Coordination Number	a(Å)	Space Group	Ionic Radii from Ref. 6 (Å)	Ionic Radii from Ref. [96] (Å)
F ⁻	F-sodalite	-1	VI	NM	P43n	1.33	
Cl ⁻	Cl-sodalite	-1	VI	8.8835	P43n	1.81	1.78
ClO ₄ ⁻	Cl-sodalite	-1	VI	8.8835	P43n	2.40	
SO ₄ ²⁻	Nosean	+6	VI	9.0932	P43n	2.30	2.37-2.57
TcO ₄ ⁻	Tc-sodalite	+7	VI	NM	P43n	2.52	
ReO ₄ ⁻	Re-sodalite	+7	VI	9.1528	P43n		
I ⁻	I-sodalite	-1	VI	9.0027	P43n		
Br ⁻	Br-sodalite	-1	VI	NM	P43n		
OH ⁻	Hydroxy-sodalite	-1	VI	8.89	P43n		
NO ₃ ⁻	Nitrated-sodalite	-1	VI	8.978	P43n		

NM=Not Measured

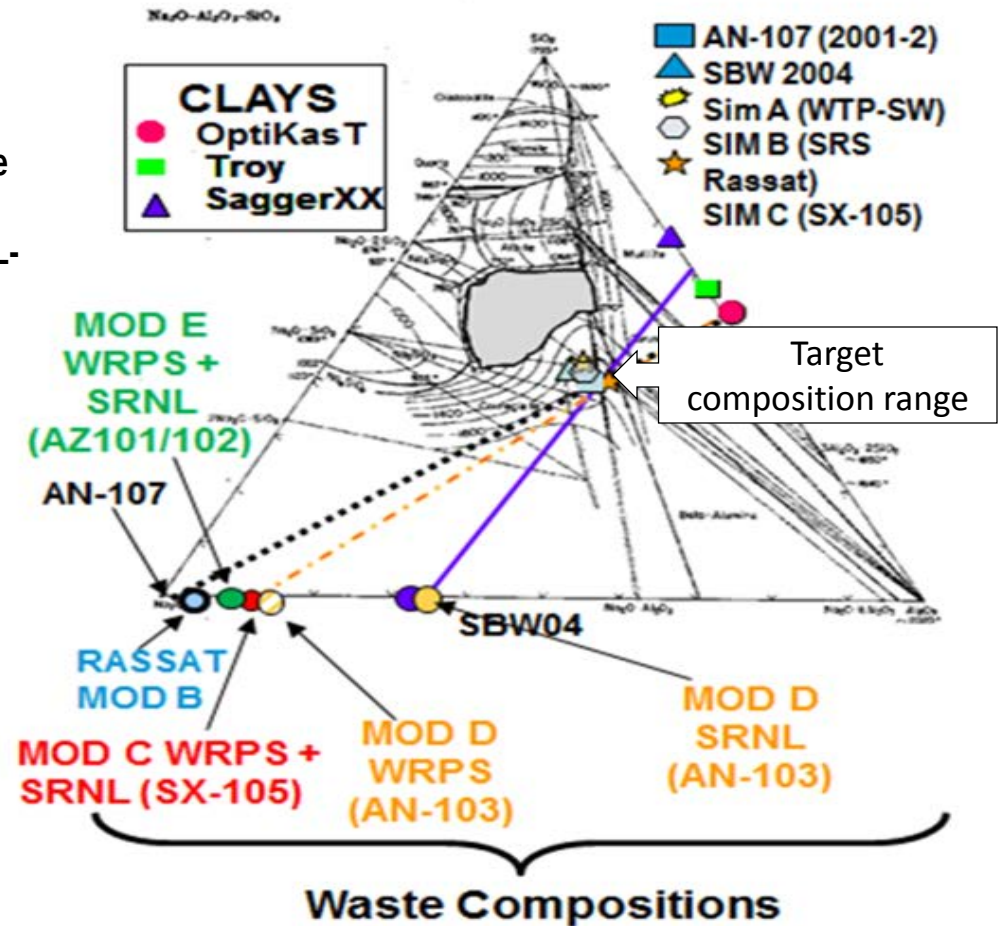
Table 2-3. Oxidation state and atomic radii for common anions incorporated in the sodalite framework (SRNL-ORNL-PNNL-WRPS 2015 down-select).

Figure 2-4. Structure of Sodalite showing (a) 2-dimensional projection of the (b) 3-dimensional structure and (c) the 4-fold ionic coordination of the Na site to the Cl ion and 3 framework oxygen bonds (SRNL-ORNL-PNNL-WRPS 2015 down-select).



The mineralized WF composition and performance has been studied since 2001

- Multiple SRNL studies developed and used “MINCALC” process control strategy for determining best mix and amount of clay additive to use for producing the durable, mineralized waste form (Jantzen 2014 WM paper, SRNL-ORNL-PNNL-WRPS 2015 downselect report)



- **Durability tests performed on both granular and monolith products:**
 - ASTM C1285 Product Consistency Test (short and long-term)
 - ANSI 16.1/ASTM C1308 Accelerated Leach Test
 - EPA Toxicity Characteristic Leaching Procedure (TCLP)
 - ASTM C1662 Single-Pass Flow-Through Test (on product of Rassat 67 tank blend LAW)
 - Pressure Unsaturated Flow-through (PUF) test (on product of Rassat 67 tank blend LAW)
- **X-ray Absorption Spectroscopy (XAS):**
 - Re (Tc surrogate) is in +7 state in sodalite cage; low solubility in durability testing
 - Tc-99: 56-79% in +7 state in sodalite cage, remainder in +4 state in TcO₂ or Tc₂S(S₃)₂; equally low solubility during durability testing (bench-scale rad tests). TcO₂ is the same oxide species present in HLW waste glasses formed under slightly reducing flowsheets like the Defense Waste Processing Facility (DWPF).
- **PCT:**
 - No impact of product REDOX on durability in short and long-term PCT tests (exc. for Cr in TCLP, controlled by iron nitrate additive to form FeCr₂O₄)
 - < 2 g/m² leachable per PCT for granular product and monoliths (using geometric surface area, equivalent to vitreous WFs)
 - <2 orders of magnitude lower than 2 g/m² if BET surface area is used for granular product
 - Durability results for the non-radioactive constituents from the 2-in. SRNL BSR testing and the 15-in. pilot plant agree with the previous data from 2001 and 2004 6-in. pilot plant tests
 - Re is a good Tc surrogate for this waste form
 - Long-term PCT testing (1, 3, 6, and 12 month) at 90°C by ASTM C1285 has not shown any significant change in the mineral assemblages as analyzed by XRD



- **SPFT: Relatively low forward dissolution rate ~10⁻³ g/(m²d)**
 - Re release was similar to both I and Tc release
 - Re, I, Tc, and S all showed delayed release from the sodalite phase(s) confirming that the Si-O-Al bonds of the sodalite cage have to dissolve before these species can be released
 - Si release from the BSR Rassat product was two orders of magnitude lower than for LAWA44 glass
- **PUF test: Simulates accelerated weathering of materials under hydraulically unsaturated conditions, thus mimicking the open-flow and transport properties that most likely will be present at the Hanford IDF**
 - PUF tests 1-year long were performed on the Rassat LAW FBSR granular products made in the BSR and the ESTD
 - Na, Si, Al, and Cs release decreased as a function of time
 - Iodine and Re release was steady
 - Differences in the release rates of Na, Si, Al and Cs compared to I and Re suggests that the release I and Re from the sodalite cage occurs at a different rate compared with the dissolution of the predominant nepheline phase
 - The 2.5-year-long PUF test results for 2004 SAIC-STAR pilot scale FBSR products were similar to results of the 1-yr BSR and 15-in pilot plant product PUF test results
 - Elemental release rates and geochemical modeling suggest that Al and Na release was controlled by nepheline solubility, whereas Si release was controlled by amorphous silica solubility after being released from the Na₂O-Al₂O₃-SiO₂ (NAS) matrix
 - Similar Re and S releases suggests that their release is either from the same phase or from different phases with similar stability
 - Re release was an order of magnitude lower than Tc release $[(2.1 \pm 0.3) \times 10^{-2} \text{ g/(m}^2\text{d)}]$ from LAW AN102 glass
 - Geochemical calculations using PHREEQ-C on 200 day PUF data suggests the steady-state S and Re concentrations are within order of magnitude of solubility of phase pure nosean and Re-sodalite, respectively
 - Re and S were released from a “mixed anion” sodalite phase (likely Re and SO₄-bearing), which has a different stoichiometry in comparison to the pure mineral end-members; and a thermodynamic stability between the pure phase end-members; such a solid solution is already known between the Cl and SO₄ sodalite/nosean endmembers and a mixed Re/Tc sodalite made at SRNL



Monolith product analyses and durability tests (SRNL-ORNL-PNNL-WRPS 2015 downselect)

- **ASTM1308/ANSI 16.1 test duration was up to 90 days. FBSR monoliths pass ANSI/ANS 16.1/ASTM C1308 durability testing with LI(Re) ≥ 9 in 5 days and achieving the LI(Na) in the first few hours.**
 - Clay monoliths had better durability than did the fly ash
- **ASTM1308/ANSI 16.1 and PCT tests (with leach rates < 2 g/m²) indicated that the binder material did not degrade the granular product durability.**
- **SPFT and PCT demonstrated slower releases from the monoliths than from the granular product but PUF release rates for the monoliths were faster than for the granular product.**
- **ASTM C39 Compressive Strength tests showed that the monoliths passed compression testing at > 500 psi but clay based monoliths performed better than fly ash based geopolymers.**



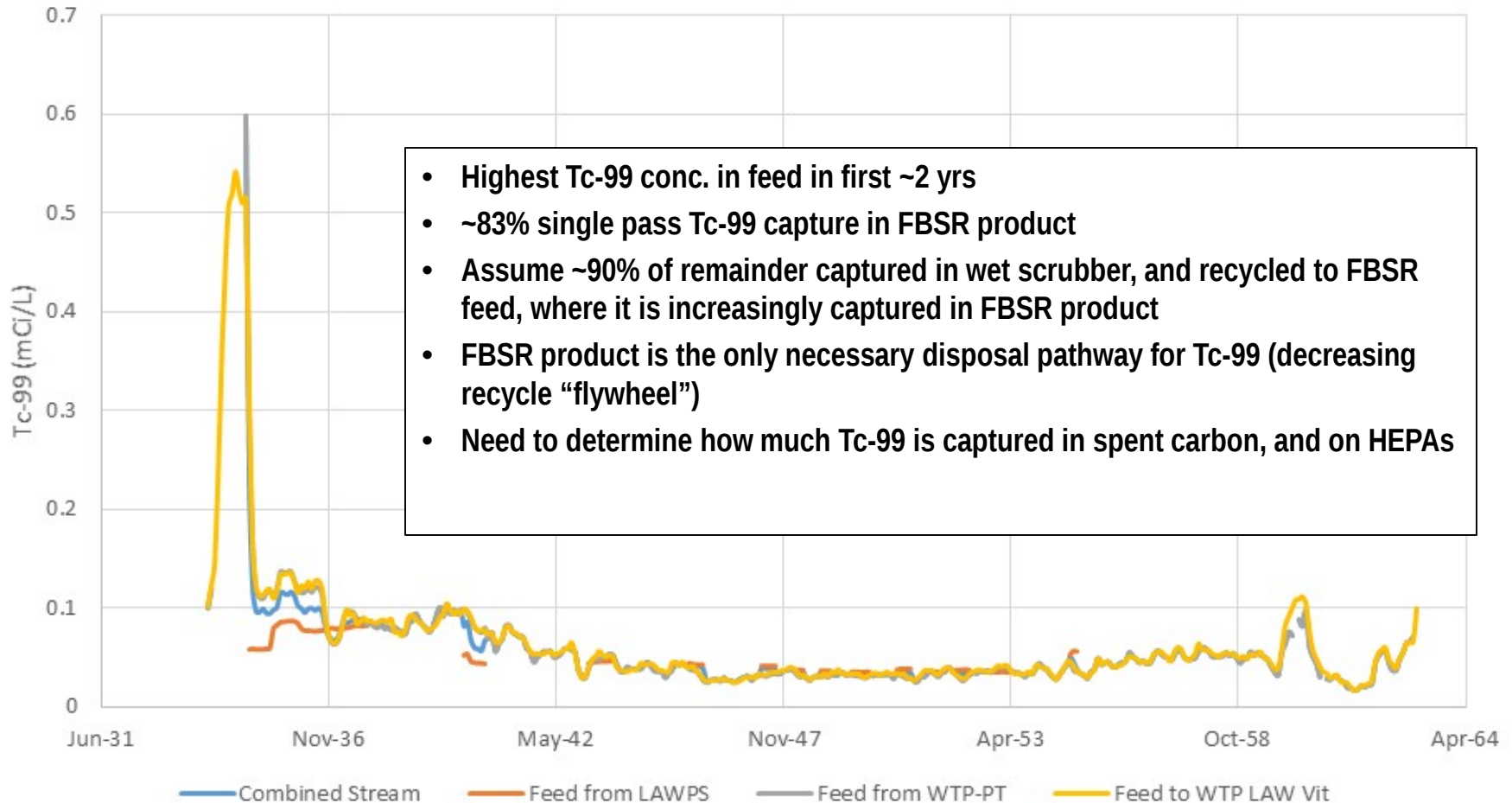
FBSR is expected to meet emission requirements similar to WTP LAW vitrification

Expected off-gas control performance requirements		
Parameter	Requirement or expected value	Basis
Stack gas NOx concentration	$\leq 100\text{-}300$ ppmv dry;	Pilot plant tests indicate this level is achievable; and it is assumed that this level of NOx emissions is regulatorily acceptable. (Need to confirm this based on WTP LAW vit NOx control requirements.)
WF organics destruction	$\geq 99.99\%$	Assume bounding requirement is HWC MACT standards for principal organic hazardous constituents
Hg decontamination factor (DF)	≥ 450	Assume FBSR requirement is similar to WTP LAW vit requirements. 100% of the Hg evolves to the off-gas where it is controlled using sulfur-impregnated activated carbon. Test data shows that Tc-99 and I-129, halogens Cl, F, I, and S are captured to a large degree in a single pass in the FBSR solid waste form. The total required control efficiency is achieved by additional >90-95% capture of these elements in the wet scrubber, and recycling them back to the FBSR.
HCl removal efficiency	$\geq 97\%$	
HF removal efficiency	$\geq 97\%$	
Iodine-129 removal efficiency	$\geq 99\%$	
Particulate capture efficiency	$\geq 99.95\%$	For final bank of HEPA filters when tested in-situ.
Combined total particulate DF	$2\text{E}+11$	Estimated minimum combined performance for process gas filter (100); followed by at least one wet scrubber, prefilter, and two HEPA filters in series ($2\text{E}+9$, from Jubin 2012).
Notes: 1. SO2 emissions, while not regulated under the HWC MACT standards, are expected to be captured in the product and >90% captured in the wet scrubber (Jubin 2012). 2. Additional requirements may apply, such as for other radionuclides, low volatile metals (As, Be, and Cr) or semivolatile metals (Cd and Pb), to the extent those are present in the WF. Semivolatile or low volatile elements are expected to be adequately captured with a combined particulate DF of $2\text{E}+9$ (Jubin 2012).		



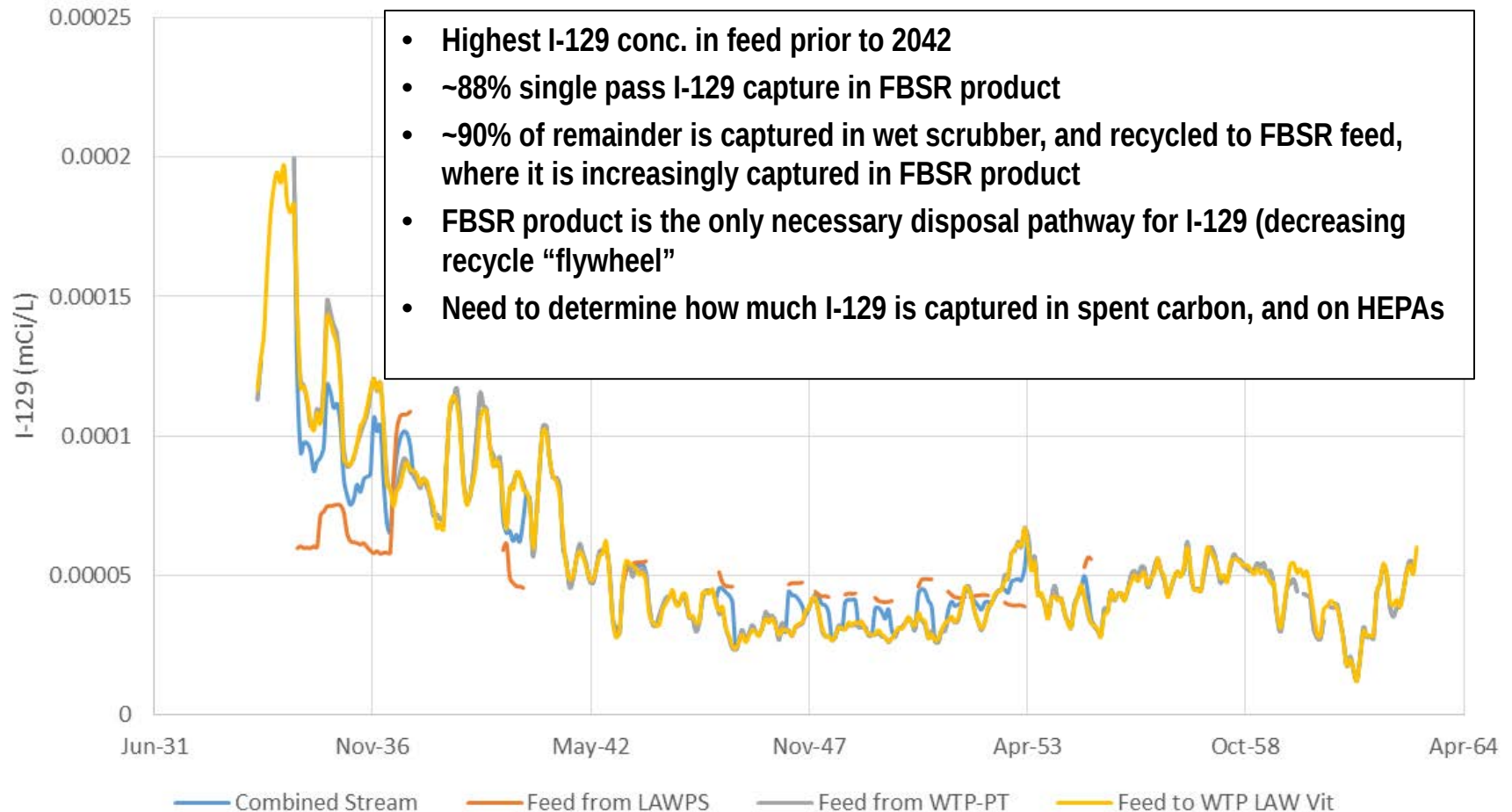
The FBSR product is the only necessary disposal path for Tc-99; but some may also be captured in spent carbon (for Hg control) and in HEPA filters

Supplemental LAW Feed Tc-99 Concentrations

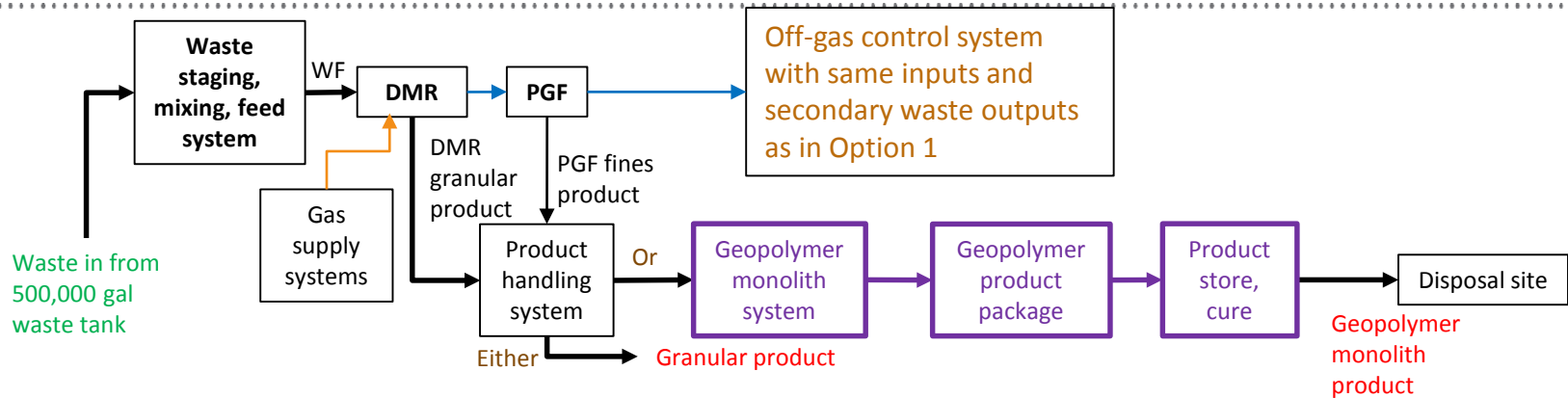


The FBSR product is the only necessary disposal path for I-129; but some may also be captured in spent carbon (for Hg control) and in HEPA filters

Supplemental LAW Feed I-129 Concentrations



FBSR Technology Readiness Level Estimates – Technology maturation is needed for some operations



Estimated Technology Readiness Level, assumptions

- Additive, WF systems TRL 7-8
 - Gas supply systems TRL 7-9
 - Not unique to FBSR, common commercial equipment
 - DMR TRL 6
 - Unique to FBSR
 - Mineralizing flowsheet TRL 6
 - Coal feed TRL 7
 - Product system TRL 6-7
 - Geopolymer monolith system TRL 4-6
 - Can use common commercial equipment
 - Off-gas system TRL 7-8
 - Wet scrubber TRL 4-6
 - Not unique to FBSR
 - Product cure, store, transport - needs design but TRL 7-8
 - Can use common commercial equipment
- **Integrated FBSR system TRL is 4-6** because of its dependence on multiple integrated subsystems, until fully integrated pilot and full-scale development and demonstration is achieved for the Hanford SLAW



Summary

- **~Two decades bench and pilot-scale R&D**
 - SRNL: Waste form studies, mineralogy, 2-in. Bench Scale Reactor, surrogate and actual wastes
 - INL: Surrogate feed streams, 3.5 and 6-in. diameter fluidized beds at SAIC STAR Center
 - Hazen Research, Inc: up to 24-in. diameter fluidized bed in the ESTD (Golden, CO)
- **Two full scale FBSR facilities (IWTU and Erwin ResinSolutions Facility)**
- **Some pros...**
 - Moderate temperature and pyrolysis in the DMR to destroy organics and NO_x
 - Production of a durable, mineralized waste form
 - Efficiently retains radionuclides, halogens, and hazardous metals in the primary waste form
 - No liquid secondary wastes – breaks the recycle “flywheel”
 - No significant volume increase
- **Some cons that need to be resolved...**
 - Needs stakeholder acceptance as alternative to vitrification
 - Complex, integrated thermal process
 - Requires design details specific to Hanford SLAW
 - Needs integrated pilot-scale and full-scale demonstration to advance TRL from 4-6 to 7-8



Backup slides



How comments from February NAS meeting were addressed, page 1

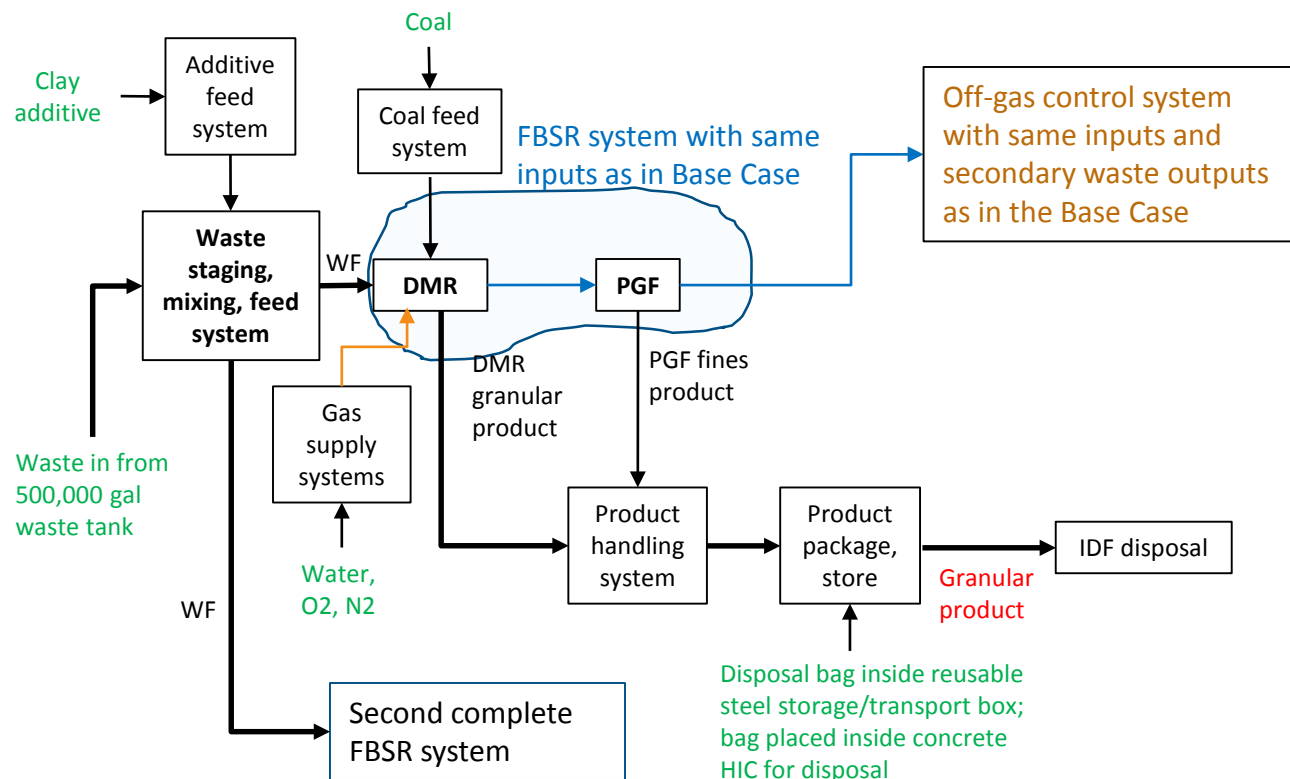
- **How is clay injected into process and form?**
 - Mincalc model for clay stoichiometry, mixer premixes clay into waste feed; slides 7-9, 12; report appendix sections 3, 5.
- **Size of fluidized beds? Size and tonnage?**
 - 5-ft bed ID, 5 ft bed height, 8 ft bed section height, 23 ft high freeboard, ; 100 ft³ bed volume, 4,000 lb nominal bed mass. Report Section 3.
- **Explain heat sources. How much coal is needed and what is the contribution to the volume increase from coal ash?**
 - Fluidizing gas is electrically preheated to ~600 C; coal/O₂ oxidation heats to ~725 C, provides energy for endothermic reactions, and heats/evaporates liquid WF. Slides 4, 5, report Section 2.
 - 0.26 kg coal per L waste feed, waste form is ~5 wt% coal/char, and ~2.7 wt% coal ash: volume increase is ~10%. Report Section 4, Slide 12.
- **What is benefit (if any) from the monolith option?**
 - Provides compressive strength to 500 psi. Also eliminates fines, although un-needed for IDF or WCS.
- **Consider replacement capability for engineered equipment in Complexity review Lines of Inquiry (LOI). First time mfg equipment is always a challenge to procure.**
 - Yes. FBSR is about as complex as vitrification, and some components including DMR are high Ni, high T metal alloys. Components needing replacement/maintenance such as feed nozzles can be removed and replaced. The vessels including the DMR should not require periodic replacement, based on Erwin facility experience; but long-term operation within DOE system not yet proven.
- **Need to address and acknowledge the challenges with IWTU startup and do best effort to separate historical challenges with current capabilities. What are current “first of a kind” technologies in the SR system?**
 - Report section 7 and 8. As of July 2018, various startup issues are still being addressed; startup is not yet complete, and the IWTU has not yet been converted to rad operations. The greatest single cause of startup delays was insufficient technology maturation, testing, modeling, and engineering demonstrations. These activities, not done prior to IWTU design and construction, had to be done using the IWTU as a full-scale demonstration along with more bench and pilot-scale testing, component testing, and modeling. As a result, some modifications to the IWTU were needed to improve design and operation.
- **How is mineral stored if not in monolith? Container types.**
 - Same as for grout waste form to WCS – 8.4 m³ bags, inside re-usable 8.4 m³ steel box, no free liquids, transports and disposes same as Erwin facility ash product (may need to use water spray to prevent fines release in event of a transport accident, as Erwin does. Disposal bag inside re-usable steel box for the monolith WF (same as for the grout WF to IDF). Report Section __, slides 7, 10.



How comments from February NAS meeting were addressed, page 2

- **What should be the on-line availability for each steam reformer system?**
 - After some discussion with reach-back team, availability estimate was increased from 50-70%. Report Section 3, slide 8. This significantly reduced need for large WF delay tanks beyond the 500,000 gal tank farm tank.
- **What could be the worst surprise from inaccurate Feed Vector (Cl, S etc.)?**
 - Higher monthly feedrates could overwhelm delay tankage, especially if on-line availability decreases to ~50%.
 - Unknown feed composition that could cause incorrect, insufficient clay stoichiometry. Because of this potential, we have two 50,000 gal WF Hold tanks for sample collection and 5-day analysis turnaround time; to ensure that the clay addition rate is based on specific sample analysis for each Hold Tank batch, and to provide time for the needed analyses.
- **Will SR make a wasteform compliant with IDF PA and WAC?**
 - Yes, report Section 5. Slides 13-18.
- **IWTU makes soluble wasteform. Is there SR experience with insoluble more suitable for LAW application?**
 - Yes, bench and pilot tests, up to 24-in. diameter (1/6th scale compared to 5-ft DMR, based on cross-section area) and full-scale Erwin facility.
- **Should Pat Lee of WRPS run IDF performance assessment model for the SR product?**
 - This is being done by Tom Brouns et al.
- **Is there enough info to assess SR WFs?**
 - Yes, from rad and non-rad bench and pilot tests and waste form performance testing. 2015 downselect report; report Section 5. Slides 13-18.
- **What type characterization/ measurement or sample analysis will be needed?**
 - For WF characterization measurements, see report Section 5. For WF analyses: Elemental composition, and total organics.
- **Need sensitivity analysis for Feed Vector deviations across all technologies and disposal options.**
 - Sensitivity analysis is not so important for FBSR. Hold Tank batching and sample analysis reduces risk of feed vector deviations on FBSR performance. Clay addition is varied mainly based on waste Na concentration. Other feed vector deviations such as in nitrate, organic, and NH₄ content are self-correcting in the FBSR process... for example higher organics = lower coal feedrate; higher nitrates/nitrites = lower O₂ input. Both are auto-controlled parameters to maintain constant measured DMR H₂ concentration and constant DMR temperature.
- **Is iron a challenge in wasteforms if pretreatment separations are degraded?**
 - No. Fe has negligible impact on waste form performance, within potential Fe ranges in the waste feed. Tests have both included and excluded iron additions with no impact on waste form.

Mineralizing FBSR (Treatment Option 3_): Two DMR systems; solid granular product, IDF disposal in HIC



- Same two identical FBSR systems
- Same shared waste staging, mixing, feed system, and same off-gas control system
- No product monolith system
- Secondary wastes (spent HEPAs, equipment, filters, PPE, etc.) in B-25s to IDF



NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Transportation and Disposal Site Considerations

Paul E. Shoemaker

Senior Manager, Defense Waste Management Programs
Sandia National Laboratories

*NDAA Evaluation of Supplemental LAW Options
NAS Committee Meeting #3
July 23–24, 2018*

Pre-Decisional

- **Waste Control Specialists**
 - **WCS Disposal Facility for Federal Wastes**
 - **Wastes Identified for Off-Site Disposal**
 - **Classifying Wastes Using WCS Waste Acceptance Criteria**
 - **Transportation Program to Ship to WCS**
- **Hanford Integrated Disposal Facility**



- **Waste Control Specialists**



- **WCS Disposal Facility for Federal Wastes**
- **Wastes Identified for Off-Site Disposal**
- **Classifying Wastes Using WCS Waste Acceptance Criteria**
- **Transportation Program to Ship to WCS**

- **Hanford Integrated Disposal Facility**



- **Commercial disposal facility** owned and operated by Waste Control Specialists LLC
- **Located** in west Texas
- **Licensed** by Texas, an NRC “Agreement State”
- **Licensed** for Class A, B & C LLW and Class A, B & C Mixed LLW (MLLW)
- **Federal Waste Disposal Facility**
 - One of the disposal facilities at WCS
 - Licensed specifically federal waste – e.g., DOE
 - Licensed Capacity: 737,000 m³ (SLAW base volume is 204,400 m³)
 - DOE signed Agreement to take ownership of the Federal Waste Facility after closure
- **Site Setting**
 - o WCS facilities are not over or adjacent to a drinking water aquifer
 - o Facilities are underlain by 600 ft (180 m) of nearly impermeable redbed clays
 - o There is a 7 ft (2 m) thick engineered liner
 - o Extensive monitoring network with over 500 core samples and monitoring wells



An aerial photograph of the Savannah River National Laboratory waste management facilities. The image shows several large, rectangular, reddish-brown containment areas, some with blue roofs, and several smaller, circular or rectangular structures. The surrounding landscape is arid and brown. The facilities are interconnected by a network of dirt roads and paths. The labels are placed over the image to identify specific areas.

11(e)2 Byproduct
Disposal Facility

RCRA Landfill

Federal Waste
Disposal Facility

Compact
Disposal Facility



Modular Concrete Containers (MCCs)

- **Class B and C MLLW** – usually disposed in their DOT shipping container, in a MCC
- **Class A MLLW** – not disposed in a MCC & the DOT shipping container is usually recycled
- Use of MCC is one reason for price difference between Class B&C wastes & Class A wastes



Photo of Rectangular MCCs

Each MCC can hold two 8.4 m³ containers of waste



Scale of WCS Disposal Facilities



- **Waste Control Specialists**
 - **WCS Disposal Facility for Federal Wastes**
 - ➔ • **Wastes Identified for Off-Site Disposal**
 - **Classifying Wastes Using WCS Waste Acceptance Criteria**
 - **Transportation Program to Ship to WCS**
- **Hanford Integrated Disposal Facility**



Wastes Identified for Off-Site Transport and Disposal

- **Grouted Waste Form**
 - Volume change due to treatment: 1.8 (increases volume & decreases specific activities)
 - **Average monthly volume: 1092 m³ / month** for 337 months
 - Density of final WF: 1770 kg/m³ (110 lb/ft³)
- **Steam Reformed Waste Form – Granular**
 - Volume change due to treatment: 1.2 (increases volume & decreases specific activities)
 - **Average monthly volume: 728 m³ / month** for 337 months
 - Density of final WF: 800 kg/m³ (50 lb/ft³)
- **Secondary Solid Wastes – grouted operational wastes (e.g., HEPA filters, PPE, etc.)**
- **Pretreatment Wastes – grouted wastes containing Tc-99 & I-129 removed prior to grouting**

Note: analysis performed on monthly averages, because Feed Vector (System Plan 8) provides information on “per month” basis



Wastes for Off-Site Transport and Disposal at WCS

Primary Wastes

- 2f - Grout with LDR pretreat & 99% Sr-90 removed
- 2g2 - Grout with LDR pretreat
- 3b - Steam Reformed Granular

Secondary Solid Wastes (HEPA filters, PPE, etc.)

From:

- 1c - cannister vit
- 1g - bulk vit
- 3b - steam reformed granular

Pretreatment Wastes (grouted Tc-99 & I-129)

From:

- 2e2 - grout to IDF



- **Waste Control Specialists**
 - **WCS Disposal Facility for Federal Wastes**
 - **Wastes Identified for Off-Site Disposal**
 - • **Classifying Wastes Using WCS Waste Acceptance Criteria**
 - **Transportation Program to Ship to WCS**
- **Hanford Integrated Disposal Facility**



WCS Radiological Criteria for Classifying Wastes with Long-Lived Nuclides (Table 1)

Radionuclide	Class A Limit		Class B Limit		Class C Limit	
C-14	0.8	Ci/m ³	¹	Ci/m ³	8	Ci/m ³
C-14 in Activated Metals	8	Ci/m ³	¹	Ci/m ³	80	Ci/m ³
Ni-59 in Activated Metals	22	Ci/m ³	¹	Ci/m ³	220	Ci/m ³
Nb-94 in Activated Metals	0.02	Ci/m ³	¹	Ci/m ³	0.2	Ci/m ³
Tc-99	0.3	Ci/m ³	¹	Ci/m ³	3	Ci/m ³
I-129	0.008	Ci/m ³	¹	Ci/m ³	0.08	Ci/m ³
Alpha-emitting transuranic radionuclides with half-lives greater than five (5) years	10	nCi/g	¹	nCi/g	100	nCi/g
Pu-241	350	nCi/g	¹	nCi/g	3,500	nCi/g
Cm-242	2,000	nCi/g	¹	nCi/g	20,000	nCi/g
Ra-226 ²	10	nCi/g	¹	nCi/g	100	nCi/g

There are no limits established for these radionuclides in Class B wastes

² This isotope is not listed in the classification tables in 10 CFR Part 61 but is required by the state of Texas to be included in classification determination

- Units are Ci/m³ or nCi/gram
- Class C limits are 10 x Class A limits
- Each limit is the full limit
- If multiple long-lived nuclides – use sum of fractions

WCS Radiological Criteria for Short-Lived Nuclides (Table 2)

Radionuclide	Class A Limit		Class B Limit		Class C Limit	
Total radionuclides with half-lives less than five (5) years	700	Ci/m ³	³	Ci/m ³	³	Ci/m ³
H-3	40	Ci/m ³	³	Ci/m ³	³	Ci/m ³
Co-60	700	Ci/m ³	³	Ci/m ³	³	Ci/m ³
Ni-63	3.5	Ci/m ³	70	Ci/m ³	700	Ci/m ³
Ni-63 in Activated Metals	35	Ci/m ³	700	Ci/m ³	7,000	Ci/m ³
Sr-90	0.04	Ci/m ³	150	Ci/m ³	7,000	Ci/m ³
Cs-137	1	Ci/m ³	44	Ci/m ³	4,600	Ci/m ³

³ There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other radionuclides in Table 2 determine the waste is Class C independent of these radionuclides.

- Units are Ci/m³
- Each limit is the full limit
- If multiple nuclides – use sum of fractions
- **Note: Sr-90 limit is 0.04 Ci/m³ for Class A**
- If long & short-lived nuclides: classify based on long-lived (Table 1), unless higher classification from short-lived (Table 2)



Classification of Wastes for Disposal at WCS

- Used radiological WAC & Feed Vector data & waste form characteristics to classify all wastes
- Essentially all waste forms meet WAC for disposal at WCS (any LDRs issues will be addressed before shipping)

Classification of Waste Forms to be Disposed at WCS (measured as number of months of output from WTP PT and LAW PS)				
Variant	Class A	Class B	Class C	GTCC
2f – Grout with LDR pretreat & 99% Sr-90 removed	406	2	33	0
2g2 - Grout with LDR pretreat	0	408	33	0
3b - Steam Reformed Granular	0	302	130	9
Secondary Solid Wastes Pretreatment Wastes (Tc-99, I-129)			TBD TBD	



Removal of Sr-90 from Grout

- The removal Sr-90 from grout could significantly reduce disposal costs, because the disposal fee for Class A wastes is assumed to be much lower than for Class B wastes

Classification of Waste Forms to be Disposed at WCS (measured as number of months of output from WTP PT and LAW PS)				
Variant	Class A	Class B	Class C	GTCC
2f – Grout with LDR pretreat & 99% Sr-90 removed	406	2	33	0
2g2 - Grout with LDR pretreat	0	408	33	0
3b - Steam Reformed Granular	0	302	130	9
Secondary Solid Wastes Pretreatment Wastes (Tc-99, I-129)			TBD	



- **Waste Control Specialists**
 - **WCS Disposal Facility for Federal Wastes**
 - **Wastes Identified for Off-Site Disposal**
 - **Classifying Wastes Using WCS Waste Acceptance Criteria**
 - ➔ • **Transportation Program to Ship to WCS**
- **Hanford Integrated Disposal Facility**

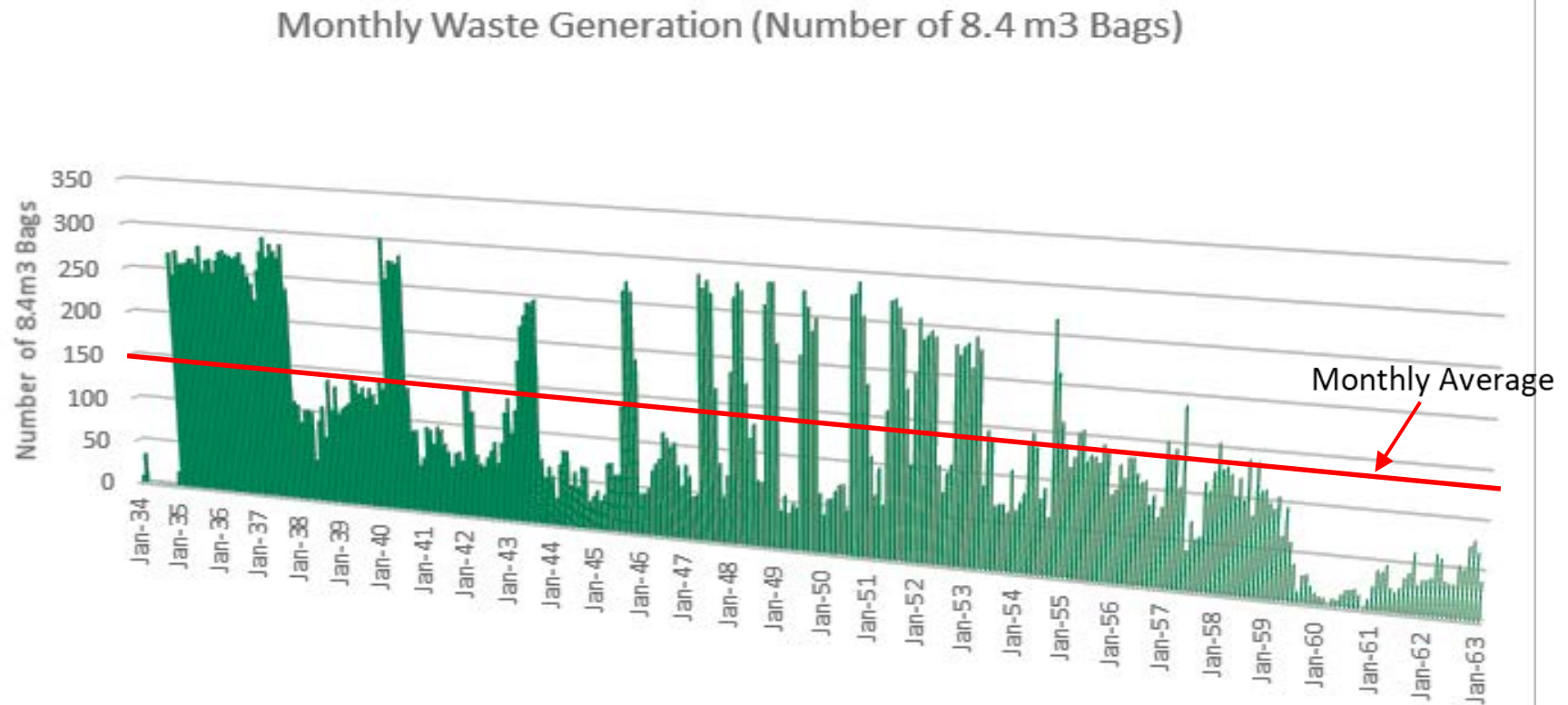
Off-Site Shipping Program

- Grout shipped as NRC Low-Specific Activity-III material (very likely)
- Steam Reformed Granular shipped as NRC LSA-II material (very likely)
- LSA II & LSA-III materials must be shipped in containers meeting DOT IP-2 criteria
- Plan to use 8.4 m3 soft side bags meeting DOT IP-2 criteria, in reusable steel box
- Reusable steel box facilitates forming, handling and public confidence, the steel box is not needed to meet DOT IP-2 criteria
- The secondary wastes will shipped in NRC Type A steel box
- All wastes shipped on gondola railcar



Lag Storage Facility Needed to Even-out Volumes for Shipping Program

- Great variability in number of 8.4 m³ containers of grout produced per month
- Lag storage facility will even-out shipping program to 130 containers / month



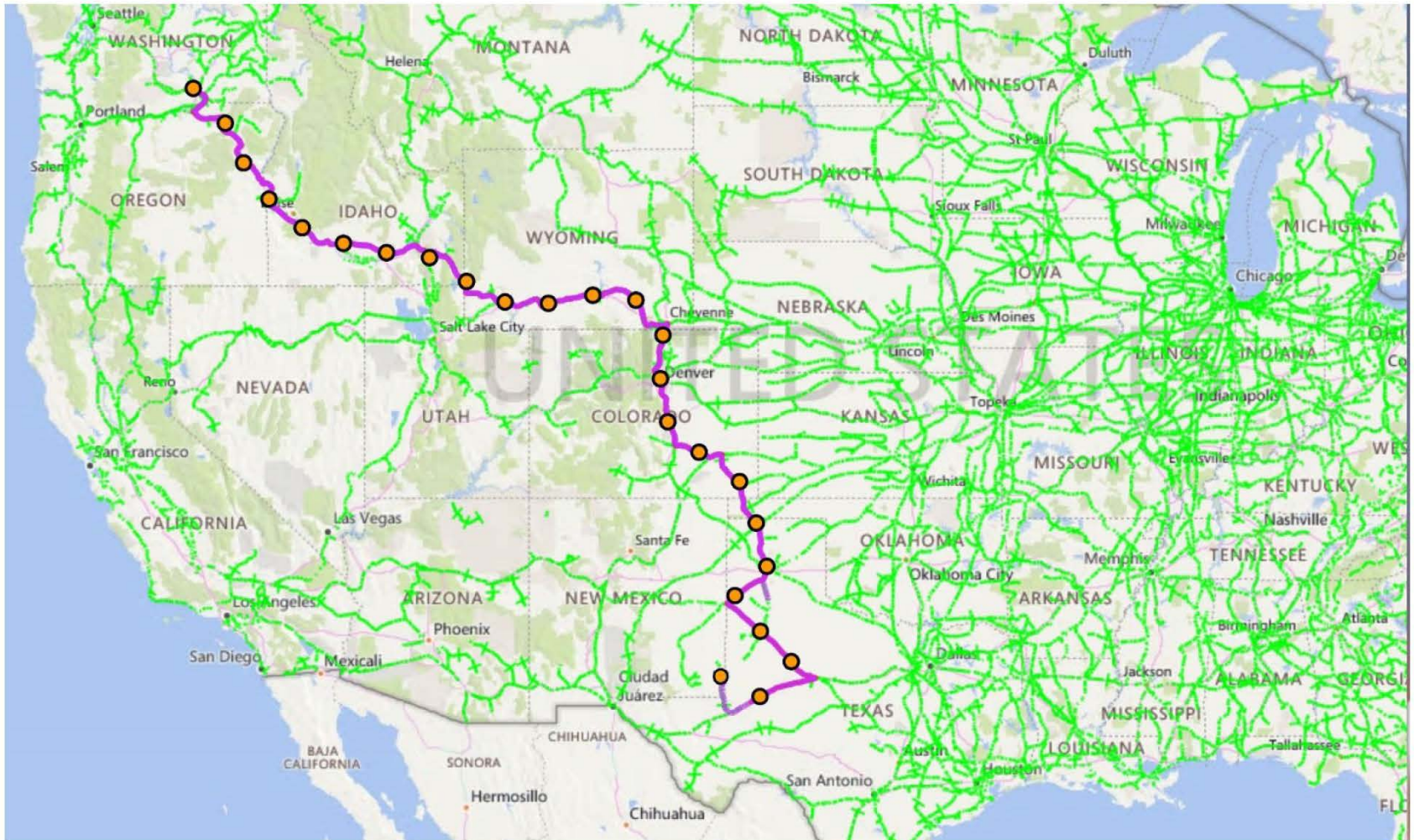
Off-Site Shipping Program

Off-Site Shipping Program Summary			
Waste Form	Container	Containers / gondola railcar	Railcars / month
2f & 2g2 – Grout & grout minus Sr-90	8.4 m3 soft side in steel box	5	26
3b Steam Reformed Granular	8.4 m3 soft side in steel box	12	8
Secondary Solid Wastes and Pretreatment Wastes (Tc-99, I-129)	2.5 m3 “B-25 box”	18	TBD TBD

- Maximum 26 gondola rail car loads per month
- For reference: there are roughly 240,000 gondola railcars in North America

Possible Rail Routing

- ~ 2,200 miles each way by rail



Relative Risks from Shipping

- **Work in Progress**
- **Points relevant to shipping risks:**
 - Shipping solid materials (no liquids, no gases)
 - Specific activity meets NRC definition of “low specific activity materials”
 - Shipping by rail
 - Shipped in DOT IP-2 containers in reusable steel boxes
 - Number shipments is low (26 railcars making 4,400 mile roundtrip per month)
- For accident frequency – will review risk of accidents per freight car mile
- For radiological dose - will review analogue studies shipping radioactive material by rail
- For programmatic risk / State concerns – plan to review analogue situations



Key Points

- **WCS LLW Disposal Facility**

- Commercially-operated LLW disposal facility accepting Class A, B C MLLW
- Federal Waste Disposal Facility has licensed volume capacity for SLAW
- DOE will provide long-term post-closure maintenance and monitoring

- **Wastes**

- Grout Waste Form with & without Sr-90: 1092 m³ / month for 337 months
- Steam Reformed Granular Waste Form - 728 m³ / month for 337 months
- Secondary and Pre-Treatment Wastes
- Essentially all waste forms meet WAC for disposal at WCS (only LDR-compliant waste forms will be shipped)

- **Transportation of Grout and Steam Reformed:**

- Grout and Steam meet NRC's LSA II & LSA-III criteria and shipped in DOT IP-2 container
- Use 8.4 m³ soft side bag meeting IP-2 criteria, in reusable steel box
- Maximum 26 gondola railcar loads per month



Hanford Integrated Disposal Facility (IDF)

- **Status**

- DOE Facility operated by Hanford Site Plateau Remediation Contractor (PRC)
- First phase of two-phase construction complete.
- Designed to accept LLW (DOE-regulated LLW cell) and mixed LLW (RCRA cell).

- **Physical Setting**

- Located on central plateau of Hanford Site, SW of the Waste Treatment and Immobilization Plant
- Based on extensive investigation program
 - Facility underlain by ~ 380 feet unconsolidated sand and gravel,
 - Approximately 300 feet to underlying aquifer

- **Design of Disposal Cells**

- Multi-barrier design including RCRA-compliant liner and leachate collection system



- **Licensing**

- DOE-self regulates LLW disposal
- Final DOE Authorization and Waste Acceptance Criteria not issued
- Department of Ecology has issued a dangerous waste permit for the RCRA cell for ILAW (glass), and for technology-demonstration quantities of a Bulk Vitrification waste form

- **Capacities**

- Approximately 165,000 m³ of total LLW and mixed LLW capacity in “first expansion” comprised of two cells
- Capacity of six cells possible





NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Estimate Methodology and Results

Frank Sinclair

FFRDC Team Cost Estimating Lead

Project Management Professional

SRNL Nuclear Materials Management Programs Directorate

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Fellow Technical Advisor

SRNL Environmental Stewardship Directorate

NAS Committee Meeting #3

July 23 and July 24, 2018

Richland, WA

Pre-Decisional

Introduction and Purpose

- Per the 2017 NDAA, the FFRDC team is to develop cost estimates of treatment options for Hanford Supplemental LAW
- As part of this activity, the team is developing Rough Order of Magnitude (ROM) cost estimates to include Pre-Process Operations, Capital Projects, Transportation/Disposition Logistics, Life-Cycle Operations, and D&D. Considerations include facility sharing of site overheads.
- Three primary treatment technologies
 - Vitrification
 - Fluidized Bed Steam Reforming
 - Grouting
- Two disposal sites
 - Hanford WA, Integrated Disposal Facility (IDF)
 - Offsite Commercial Facility



Overview

- **Cost estimating follows the process technology and pre-treatment flowsheets as well as the transportation/disposal cost (for offsite) disposal.**
- **Preliminary DRAFT estimates are provided.**
- **Not all variants will be estimated. Key focus is to determine the range within a given technology. Examples provided.**
- **Final disposal location appears to be a significant factor within a given technology variant set.**
- **Transportation/disposal logistics and cost are treated as individual field to better reflect the impacts and provide comparison.**
 - This effort will be folded into total project cost in final report.



Iterative process involving technology and regulatory SME input, Development and Construction experience, and Operations & Logistics expertise.

Class 5 estimates developed from SME flowsheets with at least 2 iterations per SME team and at May FFRDC group meeting.

1. Identification / Utilization of Analog Facility for Primary Process

Vitrification

WTP-LAW (w/ EMF)

Base Case: 2X capacity of existing LAW w/ enhanced off-gas

Variant: 2 double capacity melter's with enhanced off-gas

Grout

SRS-Saltstone

Base Case: Similar capacity, packaged form, additional load-out / logistics

Variant: Same as base, but with organic/radionuclide mitigation operations

Variant: Plant located at IDF, with disposal vaults and reduced handling

FBSR

IWTU

Base Case: 2 IWTU process lines with aluminosilicate product

Variant Same as base but with grouted monolithic waste form



Iterative process involving technology and regulatory SME input, Development and Construction experience, and Operations & Logistics expertise.

2. Systems approach based on recent DOE activity for ancillary facilities including,

<i>Pre-Process</i>	500K gallon blend tank ubiquitous for all technologies In-tank strontium removal possible for grout (off-site disposition cost)
<i>New Unit Operations</i>	None for glass (minor deviation on off-gas treatment) Organic strikes and Tc/I removal options for grout
<i>Post-Process</i>	Optional grouting to convert FBSR product to monolith 8.4 cubic meter package for grout/FBSR handling / shipping
<i>Balance of Facilities</i>	Not a major discriminator versus overall capital cost Glass > FBSR > Grout
<i>Control Room</i>	IWTU (FBSR) cost includes control room Grout option increased to upgrade versus Saltstone Vitrification assumed to use WTP control room
<i>Laboratory</i>	WTP lab shift technicians added for each technology



Iterative process involving technology and regulatory SME input, Development and Construction experience, and Operations & Logistics expertise.

3. Start-Up, Operations, Transport/Handling Logistics, etc. handled on annual basis

<i>Transportation</i>	For grout / FBSR products (preferred method – rail)
<i>Disposal</i>	Commercial facility pricing based on volume and radiological input
<i>D&D</i>	estimated as function of TEC / OPC (5%)
<i>G&A</i>	overhead and general services

Notes: Handling and site logistics (load-out) separated from transportation
Strontium strike (in tank farms) option considered to reduce disposal cost
Lab overhead and services cost share will not differentiate in this methodology - driven by WTP-PT, WTP-LAW, and WTP-HLW
Equivalent duration for processes reduces impacts



Work underway. Iterative process with multiple technology variants and transportation disposal options.

Key Points

- *Significant variation between different technologies*
 - Consistent between estimating effort and SME ranking process
- *Analogs selected for each base technology (bulk vitrification in process)*
- *Technology type appears significantly more impactful than sub-variants*
 - Vitrification
- *Transportation and off-site disposal will be included*
 - Largest impact to Grout and FBSR options
 - Will be significant cost for either technology with respect to life-cycle
- *Support from SME's in detailing transportation, regulations, and disposal cost noted and appreciated.*



Preliminary Cost Numbers

	Technology Development \$(M)	Total Estimated Cost (TEC) \$(M)	Other Project Cost (OPC) \$(M)	Life-Cycle Operations \$(M)
Vitrification	340-680	6800-8800	560-1040	8500-13,000
FBSR	480-620	1600-2100	300-390	2500-4300
Grout	75-160	250-520	250-910	1200-1600

Notes:

OPC costs vary significantly due to vault / replacement systems

D&D cost (not shown) will be estimated as percentage of TEC/OPC

T&D cost impacted by duration, maturity, type of testing

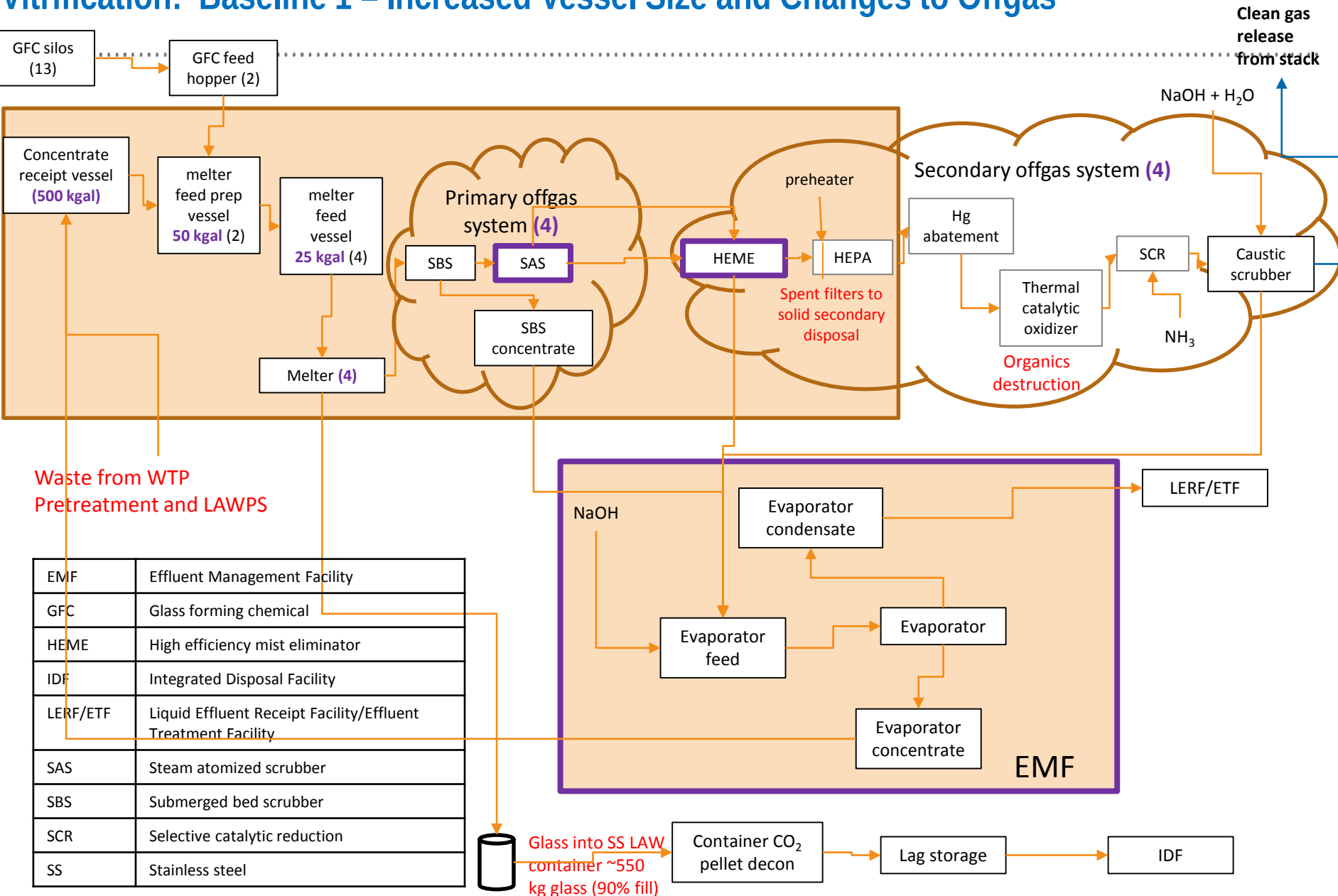
Offsite transportation and disposal cost not included in above numbers



Preliminary Estimate Range by Technology and Variant Case



Vitrification: Baseline 1 – Increased Vessel Size and Changes to Offgas



EMF	Effluent Management Facility
GFC	Glass forming chemical
HEME	High efficiency mist eliminator
IDF	Integrated Disposal Facility
LERF/ETF	Liquid Effluent Receipt Facility/Effluent Treatment Facility
SAS	Steam atomized scrubber
SBS	Submerged bed scrubber
SCR	Selective catalytic reduction
SS	Stainless steel

Vitrification Baseline, Estimate Status

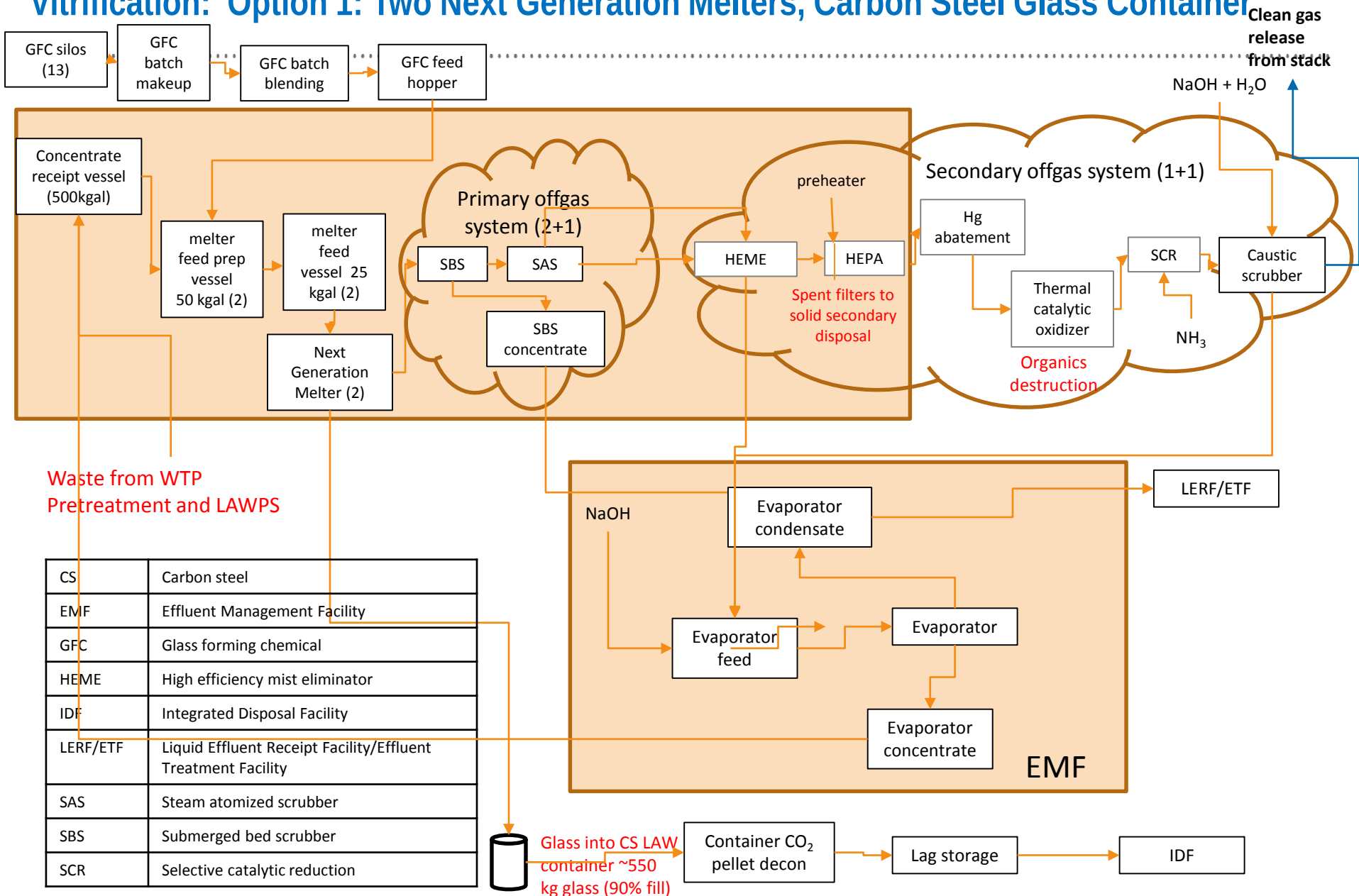
	Technology Development	TEC/OPC	Life Cycle – Operations	D&D
Low Range	\$340M	\$6800M / \$800M	\$10,000M	\$330M
High Range	\$440M	\$8800M / \$1040M	\$13,000M	\$430M

Notes:

- 1) Technology Development driven by current rate of R&D expenditure and expected lessons learned from WTP-LAW
- 2) Capital cost derived from previous (GAO) estimate with EMF capability and escalation (to 2018 dollars)
- 3) OPC driven by replacement melter (24 count) expenditure
- 4) Operations based on \$360M/yr, 28 years, no escalation
- 5) High range estimate: +30%
- 6) \$18-24 billion ROM range



Vitrification: Option 1: Two Next Generation Melter, Carbon Steel Glass Container



Vitrification, Option 1 Estimate Status

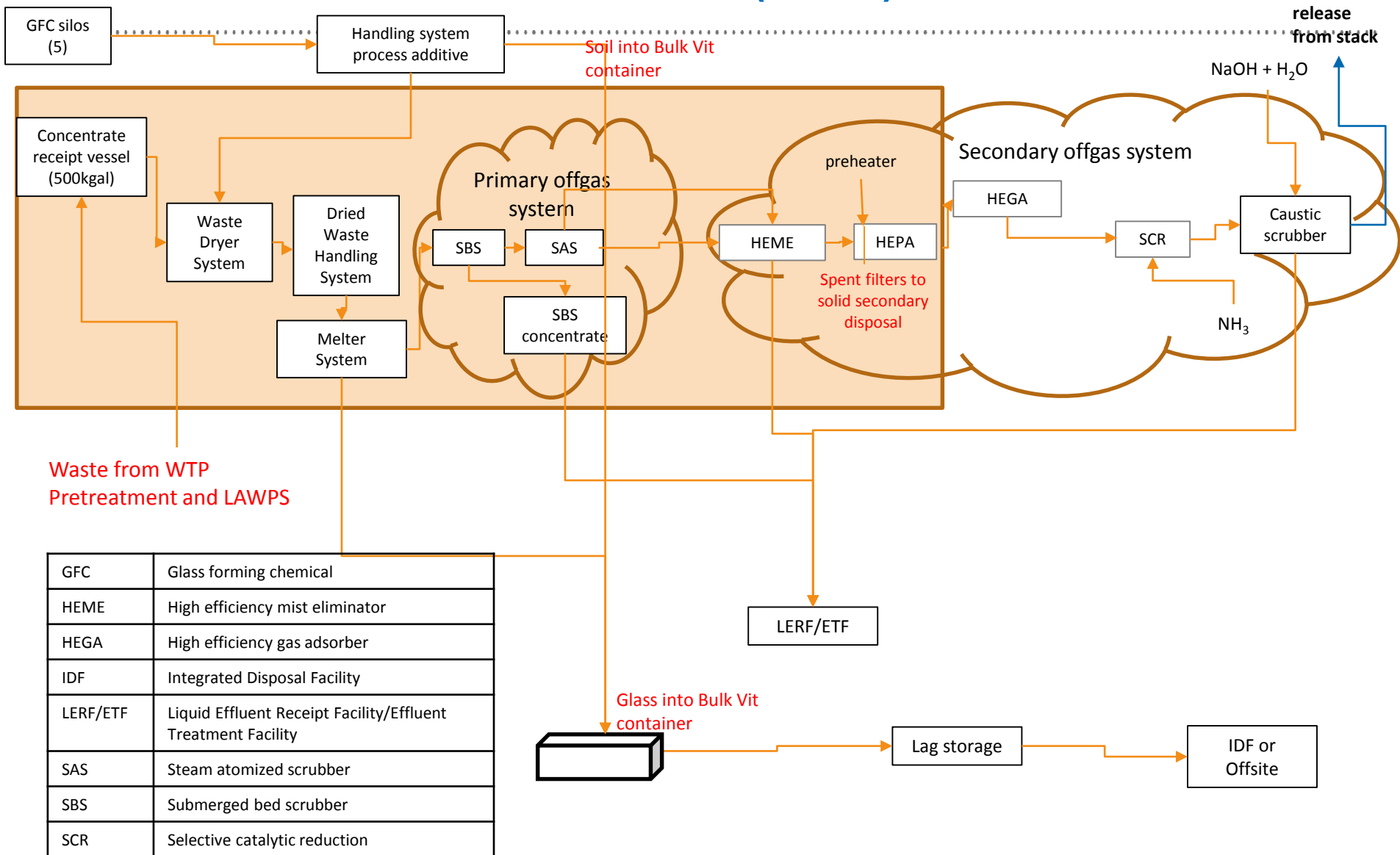
	Technology Development	TEC/OPC	Life Cycle – Operations	D&D
Low Range	\$680M	\$6800M / \$560M	\$8500M	\$330M
High Range	\$880M	\$8800M / \$730M	\$11,000M	\$430

Notes:

- 1) Technology Development higher - largest rad waste melter to be placed in service (2X WTP-LAW)
- 2) Capital nominally assumed same as base Supplemental LAW
- 3) OPC driven by replacement melter (12 count) expenditure
- 4) Operations based on \$305M/yr, 28 years, no escalation
- 5) \$17-22 billion ROM range not appreciably different than Baseline



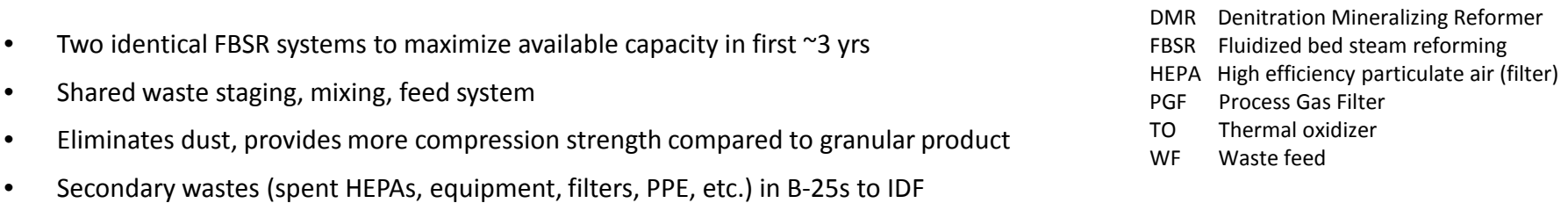
Vitrification: In Container Vitrification™ (Bulk Vit)



Notes:

1) TBD





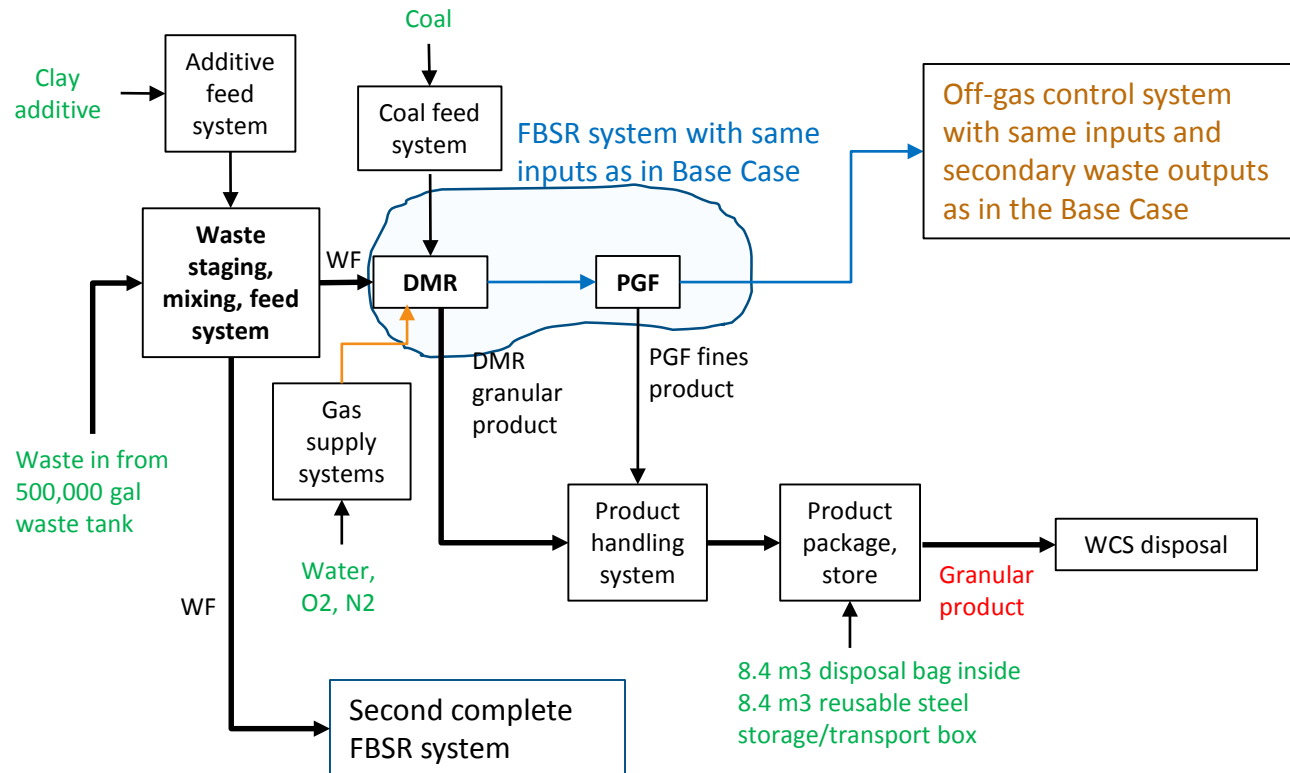
FBSR Base Case: Estimate Status

	Technology Development	TEC/OPC	Life Cycle – Operations	D&D
Low Range	\$480M	\$1600M / \$300M	\$3300M	\$95M
High Range	\$620M	\$2100M / \$390M	\$4300M	\$120M

Notes:

- 1) Technology Development higher reflecting greater uncertainty on product formulation versus vitrification and testing expense
- 2) Capital based directly from IWTU (*grout unit op's will increase capital cost*)
- 3) OPC reflects uncertainty on materials compatibility and mineral product
- 4) Operations based on \$117M/yr, 28 years, no escalation
- 5) \$6-8 billion ROM range

Mineralizing FBSR (Treatment Option 3b): Two DMR systems; solid granular product, disposal at WCS



- Same two identical FBSR systems
- Same shared waste staging, mixing, feed system, and same off-gas control system
- No product monolith system
- Secondary wastes (spent HEPAs, equipment, filters, PPE, etc.) in B-25s to WCF



FBSR Variant - Mineral to WCS: Estimate Status

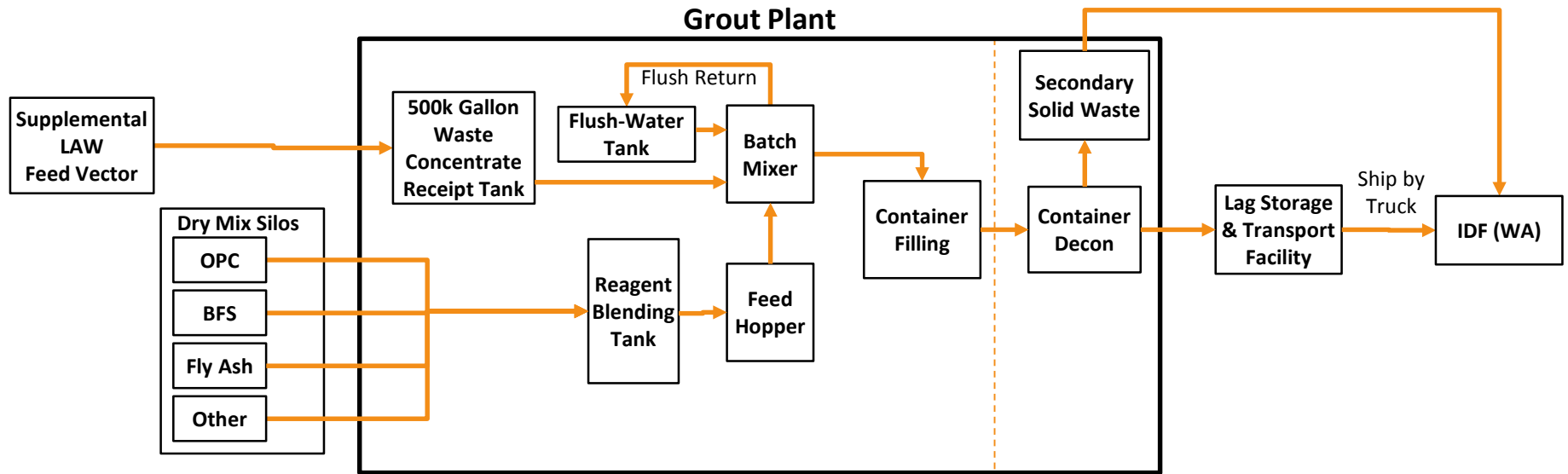
	Technology Development	TEC/OPC	Life Cycle – Operations	D&D
Low Range	\$480M	\$1600M / \$300M	\$2500M	\$95M
High Range	\$620M	\$2100M / \$390M	\$3300M	\$120M

Notes:

- 1) Technology Development higher reflecting greater uncertainty on product formulation versus vitrification and testing expense
- 2) Capital based directly from IWTU
- 3) OPC reflects uncertainty on materials compatibility and mineral product
- 4) Operations based on \$90M/yr, 28 years, no escalation
- 5) \$5-7 billion ROM range
- 6) Transportation and disposal will be significant addition.

Base-Case SLAW Cast Stone Flowsheet

Grout plant located close to WTP; no pretreatment beyond WTP-PT/LAWPS; disposal at IDF



- Assumed no pre-treatment needed beyond WTP-PT/LAWPS

- Semi continuous batch processing
- Grout formulation based on Cast Stone mix design

- TRL estimated “medium to high”

- *Container*: Grout cast in an 8.4 m³ steel box.
(Note: size of box scaled to be compatible with WCS option (variant 2g2))

- TRL estimated to be “medium”

Note: TRLs are preliminary/qualitative; final report will have quantitative ranges

- Regulatory consideration/risks estimated to be “medium to high”

- Waterless decon
- TRL estimated to be “high”

- TRL for conveying, curing, and lag storage estimated to be “medium to high”

- Transportation TRL estimated to be “high”



Grout Base Case: Estimate Status

	Technology Development	TEC/OPC	Life Cycle – Operations	D&D
Low Range	\$90M	\$300M / \$200M	\$1100M	\$25M
High Range	\$120M	\$390M / \$260M	\$1400M	\$35M

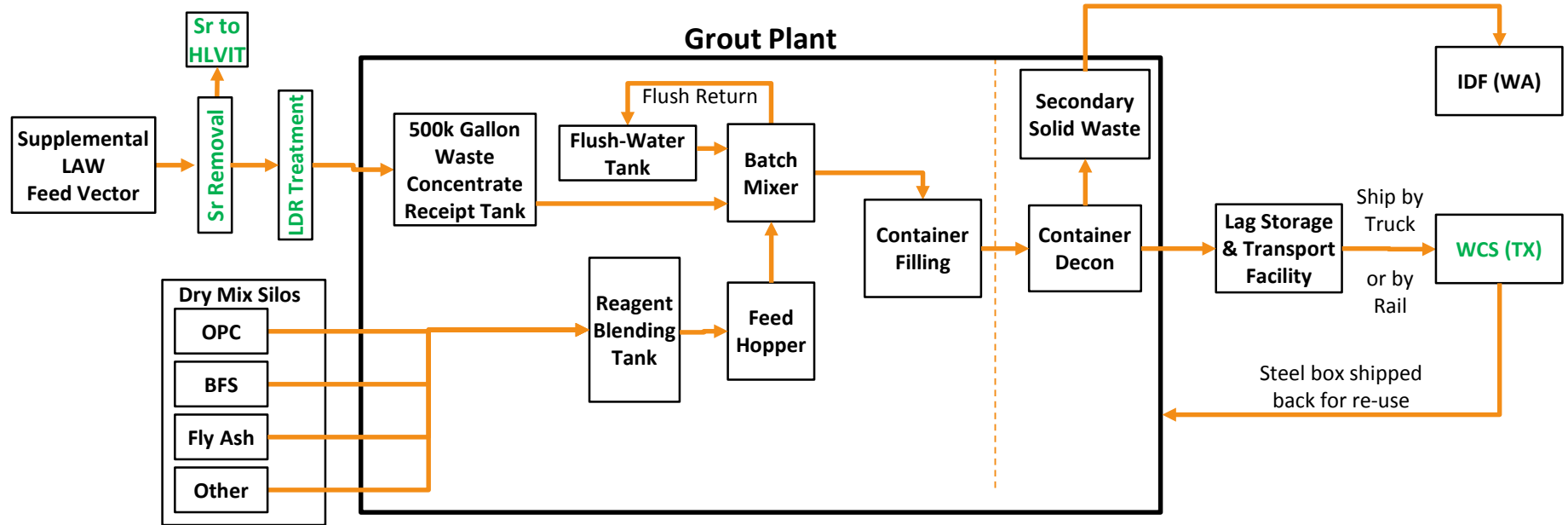
Notes:

- 1) Technology Development lower based on non-thermal testing and maturity
- 2) Capital escalated from Saltstone plus container / load-out capability
- 3) Operations based on current Saltstone plus additional manpower (~\$40M/yr)
- 4) \$2-3B ROM range.
- 5) Consistent with off-site variant – *transport and disposal cost will be appreciable*



Variant 2f for SLAW Cast Stone Flowsheet

Grout plant located close to WTP; **cast stone disposal at WCS**; **pre-treatment to comply with LDR**;
pre-treatment for Sr to reduce ship/store costs



- Additional pre-treatment prior to entering grout plant to remove **organics** & metals to comply with land disposal requirements (LDR)

- Pre-treatment to remove Sr, which is then sent to HLVT
- Ensures all waste is class A to lower transportation & disposal cost

- **Container:** Grout cast in an 8.4 m³ bag in a steel box/form; heavy-duty woven & non-woven polypropylene bags certified to meet Industrial Package type 1 (IP-1) for transport
- Bag+grout-monolith removed at storage facility for disposal in modular concrete containers (MCCs)
- Steel box/form returned to grout plant for re-use
- TRL estimated to be “medium”

- Regulatory consideration/risks estimated to be “low to medium”
 - Significantly lower than base case because WCS facility is permitted to accept waste containing Tc/I
 - Added risk for transportation (class A wastes)

Note: TRLs are preliminary/qualitative; final report will have quantitative ranges



Grout Pre-Treatment Case: Estimate Status

	Technology Development	TEC/OPC	Life Cycle – Operations	D&D
Low Range	\$120M	\$400M / \$250M	\$1200M	\$35M
High Range	\$160M	\$520M / \$320M	\$1600M	\$40M

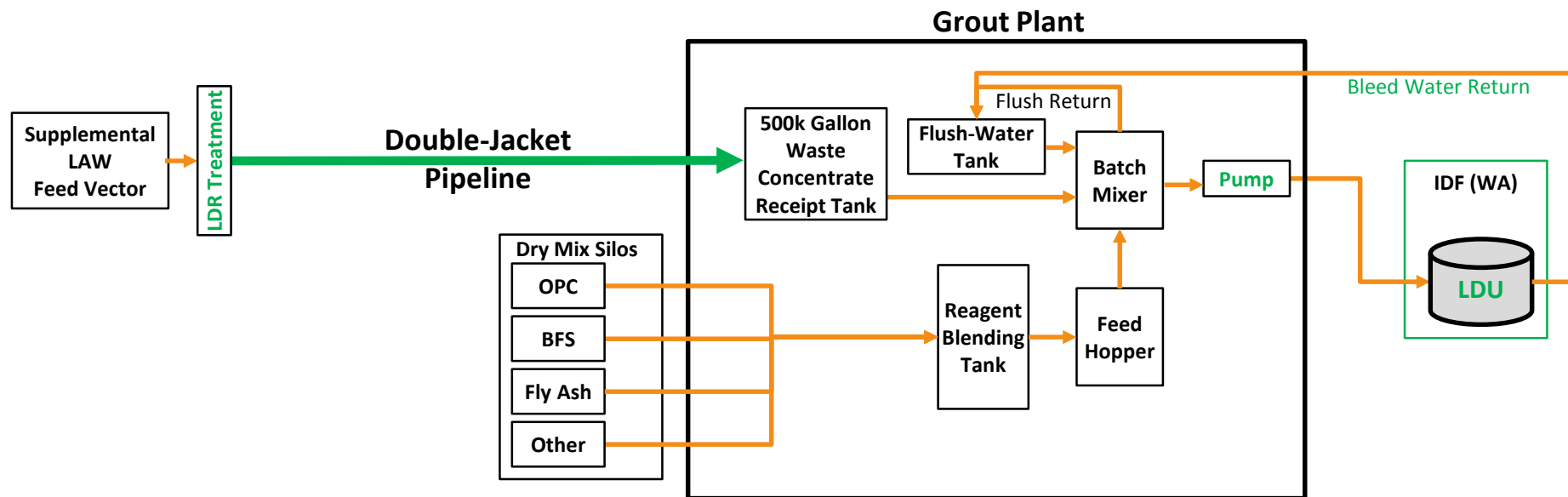
Notes:

- 1) Capital and technology development increased to include pretreatment unit operations (LDRD, etc.)
- 2) Operations based on current Saltstone plus additional manpower (~\$40M/yr)
- 3) Tank farm operations (Sr strike not included)
- 4) \$2-3B ROM range not appreciably different from base case



Opportunity 2h for SLAW Cast Stone Flowsheet

Grout plant located close to IDF; pre-treatment for LDR; disposal in large disposal units (LDUs) at/near IDF



- Process similar to variant 2d, except that grout facility is located near IDF, allowing ability to cast waste in place in large disposal units.
- Relocation of grout facility requires additional double jacketed pipeline to deliver supplemental LAW.
- Facility would **not** require some processes from base case (e.g., container filling, container decon, and lag storage)
- Facility **would** require additional processes from base case (e.g., pumping of grout; bleed water return)
- Large disposal units (LDUs) would be significantly larger than transportable units (i.e., comparable to saltstone disposal units or SDUs).



Grout at IDF Case: Estimate Status

	Technology Development	TEC/OPC	Life Cycle – Operations	D&D
Low Range	\$75M	\$250M / \$700M	\$1000M	\$25M
High Range	\$100M	\$320M / \$910M	\$1300M	\$30M

Notes:

- 1) OPC significantly increased due to 4 disposal units (\$125M/unit, 4 count)
- 2) TEC and handling operations reduced
- 3) ROM range not appreciably different from base case



NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview – Analysis Results

R. T. Jubin

S. M Robinson

Distinguished R&D Staff Member

Oak Ridge National Laboratory

Nuclear Security and Isotope Technology Division

NAS Committee Meeting #3

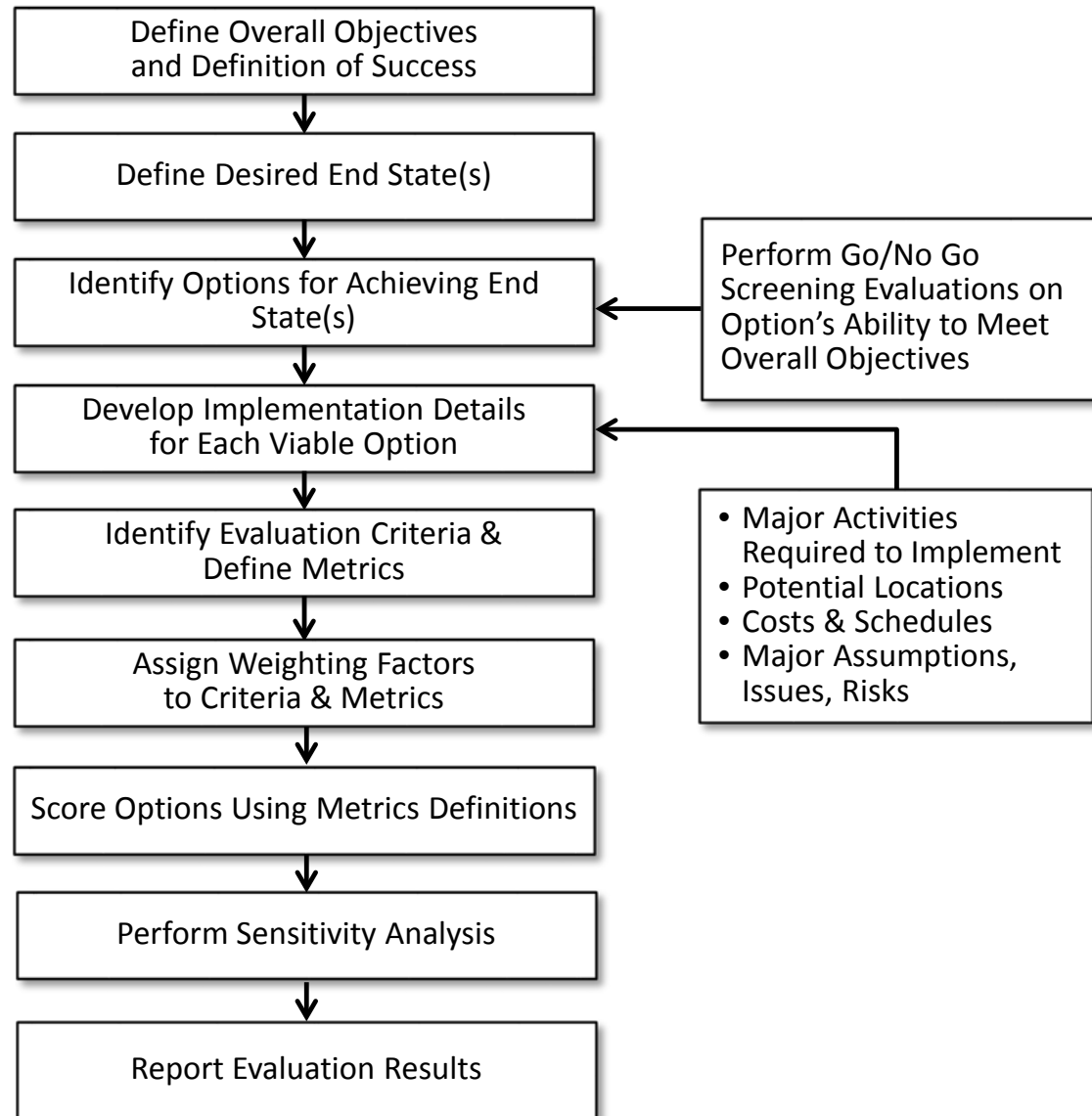
July 23 – 24, 2018

Pre-Decisional

- **Goal: Use a structured evaluation approach to evaluate options for alternative treatment of SLAW**
 - Used Analytical Hierarchy Process decision modeling method developed at the Wharton School of Business at the University of Pennsylvania and used by many Fortune 500 companies and the federal government for project planning
 - It is ideal for evaluating qualitative, quantitative, and potentially conflicting criteria
 - It uses pairwise comparisons to measure the relative importance of criteria and metrics
 - It provides a documentable structured process for selecting a preferred implementation option
- **Approach: Considered 22 options for alternative treatment of SLAW**
 - Twelve options were evaluated and ranked using 10 criteria defined by the FFRDC team
 - The FFRDC team assessed that 10 were bounded by the other criteria and were not evaluated in detail



AHP Options Analysis Process



Options Considered for Evaluation

Option	Evaluated
1 - Vitrification - Base Case	Yes
1a - Vit to WCS, Secondary to IDF	No
1b - Vit to WCS, Secondary to WCS	No
1c - Vit to IDF, Secondary to WCS	Yes
1d - Bulk Vitrification	Yes
1e - Bulk vit to WSC, Secondary to IDF	No
1f - Bulk vit to WSC, Secondary to WCS	No
1g - Bulk vit to IDF, Secondary to WCS	Yes
2 - Grout - Base Case	Yes
2a - Grout to WCS, Secondary to IDF	No
2b - Grout to WCS, Secondary to WCS	No
2c - Grout to IDF, Secondary to WCS	No
2d - Grout with LDR pretreatment, Primary & Secondary to IDF	Yes

Option	Evaluated
2e1 - Grout with LDR and Tc & I Pretreatment to HLVit, Primary & Secondary to IDF	Yes
2e2 - Grout with LDR and Tc & I Pretreatment to WCS, Primary & Secondary to IDF	Yes
2f - Grout with LDR and Sr pretreatment to HLVit, Primary to WCS, Secondary to IDF	Yes
2g1 - Grout with LDR pretreatment; Primary to WCS - B25 box	No
2g2 - Grout with LDR pretreatment; Primary to WCS – 8.3m ³ bag in box	Yes
3 - Steam Reforming - Base Case	Yes
3a - Steam Reforming to WCS, Secondary to IDF	No
3b - Steam Reforming to WCS, Secondary to WCS	Yes
3c - Steam Reforming to IDF, Secondary to WCS	No



Evaluation Criteria & Metrics

Criteria	Metrics
Technical Maturity and Process Simplicity & Reliability	TRL
	Maturation of TRL
	Number of unit operations
	Simplicity of feed start-up/shut down
	Simplicity of control of unit operations
Safety	Nuclear and radiological hazards
	Chemical hazards
	Physical hazards
	Transportation hazards
Operational Flexibility	Ability to handle range of feed vector compositions
	Ability to handle range of feed vector flowrates
	Ability to prevent/rework off-spec product
	Analytical requirements



Evaluation Criteria & Metrics Continued

Criteria	Metrics
Economy	Development cost
	Capital cost (includes permits & D&D etc.)
	Operational / annual cost
Schedule (Speed)	Development time prior to design
	Time to complete design, construction, and hot startup
Imperviousness to Risks	Project risks
	Operational execution risks
	TRL related risks
Primary Waste Form Compliance	Primary waste form compliance
Secondary Waste	Quantity
	Compatible with existing / draft disposal site WAC
Regulatory Considerations	Permitting/licensing complexity for new facilities & processes
	Compliance with shipping regulations
	Permitting/licensing complexity for disposal
End State Decommissioning	Complexity (includes residual inventory)
	Waste volume



Example Metric Value Definitions

Criteria/Metrics	1 - None	3- Moderate	5 - Strong
Technical Maturity and Process Simplicity & Reliability			
TRL	TRL is judged to be 3 or less	TRL is judged to be 4 to 6	TRL is judged to be 7 or greater
Waste Form Performance			
Compability with Disposal Site WAC	Low confidence that waste form meets all pertinent criteria	Moderate confidence that waste form meets all pertinent criteria	High confidence that waste form meets all pertinent criteria
Regulatory Considerations			
Permitting/Licensing Complexity for Disposal	A limited technical basis exists to support the timely completion of permit applications and moderate confidence that applications will support mission. Significant permit modifications required for option's final waste forms	A moderate technical basis exists to support the timely completion of permit applications and moderate confidence that applications will support mission. Moderate permit modifications required for option's final waste forms	A strong technical basis exists to support the timely completion of permit applications and high confidence that applications will support mission. Minor permit modifications required for option's final waste forms



Pairwise Evaluation of Selection Criteria and Metrics Generate Weighting Factors

Criteria 1	Very Strong (4)	Strong (3X)	Moderate (2X)	Equal	Moderate (2X)	Strong (3X)	Very Strong (4)	Criteria 2
Technical Maturity and Process Simplicity & Reliability			X					Safety
Technical Maturity and Process Simplicity & Reliability					X			Operational Flexibility
Technical Maturity and Process Simplicity & Reliability						X		Economy
Technical Maturity and Process Simplicity & Reliability						X		Schedule ("Speed")
Technical Maturity and Process Simplicity & Reliability					X			Imperviousness to Risks
Technical Maturity and Process Simplicity & Reliability							X	Primary Waste Form Compliance
Technical Maturity and Process Simplicity & Reliability					X			Secondary Waste
Technical Maturity and Process Simplicity & Reliability						X		Regulatory Considerations
Technical Maturity and Process Simplicity & Reliability			X					End State Decommissioning



Evaluation Criteria & Metrics Weighting Factors

Criteria	Weighting Factor	Metrics	Weighting Factor
Technical Maturity and Process Simplicity & Reliability	5.9%	TRL	7.6%
		Maturation of TRL	33.6%
		Number of unit operations	13.7%
		Simplicity of feed at start-up/shut down	22.3%
		Simplicity of control of unit operations	22.8%
Safety	5.0%	Nuclear and radiological hazards	41.5%
		Chemical hazards	23.2%
		Physical hazards	12.0%
		Transportation hazards	23.2%
Operational Flexibility	8.3%	Ability to handle range of feed vector compositions	41.5%
		Ability to handle range of feed vector flowrates	23.2%
		Ability to prevent/rework off-spec product	12.0%
		Analytical requirements	23.2%

Evaluation Criteria & Metrics Weighting Factors Continued

Criteria	Weighting Factors	Metrics	Weighting Factors
Economy	12.0%	TRL	10.1%
		Maturation of TRL	54.0%
		Number of unit operations	35.9%
Schedule (Speed)	11.4%	Development time prior to design	20.0%
		Time to complete design, construction, and hot startup	80.0%
Imperviousness to Risks	7.6%	Project risks	33.3%
		Operational execution risks	19.0%
		TRL related risks	47.6%
Primary Waste Form Compliance	19.0%	Primary waste form compliance	100%
Secondary Waste	11.4%	Quantity	25.0%
		Compatible with existing / draft disposal site WAC	75.0%
Regulatory Considerations	15.9%	Permitting/licensing complexity for new facilities & processes	25.0%
		Compliance with shipping regulations	75.0%
		Permitting/licensing complexity for disposal	25.0%
End State Decommissioning	3.5%	Complexity (includes residual inventory)	25.0%
		Waste volume	75.0%



Each Option Is Evaluated Using the Established Metrics Value Definitions

Criteria	Technical Maturity and Process Simplicity & Reliability				
Metrics	TRL	Maturation of TRL	Number of unit operations	Simplicity of Feed Start-up/shut down	Simplicity of control of unit operations
1 - Vitrification - Base Case	4	5	1	1	2
1c - Vit to IDF, Secondary to WCS	4	5	1	1	2
1d - Bulk Vitrification	3	5	2	4	3
1g - Bulk vit in large container to IDF, Secondary to WCS	3	5	2	4	3
2 - Grout - Base Case	4	5	5	5	5
2d - Grout with LDR pretreatment, Primary & Secondary to IDF	3	5	4	5	5
2e1 - Grout with LDR and Tc & I pretreatment to HLVit, Primary & Secondary to IDF	2	3	3	5	4
2e2 - Grout with LDR and Tc & I pretreatment to WCS, Primary & Secondary to IDF	2	3	3	5	4
2f - Grout with LDR and Sr pretreatment; Primary to WCS	2	4	3	5	4
2g2 - Grout with LDR pretreatment; Primary to WCS	3	5	4	5	5
3 - Steam Reforming - Base Case	3	5	2	3	3
3b - Steam Reforming to WCS, Secondary to WCS	3	5	2	3	3



Apply Weightings for Metrics & Criteria to Obtain Overall Rating for Each Option

Options Evaluated	Score (1 – 100)
2g2 - Grout with LDR pretreatment; Primary to WCS	87
2f - Grout with LDR and Sr pretreatment to HLVit, Primary to WCS	85
3b - Steam Reforming to WCS, Secondary to WCS	77
1c - Vit to IDF, Secondary to WCS	67
2d - Grout with LDR pretreatment, Primary & Secondary to IDF	67
2 - Grout - Base Case	65
1g - Bulk vit in large container to IDF, Secondary to WCS	63
2e2 - Grout with LDR and Tc & I Pretreatment to WCS, Primary & Secondary to IDF	63
2e1 - Grout with LDR and Tc & I Pretreatment to HLVit, Primary & Secondary to IDF	62
1 - Vitrification - Base Case	56
1d - Bulk Vitrification	55
3 - Steam Reforming - Base Case	53



Relative Comparison of Options on a Criterion Basis

Options	Technical Maturity and Process Simplicity & Reliability	Safety	Operational Flexibility	Economy	Schedule ("Speed")	Imperviousness to Risks	Primary Waste Form Compliance	Secondary Waste	Regulatory Considerations	End State Decommissioning
Relative Weight	5.9	5	8.3	12	11.4	7.6	19	11.4	15.9	3.5
2g2 - Grout with LDR pretreatment; Primary to WCS	5	2	7	8	8	7	19	11	15	4
2f - Grout with LDR and Sr pretreatment to HLVi, Primary to WCS	4	2	7	9	8	6	19	11	15	4
3b - Steam Reforming to WCS, Secondary to WCS	4	3	8	6	5	6	19	11	15	2
1c - Vit to IDF, Secondary to WCS	3	2	7	2	5	5	19	9	16	0
2d - Grout with LDR pretreatment, Primary & Secondary to IDF	5	4	7	11	8	6	0	11	10	4
2 - Grout - Base Case	6	4	6	12	9	6	0	11	8	4
1g - Bulk vit in large container to IDF, Secondary to WCS	4	2	8	4	6	4	9	9	15	2
2e2 - Grout with LDR and Tc & I Pretreatment to WCS, Primary & Secondary to IDF	4	3	7	10	8	5	0	11	12	3
2e1 - Grout with LDR and Tc & I Pretreatment to HLVi, Primary & Secondary to IDF	4	4	7	10	8	5	0	11	12	3
1 - Vitrification - Base Case	3	3	7	2	5	5	19	2	11	0
1d - Bulk Vitrification	4	3	8	4	6	4	9	4	10	2
3 - Steam Reforming - Base Case	4	4	8	7	5	6	0	9	10	2



Sensitivity Analysis – Relative Rankings if Criterion Weighting Factor = 30%

Options	Technical Maturity and Process Simplicity & Reliability	Safety	Operational Flexibility	Economy	Schedule ("Speed")	Imperviousness to Risks	Primary Waste Form Compliance	Secondary Waste	Regulatory Considerations	End State Decommissioning
2g2 - Grout with LDR pretreatment; Primary to WCS	87	77	86	82	82	88	89	89	87	89
2f - Grout with LDR and Sr pretreatment to HLViit, Primary to WCS	80	74	83	81	79	80	86	84	84	86
3b - Steam Reforming to WCS, Secondary to WCS	70	70	76	67	66	74	78	77	77	67
1c - Vit to IDF, Secondary to WCS	55	56	63	49	54	60	67	61	67	45
2d - Grout with LDR pretreatment, Primary & Secondary to IDF	80	76	79	81	75	79	60	82	74	82
2 - Grout - Base Case	81	79	75	81	76	77	59	81	70	81
1g - Bulk vit in large container to IDF, Secondary to WCS	64	60	70	57	60	61	60	65	69	60
2e2 - Grout with LDR and Tc & I Pretreatment to WCS, Primary & Secondary to IDF	68	68	72	71	69	69	53	74	70	70
2e1 - Grout with LDR and Tc & I Pretreatment to HLViit, Primary & Secondary to IDF	67	69	72	70	68	67	53	74	70	70
1 - Vitrification - Base Case	49	51	56	43	48	53	61	43	54	39
1d - Bulk Vitrification	59	56	65	52	55	57	55	52	58	55
3 - Steam Reforming - Base Case	60	62	66	59	56	62	46	63	60	57



Sensitivity Analysis – Relative Rankings if Criterion Weighting Factor = 70%

Options	Technical Maturity and Process Simplicity & Reliability	Safety	Operational Flexibility	Economy	Schedule ("Speed")	Imperviousness to Risks	Primary Waste Form Compliance	Secondary Waste	Regulatory Considerations	End State Decommissioning
2g2 - Grout with LDR pretreatment; Primary to WCS	90	61	87	74	75	92	95	95	90	95
2f - Grout with LDR and Sr pretreatment to HLvit, Primary to WCS	76	60	86	79	74	77	94	90	89	94
3b - Steam Reforming to WCS, Secondary to WCS	66	64	84	57	54	76	91	87	86	57
1c - Vit to IDF, Secondary to WCS	49	53	72	32	46	64	86	69	86	19
2d - Grout with LDR pretreatment, Primary & Secondary to IDF	87	74	84	89	72	83	26	92	68	92
2 - Grout - Base Case	91	84	73	90	75	79	25	92	58	92
1g - Bulk vit in large container to IDF, Secondary to WCS	67	54	84	45	54	59	54	71	82	54
2e2 - Grout with LDR and Tc & I Pretreatment to WCS, Primary & Secondary to IDF	66	67	80	75	69	70	23	85	75	73
2e1 - Grout with LDR and Tc & I Pretreatment to HLvit, Primary & Secondary to IDF	66	71	79	75	69	65	23	85	75	73
1 - Vittrification - Base Case	47	54	70	29	43	61	83	29	64	17
1d - Bulk Vittrification	65	56	82	43	52	57	52	44	61	52
3 - Steam Reforming - Base Case	62	68	80	59	50	69	20	70	62	53



Summary and Next Steps

Bill Bates

FFRDC Team Lead

Deputy Associate Laboratory Director

SRNL Nuclear Materials Management Programs Directorate

NAS Committee Meeting #3

July 23 and July 24, 2018

Richland, WA

Pre-Decisional

Summary and Next Steps

- **Team Review and Analysis May 1-3, 2018**
- **Report Drafted and Maturing**
 - Drafting helped reveal areas requiring maturation
- **Next Steps**
 - Collect Meeting #3 Feedback
 - Await NAS Report #2
 - Mature Cases, Risks, and Estimates
 - Prepare Final Draft Report – Late October

