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NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview

Bill Bates

FFRDC Team Lead

Deputy Associate Laboratory Director

SRNL Nuclear Materials Management Programs Directorate

NAS Committee Meeting #2

February 28 and March 1, 2018

Richland, WA

Pre-Decisional



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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 It is important for readers to understand that much of what is presented in these working draft documents has not been peer reviewed and is not intended to imply any final conclusions or represent a complete analysis.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 spring and summer of 2018. 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). Slides will be presented at the NAS Public Meeting #2 in Richland, WA on February 28 and March 1, 2018. These slides provide an overview of the working draft information included in the documents described above. The slides also have not undergone technical peer review and are considered working drafts on the subject matter presented.

Bill Bates
FFRDC Team Lead

- **2017 NDAA Section 3134 Analysis of Approaches for Supplemental Treatment of Low Activity Waste at Hanford Nuclear Reservation**
 - Analyze Treatment Approaches
 - *Further Removal of long lived constituents (i.e. ^{99}Tc , ^{129}I)*
 - *Vitrification, Grouting, Steam Reforming and Other identified alternatives*
 - Further Analysis
 - *Risks*
 - *Cost/Benefit/Estimate/Schedule*
 - *Regulatory Compliance*
 - *Obstacles inhibiting pursuit of options*
- **Status**
 - All slides are considered Working – Draft
 - Peer Review has not been completed (pending)

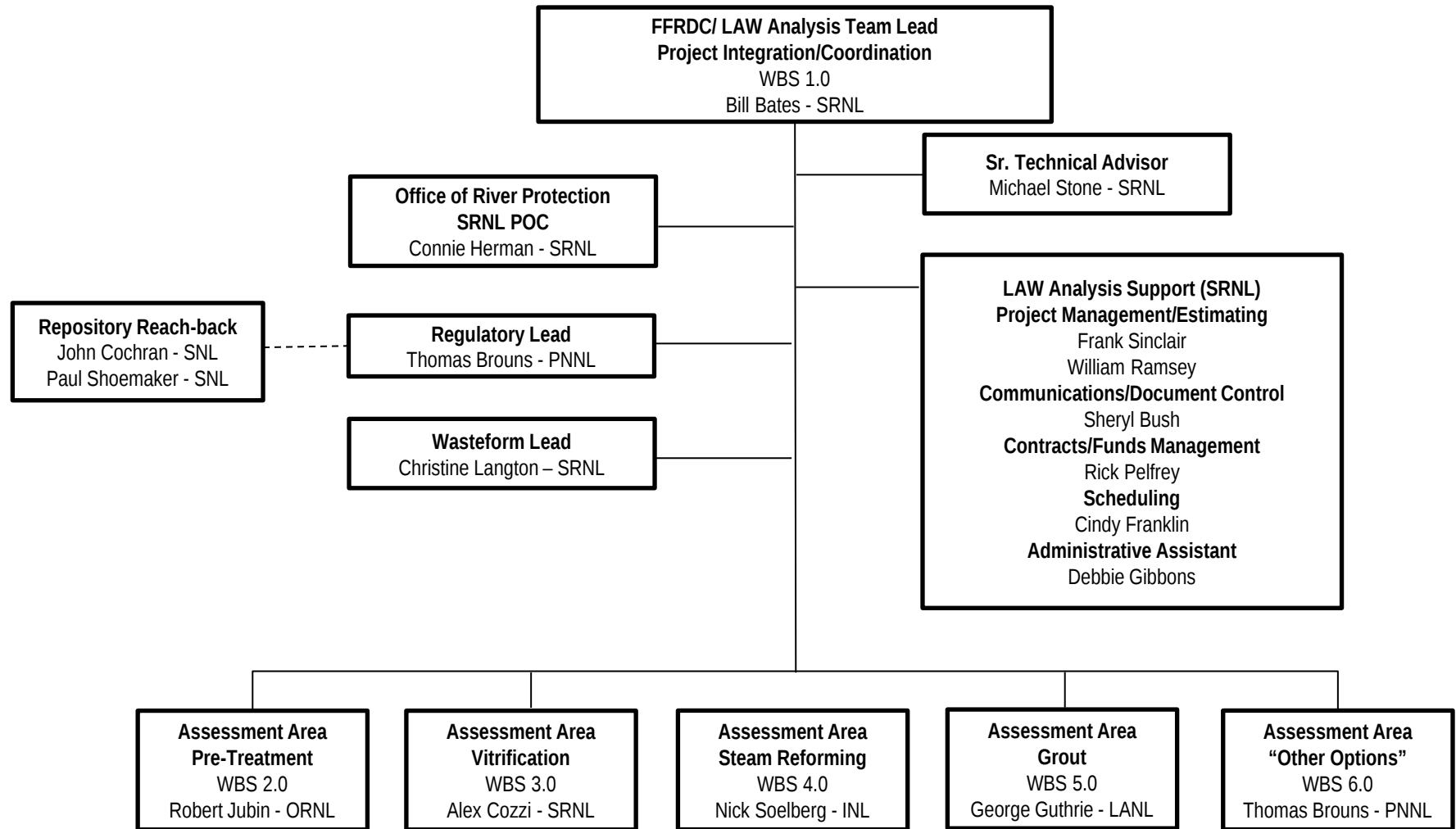


FFRDC Team Overview

- **FFRDC – Federally Funded Research and Development Center**
 - 42 in the US (see National Science Foundation (NSF) website)
 - Defined per 49 CFR 35.017
 - *Recertified and Approved by Secretary of Energy at least every 5 years*
 - “FFRDCs, such as DOE’s National Laboratories, are sponsored and funded by the United States Government to meet special long-term research or development needs that cannot be met effectively in-house or by contractors.”
 - “Required to conduct its business in a manner befitting its special relationship with the Government, to operate in the public interest with objectivity and independence, to be free from organizational conflicts of interest, and to have full disclosure of its affairs to the sponsoring agency.”
- **EMNLN – Environmental Management National Laboratory Network**
 - Sponsored/Chartered by EM National Lab Policy Office and EM-1
 - SRNL – Savannah River National Laboratory
 - PNNL – Pacific Northwest National Laboratory
 - ORNL – Oak Ridge National Laboratory
 - INL – Idaho National Laboratory
 - LANL – Los Alamos National Laboratory
 - SNL – Sandia National Laboratories



FFRDC Team Organization and Work Breakdown Structure (WBS)

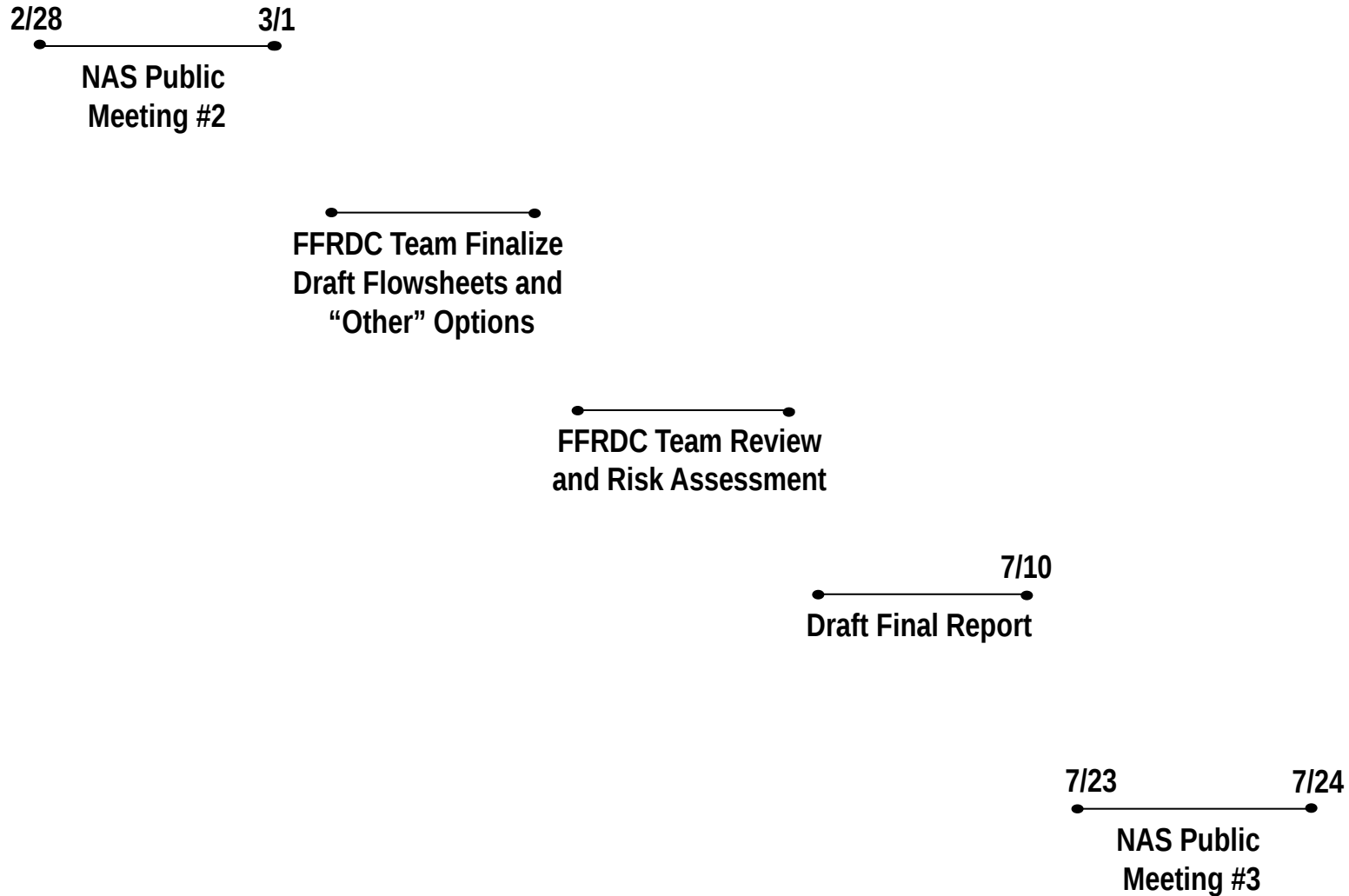


FFRDC Team Agenda

- **Near-Term Schedule Overview – Bill Bates**
- **WTP Baseline Process and Supplemental LAW Feed Vector Overview – Michael Stone**
- **Vitrification Flowsheets and Wasteforms – Alex Cozzi**
- **Grout Flowsheets and Wasteforms – George Guthrie**
- **Fluidized Bed Steam Reforming Flowsheets and Wasteforms – Nick Soelberg**
- **Other Technologies Considered – Tom Brouns**
- **Disposal Facilities Overview, Waste Acceptance Criteria, and Transportation – John Cochran**
- **Alternatives Analysis Approach – Tom Brouns**
- **Cost Estimating Methodology – Frank Sinclair**
- **Summary and Next Steps – Bill Bates**



Near Term Schedule Overview





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WTP Baseline Process and Supplemental LAW Feed Vector Overview

Michael Stone

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SRNL Environmental Stewardship Directorate

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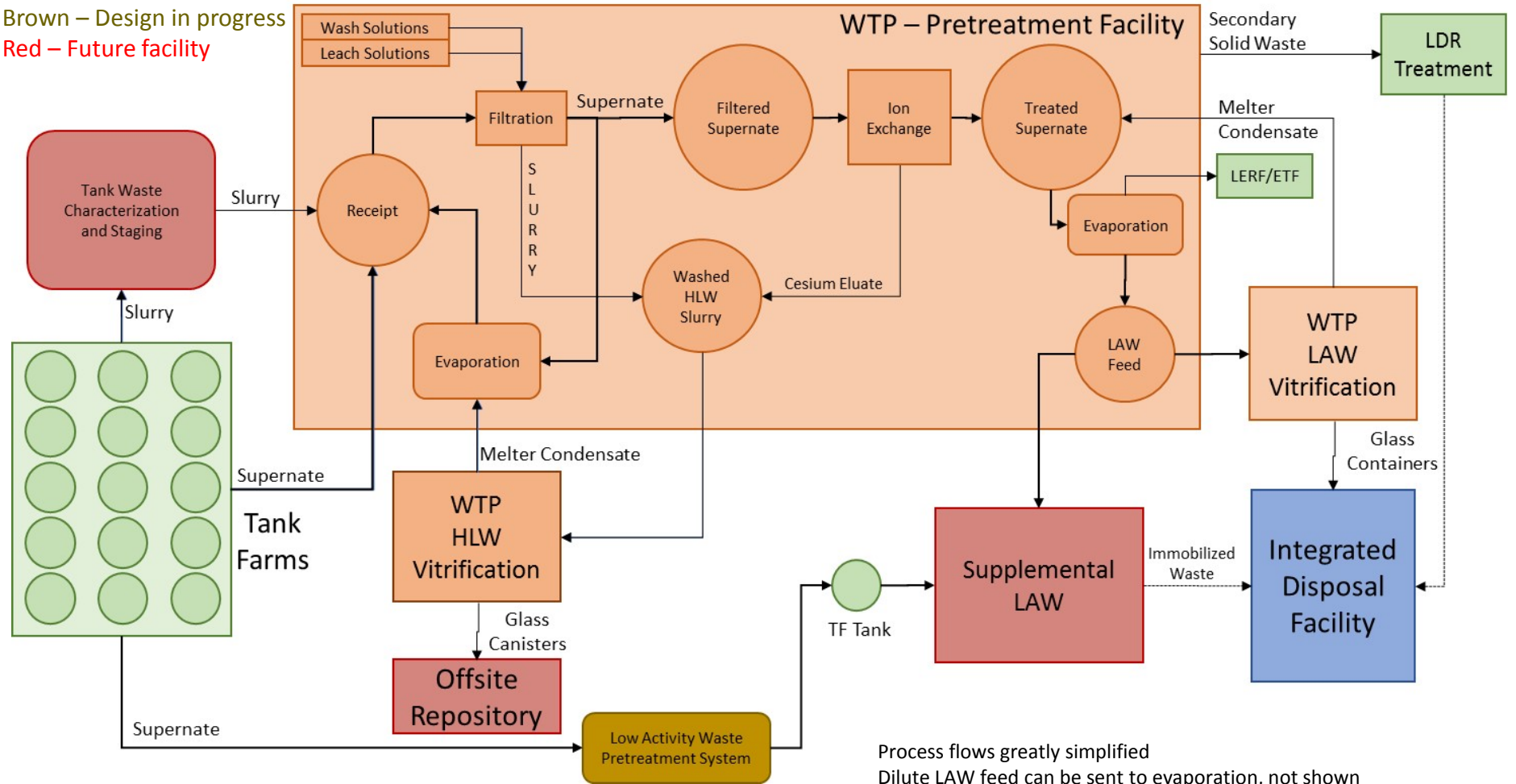
- **Definitions**
- **One System Integrated Flowsheet Overview**
- **WTP Baseline Process in Integrated Flowsheet**
- **Supplemental LAW Description in Integrated Flowsheet**
- **Feed Vector Overview**
 - Assumptions
 - Data Review
- **Uncertainties**
- **Challenges**

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 baseline process
- **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

WTP Baseline Process as Defined in Integrated Flowsheet

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



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

Direct feed options not shown

One System Integrated Flowsheet – Why use it?

- **Integrated Flowsheet is the only current estimate of the feed vector for Supplemental LAW**
 - System Plan 8 used as input
 - “Best Available Data”
- **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.



- **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*



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**

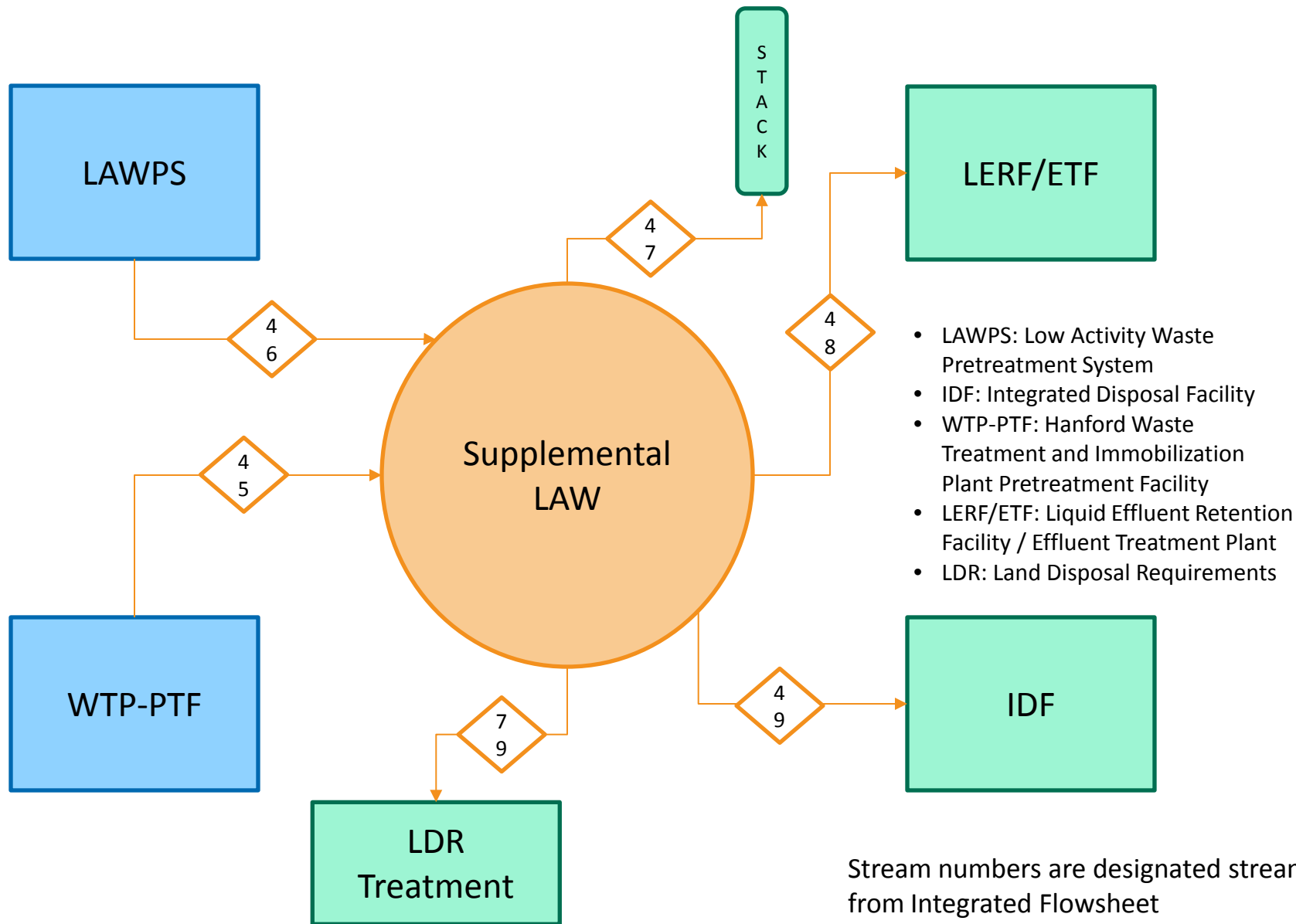
- Integrated flowsheet operates to optimize HLW canister production rate
- LAW generated from HLW processing (concentration, washing, leaching, melter condensate recycle, etc.) is greater than LAW vitrification facility capacity when added to the LAW processed as needed to complete mission at same time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

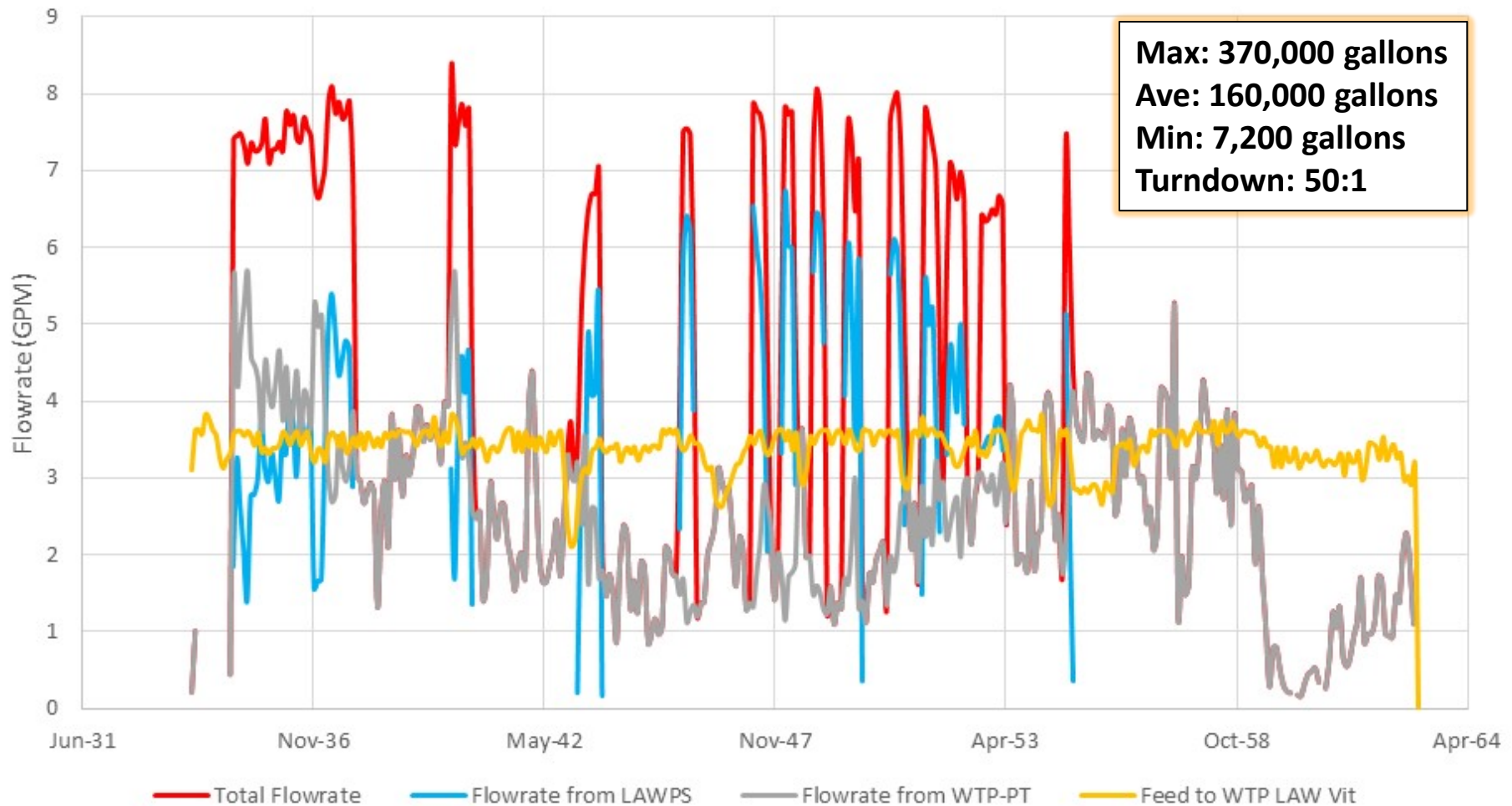


Integrated Flowsheet: Baseline Process Flows to/from Supplemental LAW

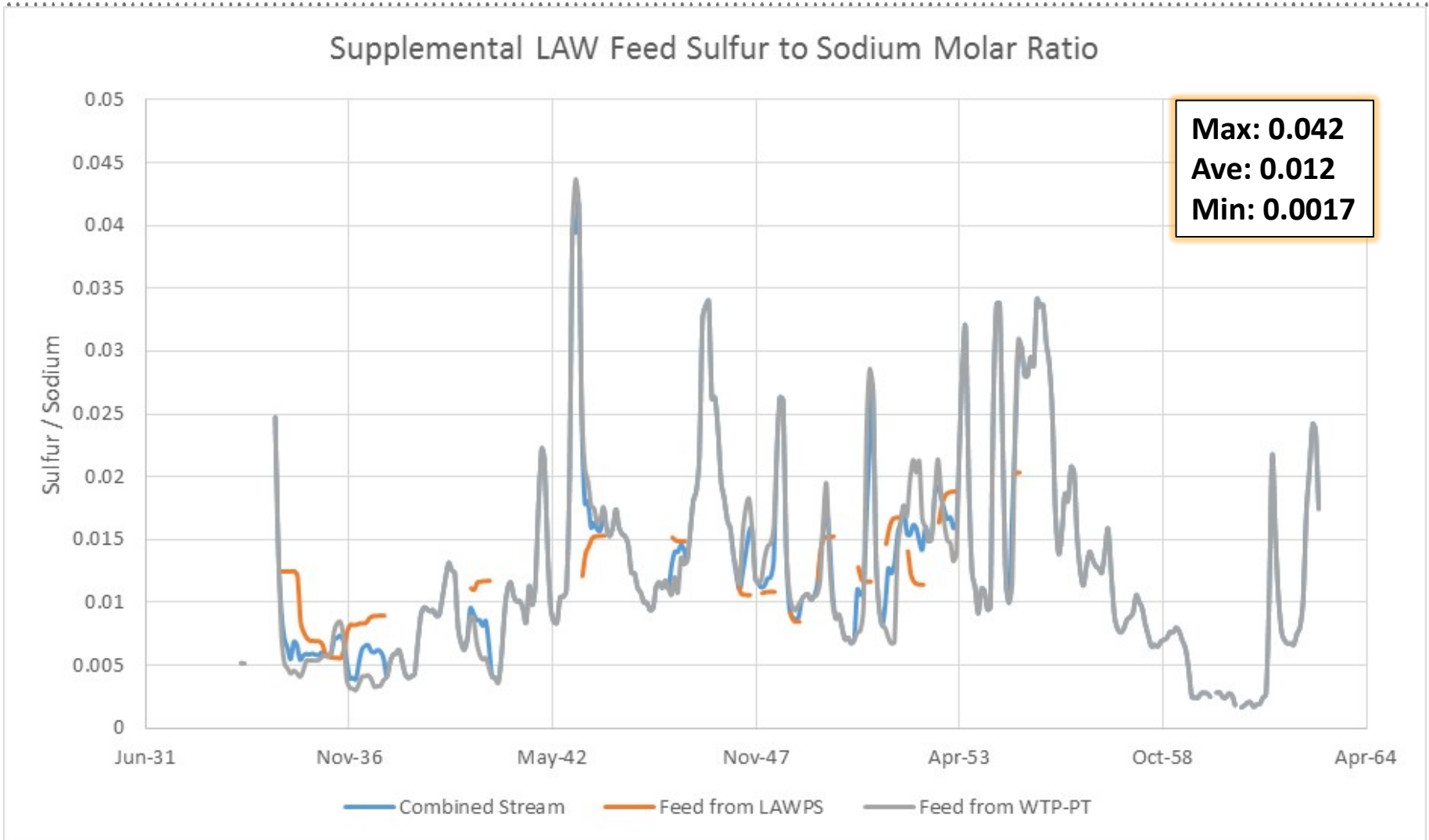


Feed Vector: Flowrates

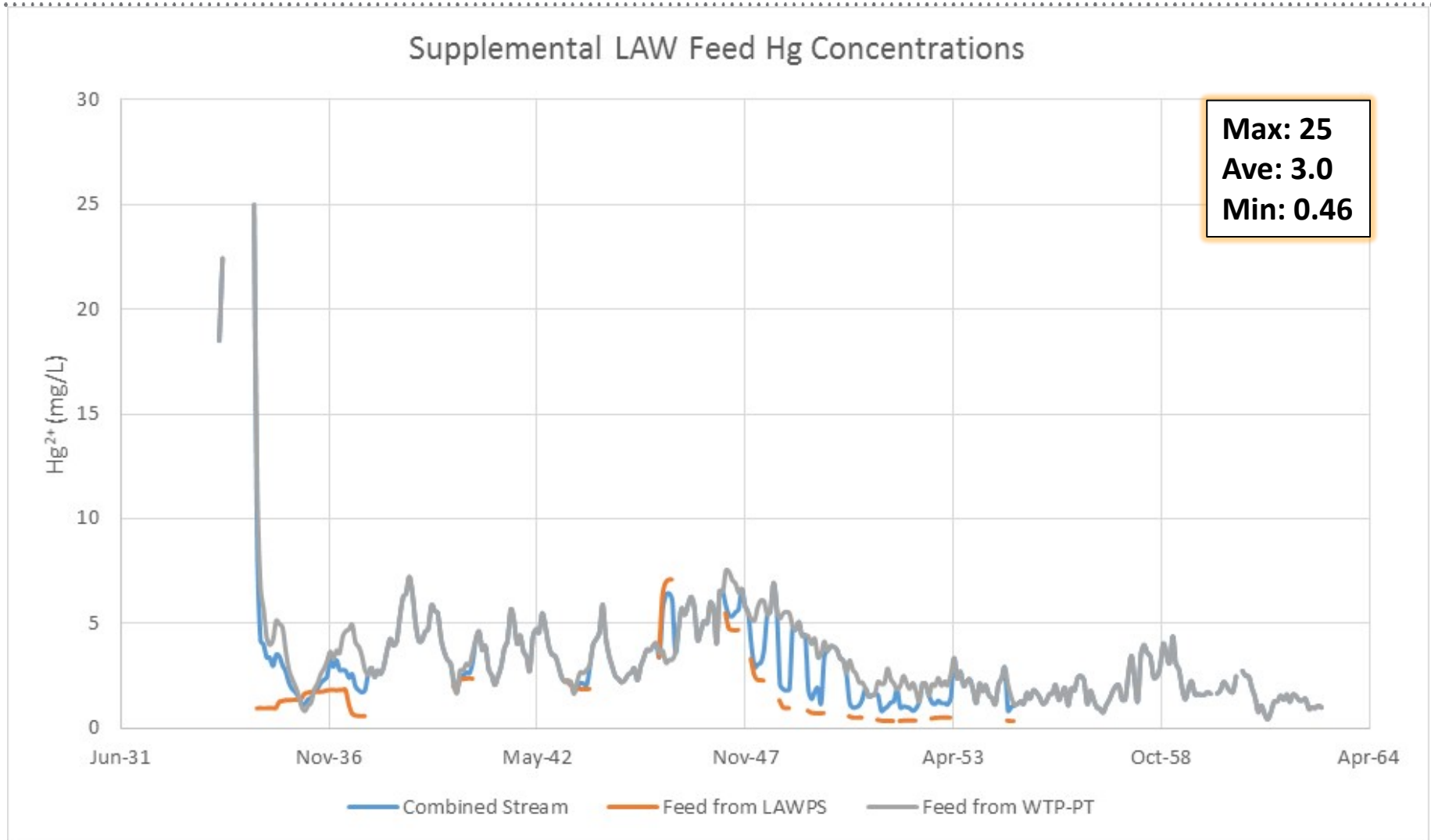
Average Monthly Volumetric Flows to Supplemental LAW



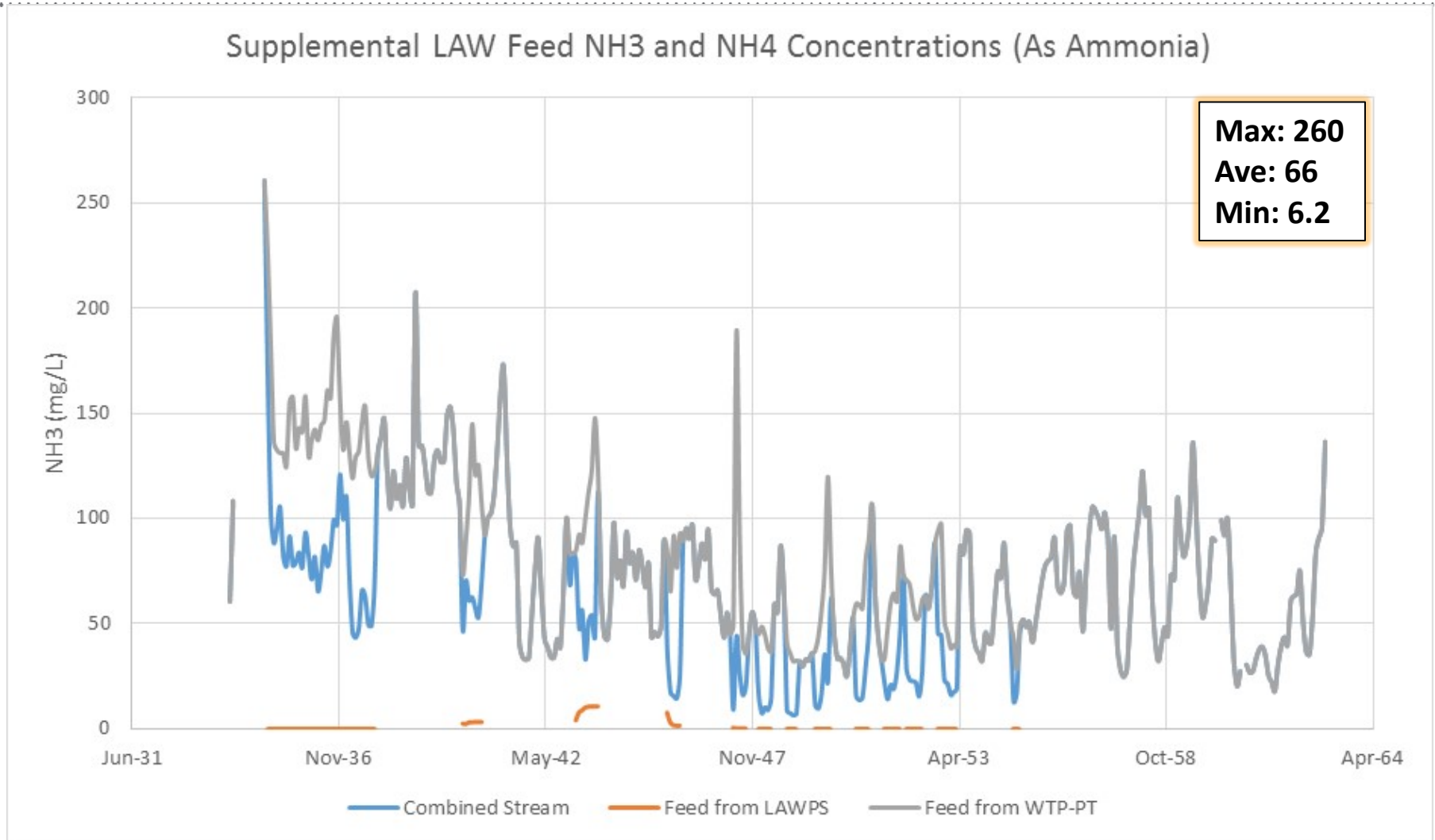
Feed Vector: Sulfur to Sodium Ratio



Feed Vector: Mercury Concentrations

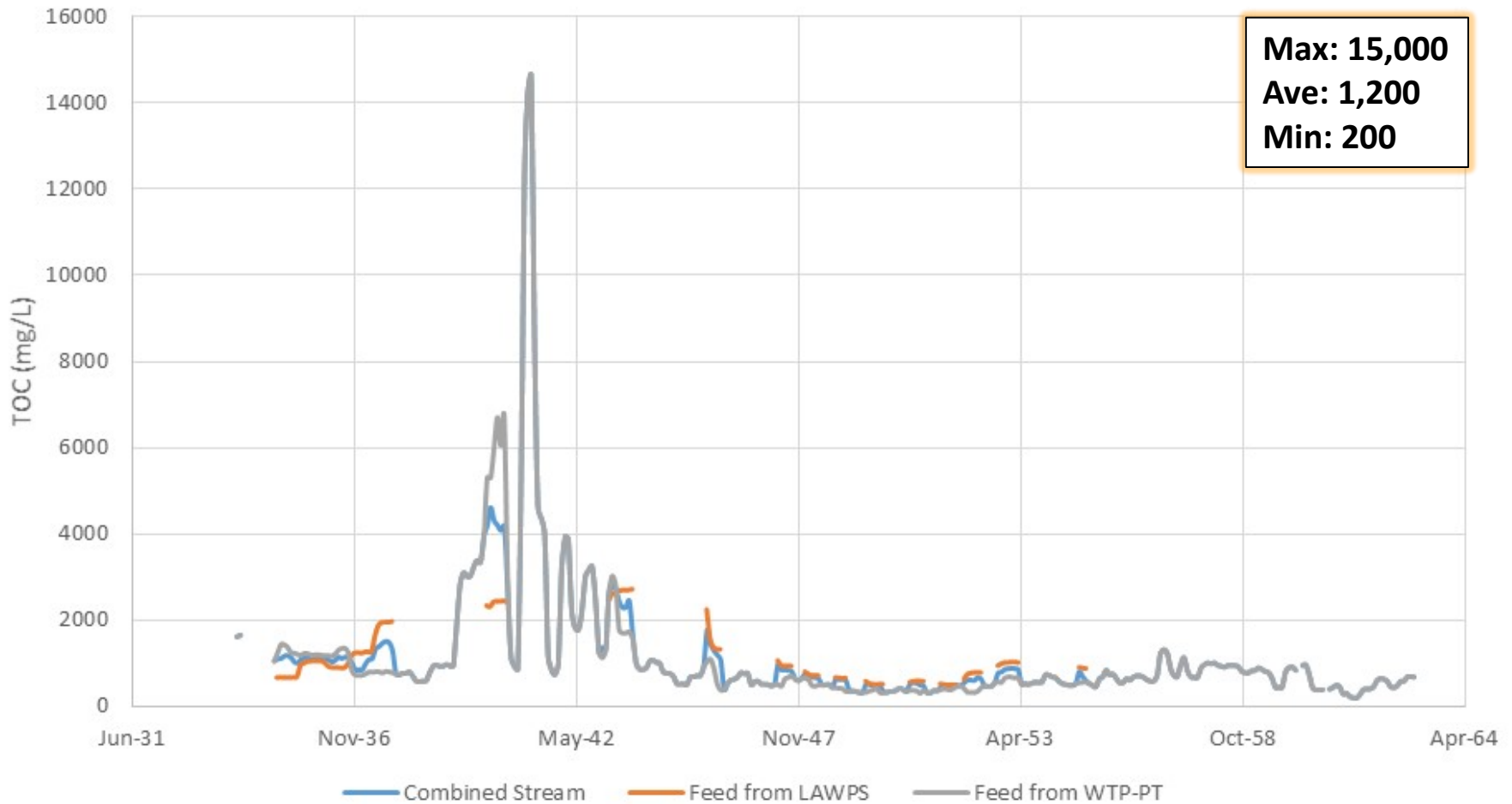


Feed Vector: Ammonia Concentrations



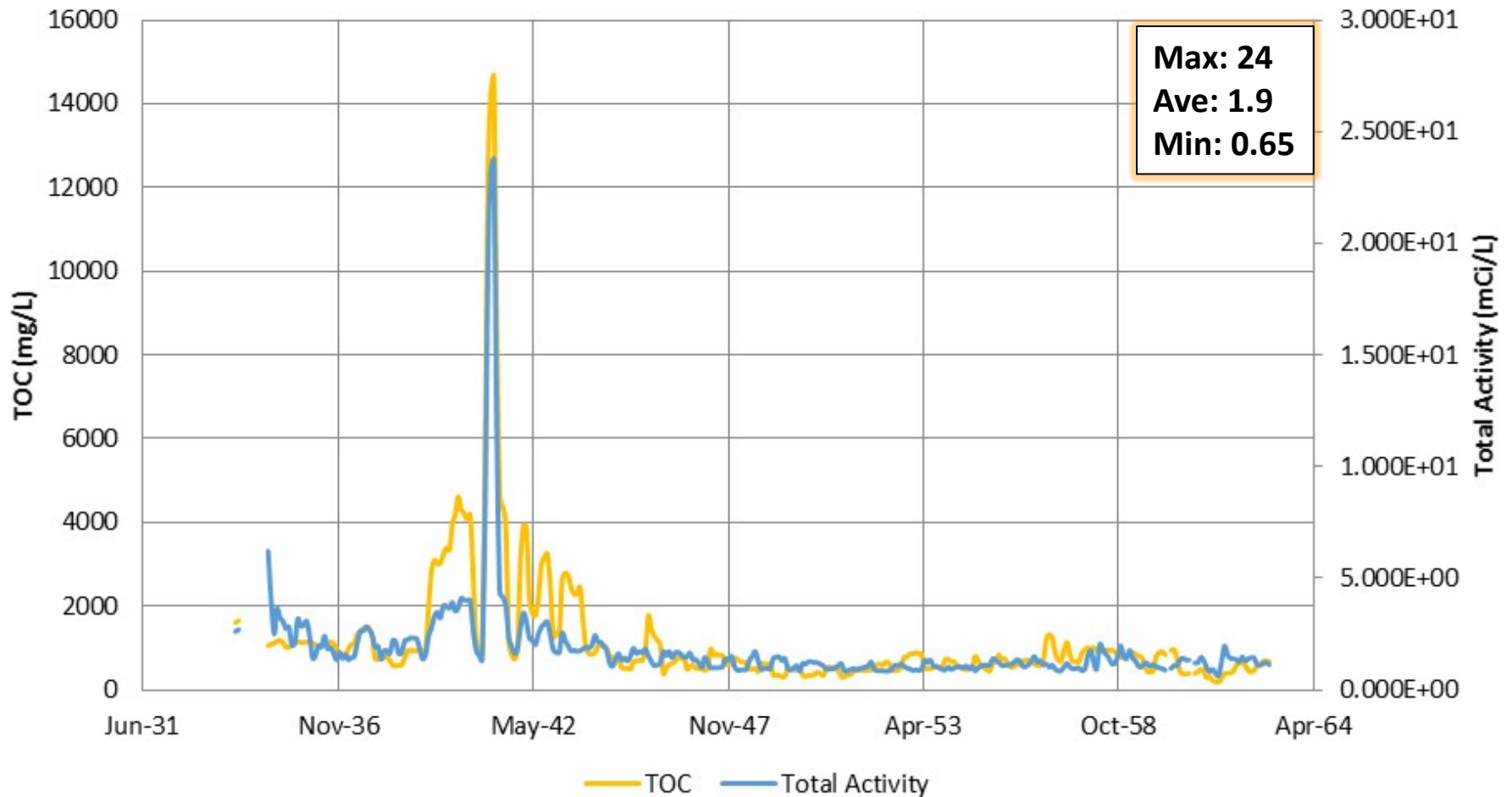
Feed Vector: Total Organic Carbon Concentrations

Supplemental LAW Feed TOC Concentrations



Feed Vector: Total Activity per Liter

Supplemental LAW Feed Total Activity



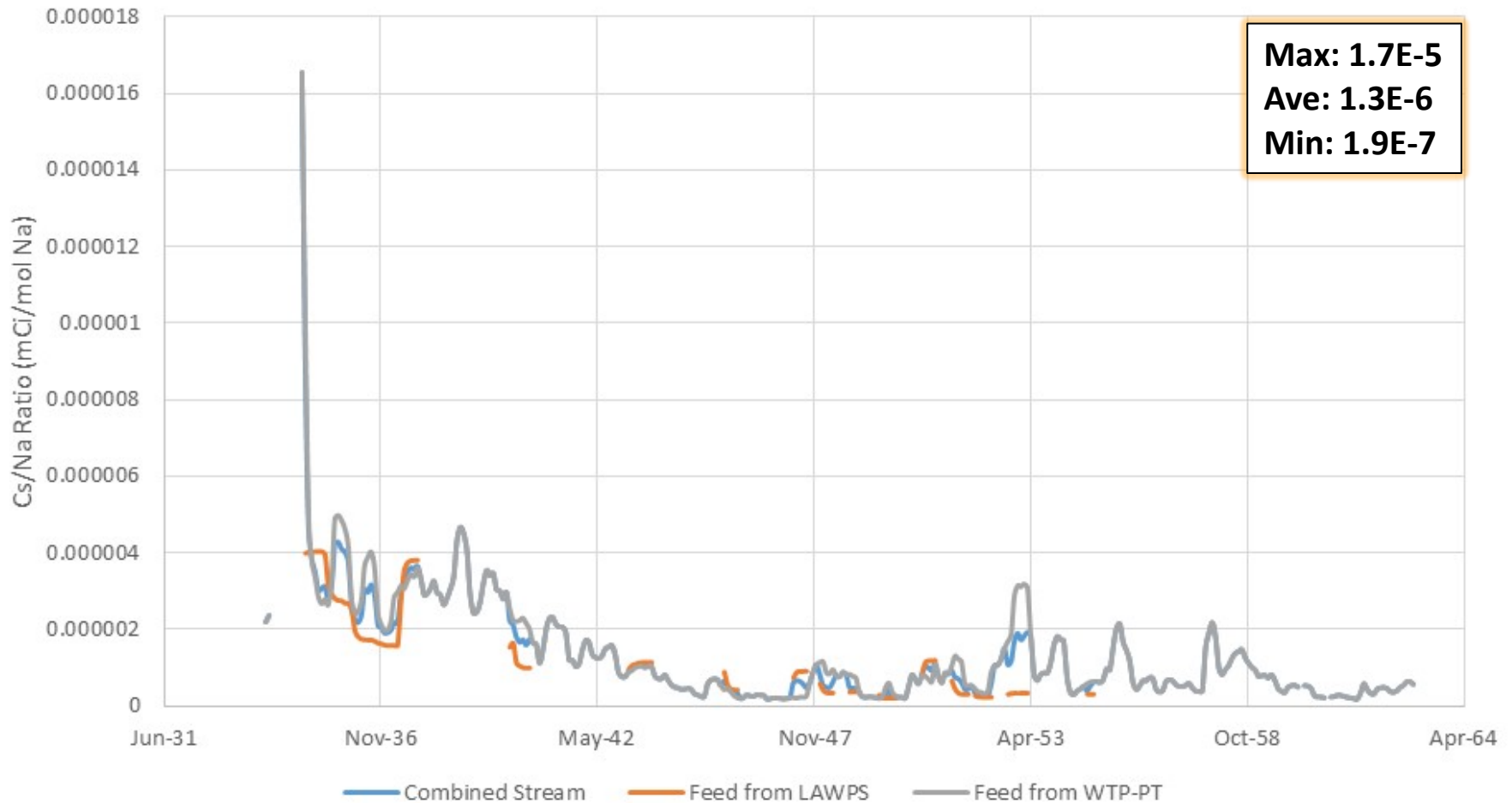
Feed Vector: Technetium-99 Concentrations

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.



- **Feed Vector**
 - Composition Uncertainty
 - *Described above*
 - *Entire tank farm feed is processed, so feed vector should allow a reasonable comparison between technologies to be made*
 - Volume Uncertainty
 - *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*
- **IDF Performance Assessment**
 - Still in draft form, but nearly finalized
- **Cost Estimation**
 - Comparison of costs between sites is challenging
 - *Different regulatory environment, etc.*



- **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 project

Conclusions

- **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*





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NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview

Alex Cozzi

Vitrification Lead

Manager, Immobilization Technology Group
SRNL Environmental Stewardship Directorate

*NAS Committee Meeting #2
February 28 - March 1, 2018*

Pre-Decisional

Vitrification Baseline and Options

1. “Traditional” Joule-Heated Ceramic-Lined Melter

WTP LAW (First LAW) – Two Melter Facility used as framework for baseline and options

- Baseline – Four WTP LAW melters based on ORP-11242 Revision 8
 - Resized vessels and modified primary offgas system
 - Additional EMF (2x WTP size)
- Option 1 – Two Next Generation Melters (NGM)
 - Similar design to WTP LAW
- Option 2 – Option 1 with Alternative Container Design

2. In Container Vitrification™ (Bulk Vitrification) Based on RPP-24544 Revision 1D

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

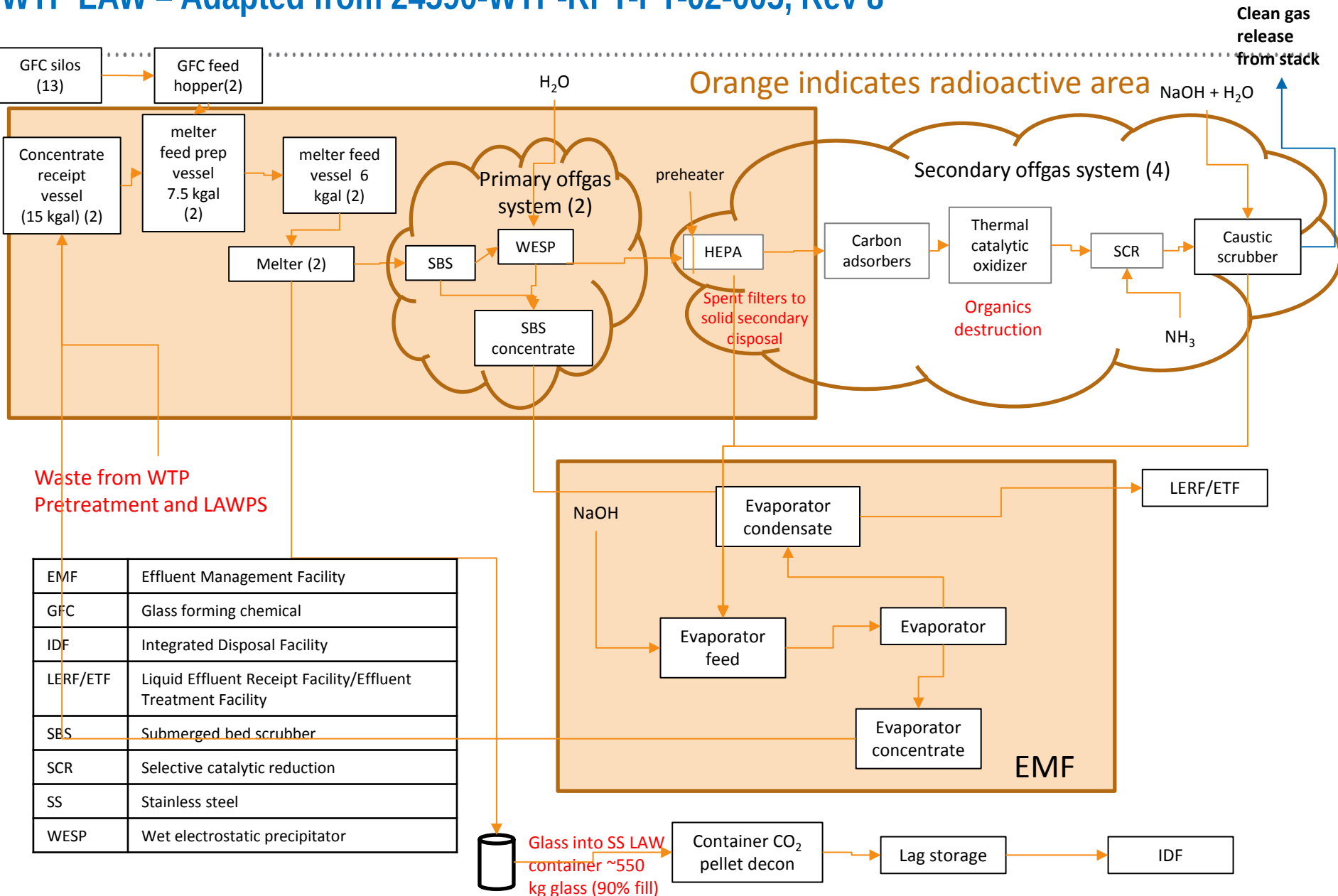


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WTP LAW – Adapted from 24590-WTP-RPT-PT-02-005, Rev 8

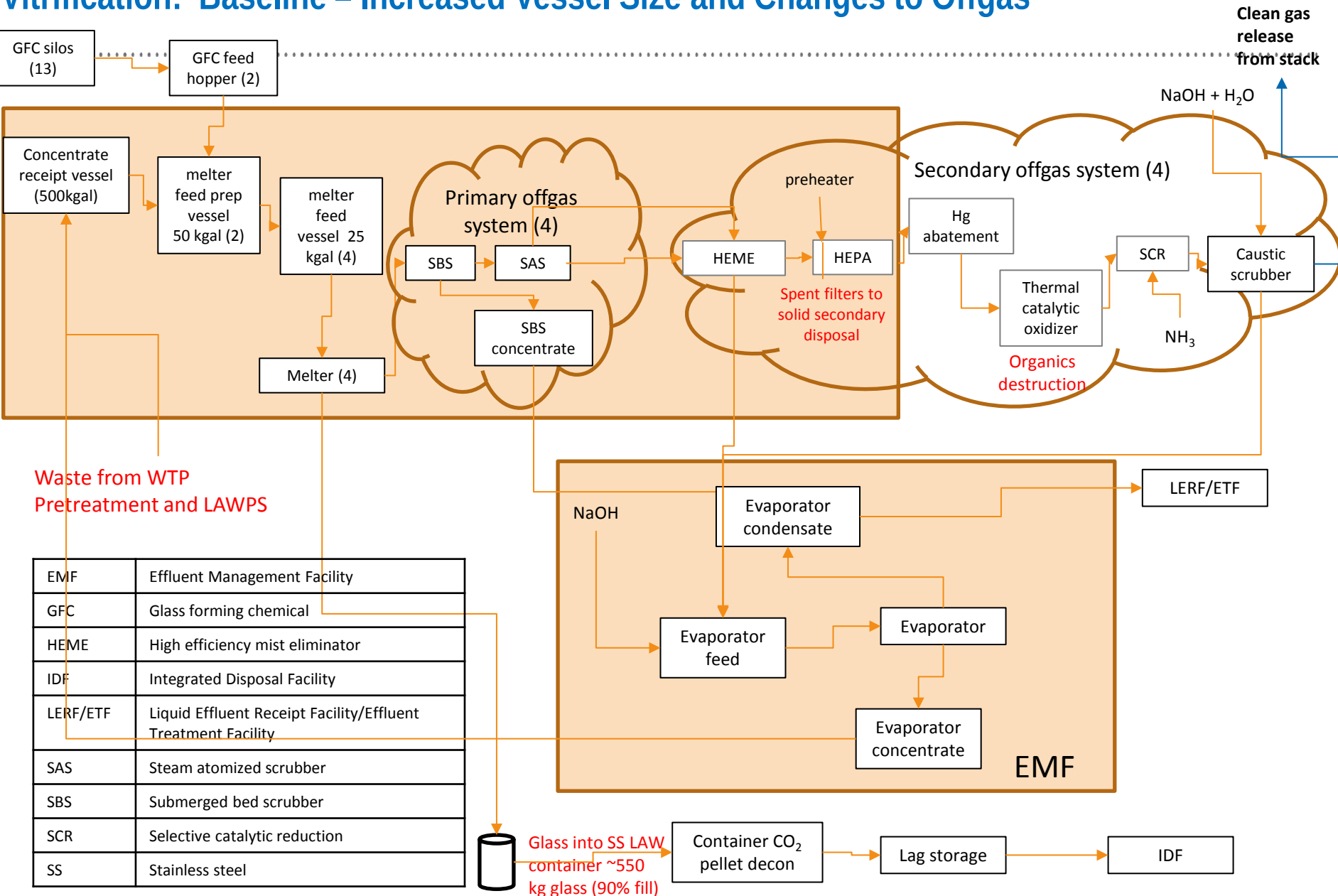


Waste from WTP Pretreatment and LAWPS

EMF	Effluent Management Facility
GFC	Glass forming chemical
IDF	Integrated Disposal Facility
LERF/ETF	Liquid Effluent Receipt Facility/Effluent Treatment Facility
SBS	Submerged bed scrubber
SCR	Selective catalytic reduction
SS	Stainless steel
WESP	Wet electrostatic precipitator



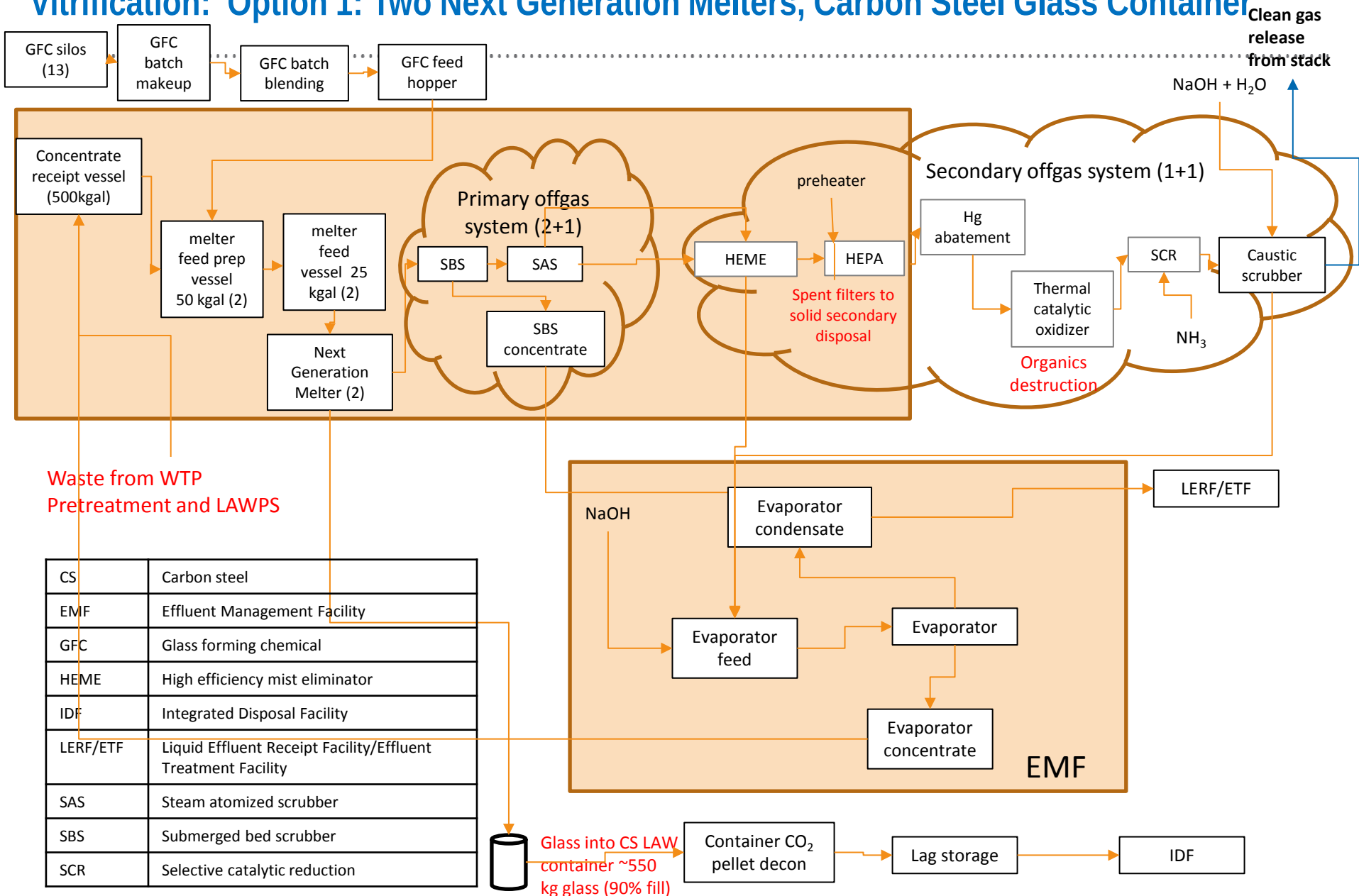
Vitrification: Baseline – Increased Vessel Size and Changes to Offgas



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

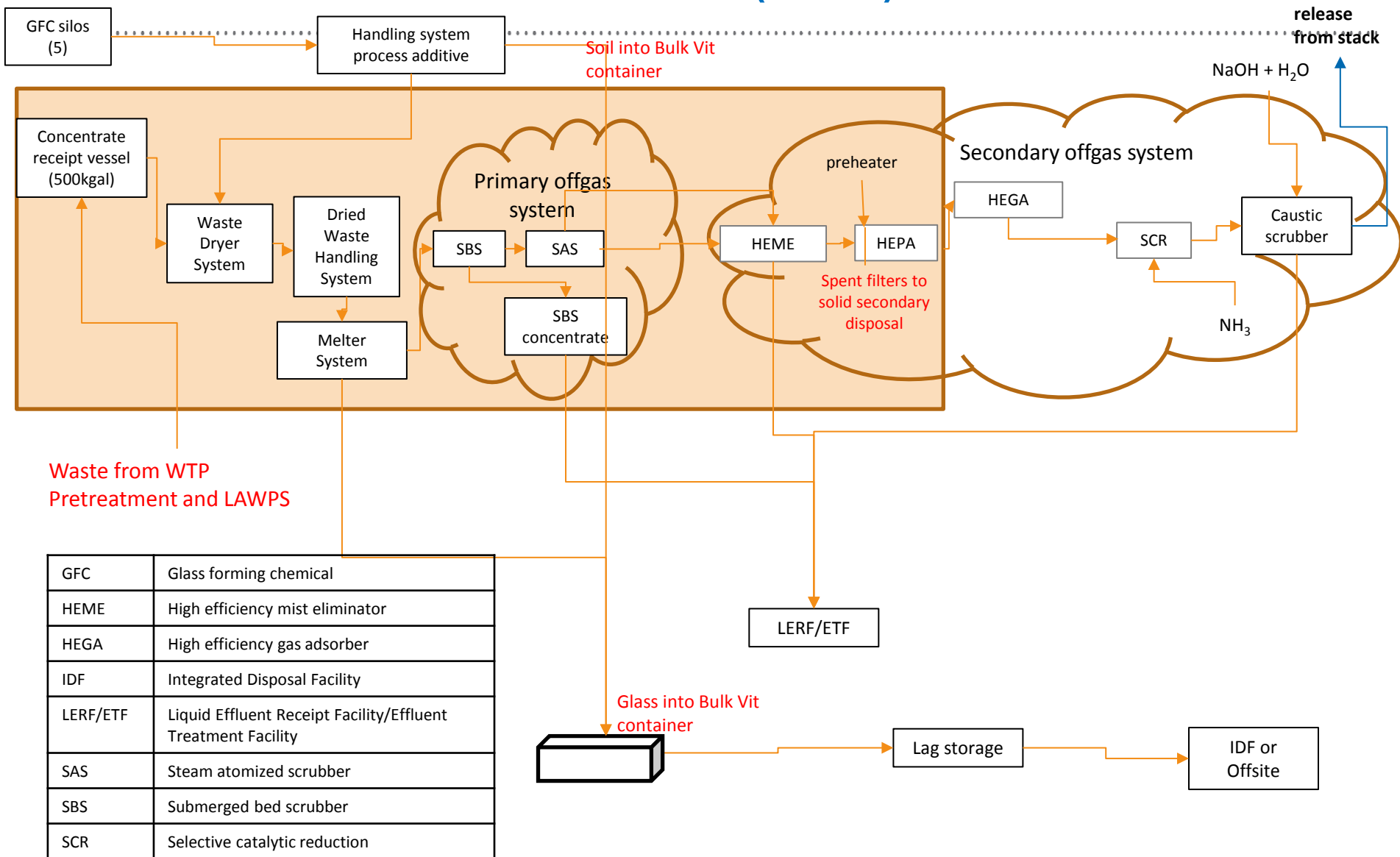


Clean gas release from stack



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

Vitrification: In Container Vitrification™ (Bulk Vit)



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
- NGM Medium
- Needs to incorporate modifications
- ICV™ TRL Medium
- Demonstrated in limited testing

Common to all flowsheets

- Off-gas system TRL high
- 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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Grout Flowsheets and Wasteforms

George Guthrie

Grout Lead

Program Manager for Fossil & Geothermal Energies
Los Alamos National Laboratory

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Pre-Decisional

- **Background**
 - Grout waste forms
 - Other applications of grout to LAW
 - Comparison between SRS LAW and Hanford LAW as relevant to grout
- **Process Flow Diagrams**
- **Key Information and Data Under Consideration**



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 ≤ 1.8
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)

SRS Saltstone (1991 to present)

10 wt% Type I/II Portland cement
45 wt% Blast furnace slag
45 wt% Class F fly ash
Water : Dry-Blend 0.58 to 0.6
Na molarity ~ 5 to 6

Hanford Cast Stone (laboratory testing)

8 wt% Type I/II Portland cement
47 wt% Blast furnace slag
45 wt% Class F fly ash
Water : Dry-Blend 0.35 to 0.60
Na molarity ~ 5.8 to 9.1 (7.4 ave)



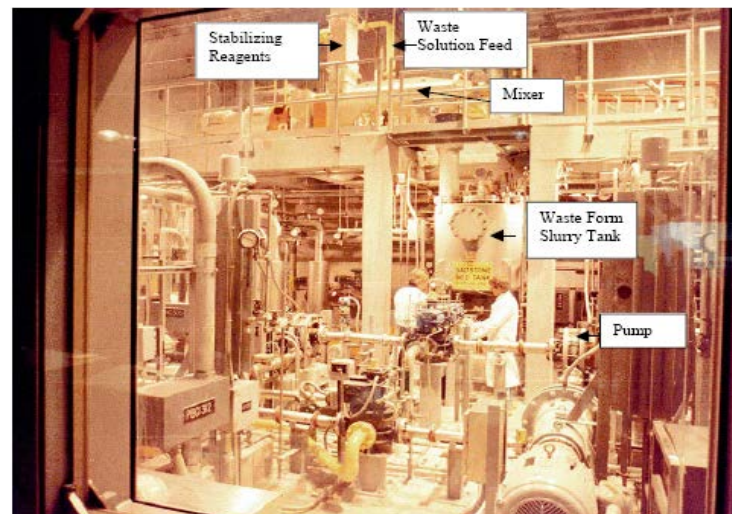
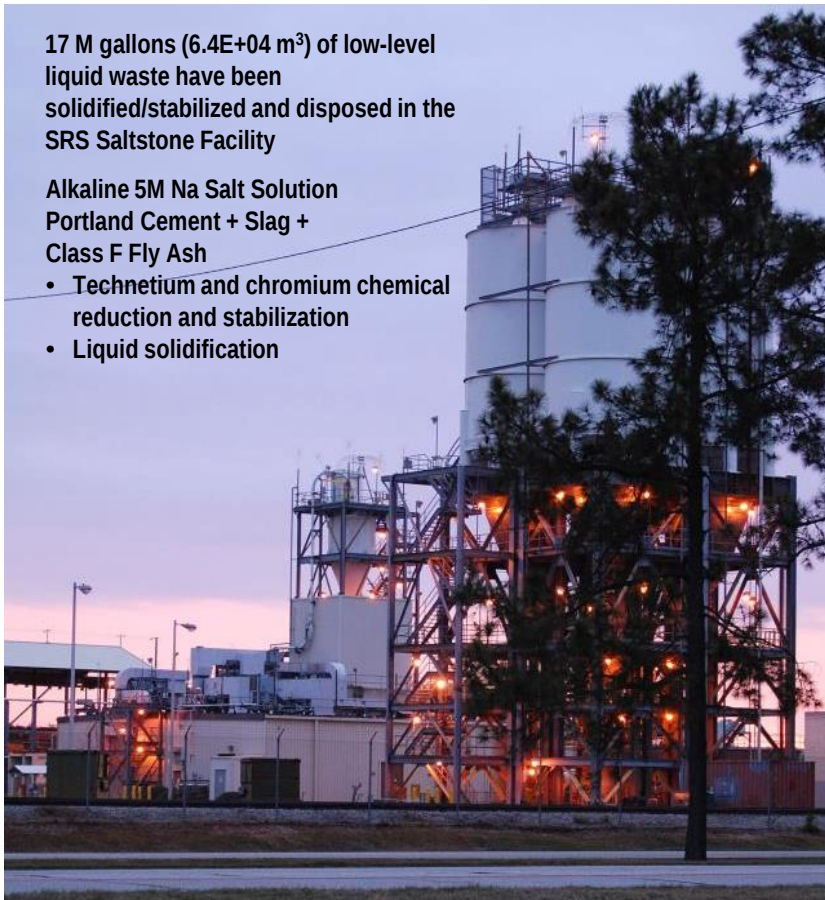
Savannah River Site's (SRS) Saltstone Process: SLAW Cast Stone Analogue

Saltstone Processing and Disposal Facilities

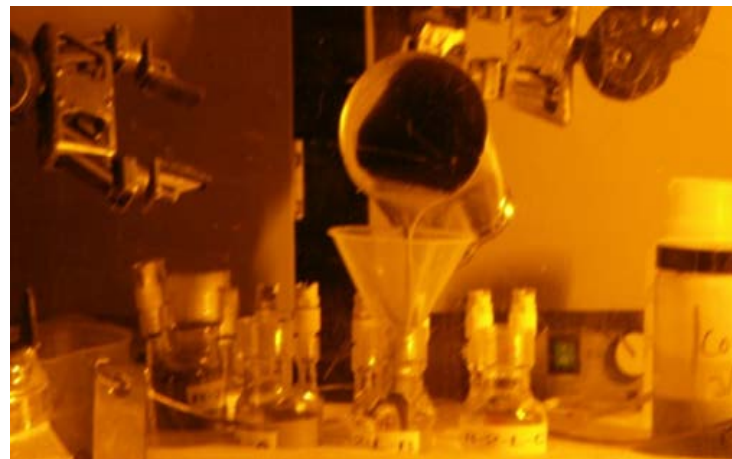
17 M gallons ($6.4 \times 10^4 \text{ m}^3$) of low-level liquid waste have been solidified/stabilized and disposed in the SRS Saltstone Facility

Alkaline 5M Na Salt Solution
Portland Cement + Slag +
Class F Fly Ash

- Technetium and chromium chemical reduction and stabilization
- Liquid solidification



Saltstone Processing Room



Saltstone TCLP Sample Preparation



Saltstone Disposal Units (SDUs)

- Reinforced Concrete units - rectangular and circular cross sections
- Large volume forms for grout placement
- Engineered Barriers



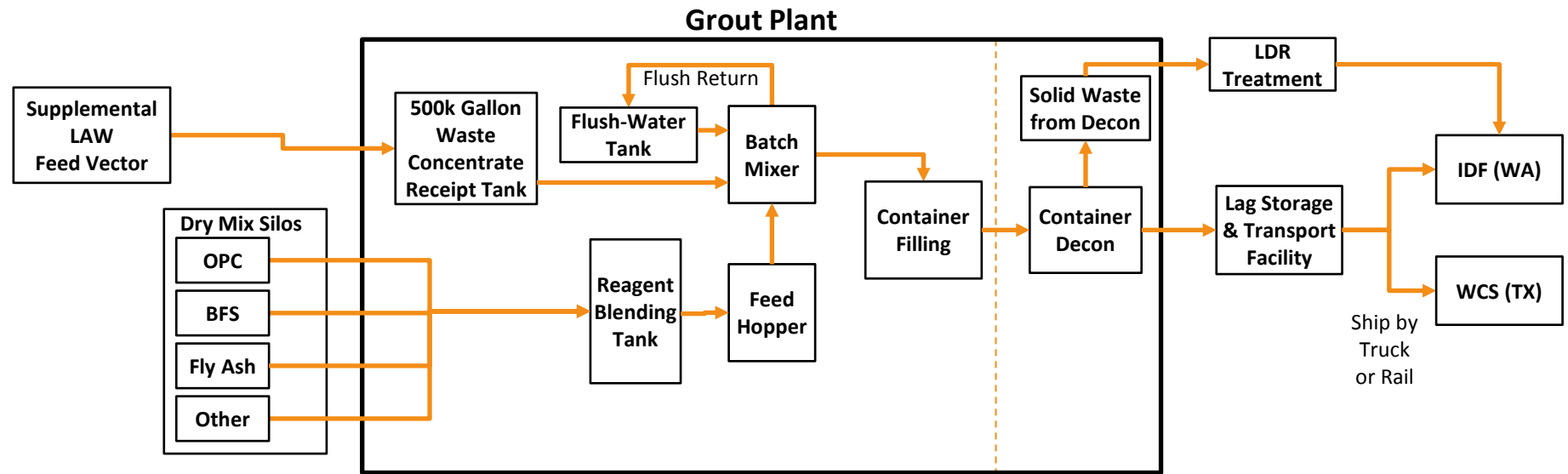
Comparison of SRS and Hanford LAW Grout Waste Forms

Waste Form	Pretreatment	Solution feed rate	Grout Production Rate	Molarity of Na in Feed	Reagents	Volume Factor	Fresh Grout	Disposal	Permitting
SRS Saltstone (Nominal values used for compliance modeling)	ARP/MCU for caustics and actinide / solids removal	Current 80 gal/m 35,000 gal/d 2M gal/y	130 gal/m	5–6	Portland cement, slag, class F fly ash (10:45:45 by weight)	1.6–1.7	Pumped 1500–1800 ft through -in C steel line	On-site disposal in reinforced concrete disposal units (SDUs) 1.7 to 32 M gal capacity	<i>Grout Technology:</i> Process Specific Treatment Standard for SRS decontaminated tank waste (SCDHEC) <i>Feed:</i> Characteristically Hazardous Radioactive Liquid Waste <i>Processing Facility:</i> Industrial Waste Water Treatment Facility (SCDHEC) <i>Saltstone:</i> “Decharacterized” LL Solid Waste <i>Disposal Facility:</i> Class 3 Industrial Solid Waste Landfill (SCDHEC)
SLAW Cast Stone	WTP-PT & LAWPS; additional TBD	From feed vector 8.3 gal/m (max) 3.6 gal/m (ave) (continuous)	From feed vector ~6-7 gal/m (ave) (continuous; actual TBD)	From feed vector Supernate 5.8 to 9.1M ~7.4M (ave)	Portland cement, slag, class F fly ash (10:45:45 by weight) Getters?	≤1.8	(a) Direct discharge into transportable container (b) Pumped into disposal unit at or near IDF	<i>Base Case & Option I:</i> Transportable containers to IDF or to WCS <i>Base Case & Option II:</i> Large containers in place	Tom Brouns’s Presentation



Base-Case SLAW Cast Stone Flowsheet

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

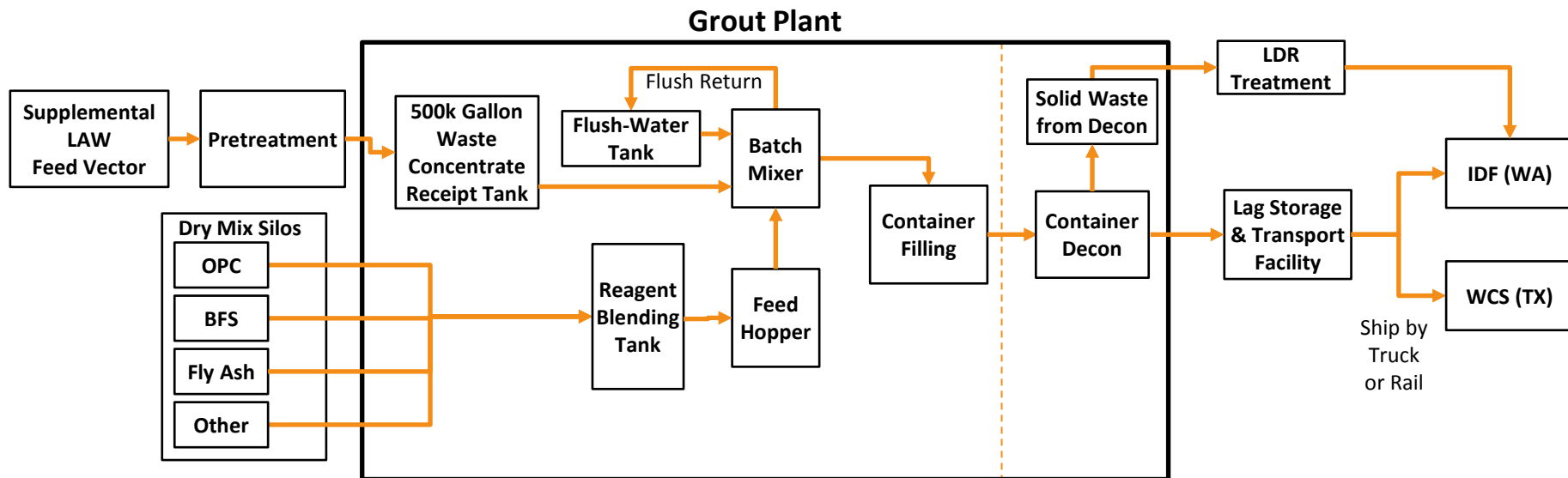


- Waste input assumes SLAW feed vector generated by TOPSim model of the One system integrated flow sheet
- Assumed no pre-treatment needed beyond WTP-PT/LAWPS
- Semi continuous batch processing
- Grout formulation based on Cast Stone and Saltstone
- Alternative formulations to meet disposal-site WACs will be considered
- TRL estimated "medium to high"
- Grout discharged into largest container that can be accepted by disposal facility and safely transported.
- Container details to be determined based on costs and feasibility
- TRL estimated to be "medium"
- Waterless decon
- TRL "high"
- TRL for conveying, curing, and lag storage estimated "medium to high"
- IDF and WCS disposal under consideration
- Regulatory consideration/risks estimated to be "medium to high"
- Transportation TRL estimated to be "high"



Option I SLAW Cast Stone Flowsheet

Grout plant located close to WTP; pretreatment as needed; disposal at IDF or WCS

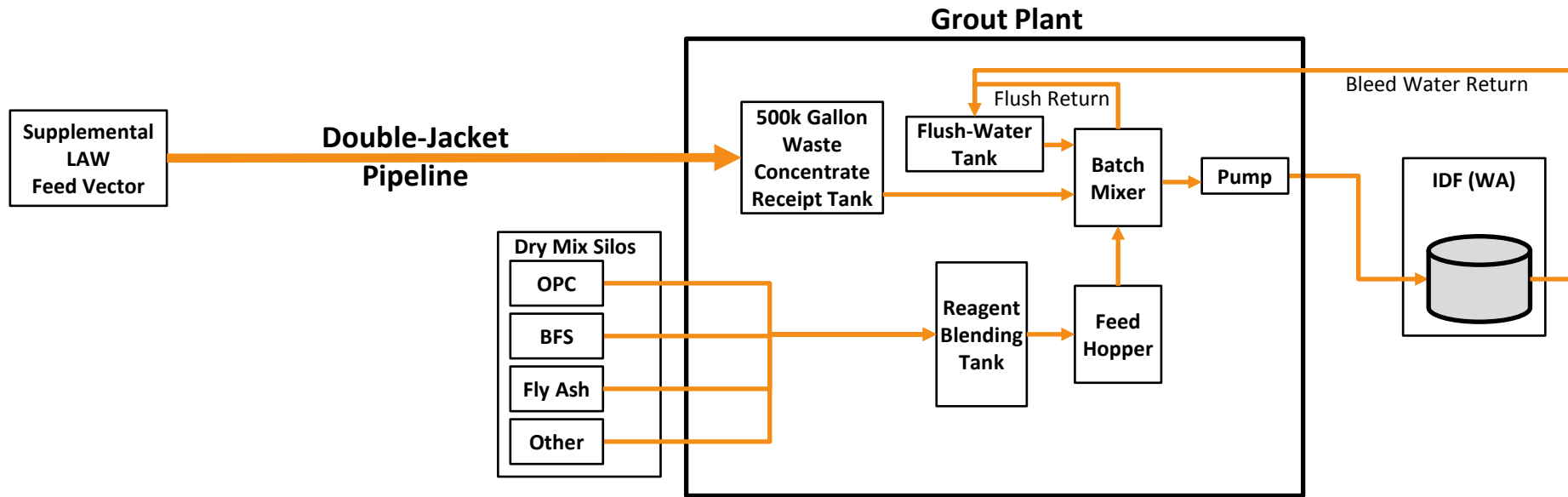


- Process similar to base-case, except that feed vector enters a pretreatment facility (TBD) prior to entering grout plant.
- Pretreatment technologies are TBD but are selected to address any concerns over waste acceptance (e.g., Tc, I, and/or RCRA constituents), waste transport (e.g., Sr), air emissions (e.g., ammonia), etc.



Option II SLAW Cast Stone Flowsheet

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



- Process similar to base-case, except that grout facility is located near IDF, allowing potential to cast waste in place in large disposal units.
- Relocation of grout facility would require additional pipeline to deliver supplemental LAW.
- Facility would not require some container-related components needed in the base-case.
- Facility would require additional components to pump the slurry to the storage units at or near IDF (if possible).
- Storage units could be significantly larger than transportable units.



Key information needed and considerations for grout assessment

- **Regulatory compliance and stakeholder acceptance**
 - Long-term performance of waste package in IDF
- **Waste form considerations**
 - Performance assessment methodologies and input data
 - Technetium-99 and iodine-129 release and transport (e.g., PNNL-22747 and many others)
- **Pretreatment technology selection and optimization (if needed)**
- **Containerization considerations**
 - Large volume of grout, large number of containers (curing, staging, handling, transport)
 - Container size/volume optimization
 - Construction of large disposal units at or near IDF
- **Transportation**
 - DOT shipping containers: Type A shipping containers or Type B shipping casks
 - Road or railroad
 - Cost evaluation and optimization



- **Many Analogs for Grout Wasteform Process**

- Saltstone: 17+ M gallons of liquid decontaminated tank waste (LAW) grouted and disposed at SRS since 1991
- West Valley Demonstration Project (19,000+ 71-gallon square drums) of grouted tank supernate were shipped to NNSS (2006)
- Oak Ridge Reservation aqueous tank low-level waste grouted and shipped to NNSS

- **Updated information on grout effectiveness is needed for IDF disposal but not for WCS disposal**

- **IDF** concerns include potential release of technetium and iodine
 - *PA input parameters can be re-assessed based on PNNL test results, saltstone PA parameters, and WTP Secondary Solid Waste grout parameters (all similar mix designs)*
 - *Formulation optimization is expected*
- **WCS** can accept total inventory of SLAW in solid waste form based on radiological criteria (RCRA land-disposal restrictions need resolution)

- **Lifecycle Costs for Base Case Flowsheet and Alternatives will be based on:**

- SRS saltstone treatment costs
- Waste container and shipping optimization (rail vs commercial truck)
- Disposal costs for IDF and WCS





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Fluidized Bed Steam Reforming for Hanford Supplemental LAW – Process Description, Wasteforms, and Preliminary TRL Estimates

Nick Soelberg

Steam Reforming Lead

Chemical Engineer Level 5, Environmental & Geological Engineering
Idaho National Laboratory

*NAS Committee Meeting #2
February 28 and March 1, 2018
Richland, WA*

Pre-Decisional

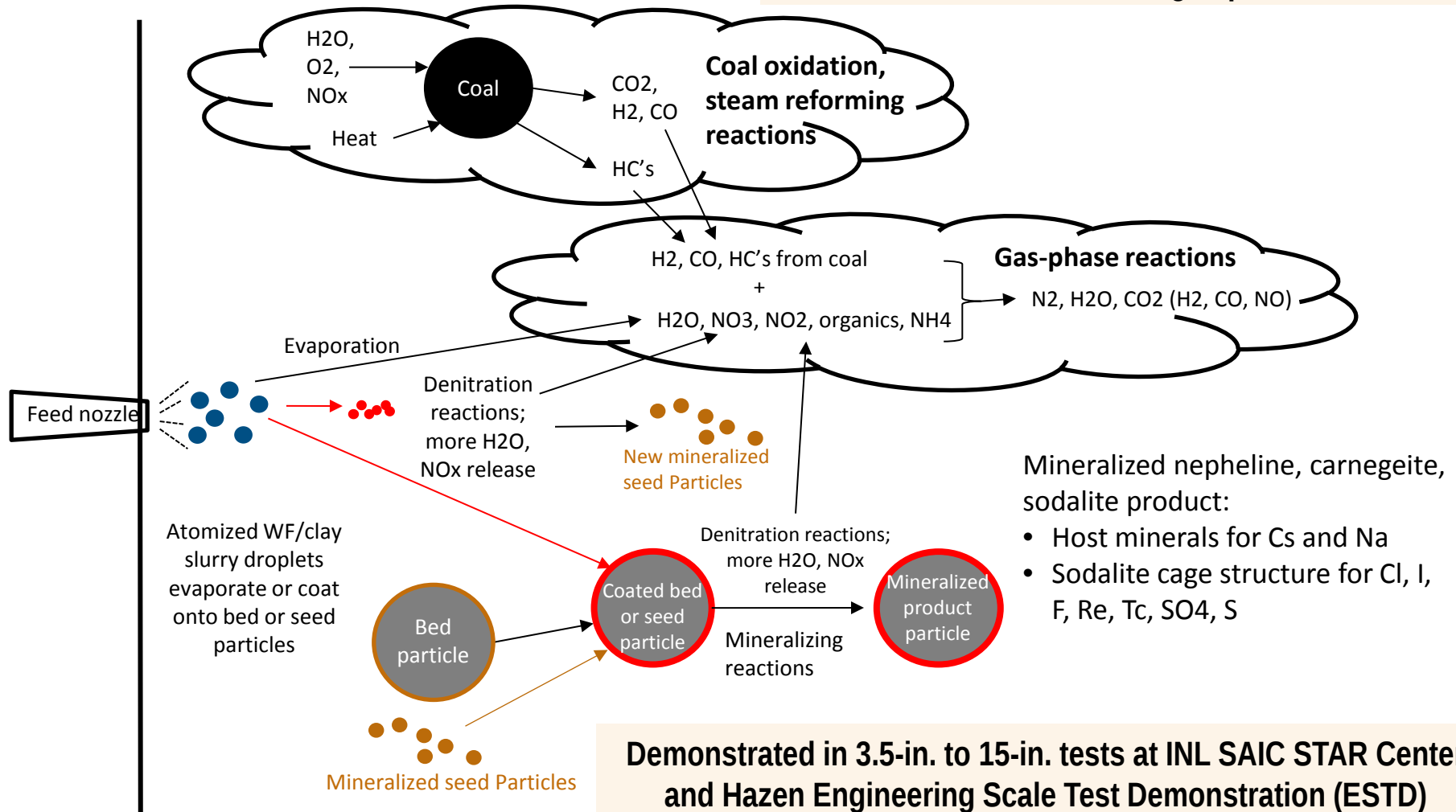
The Supplemental LAW treatment system feed vector is expected to vary widely and presents flowrate and composition challenges for the SLAW treatment process

Parameter	Monthly average	Monthly turndown ratio (max/min)	Comments
SLAW feedrate, gpm	3.6	51	High turndown ratio; feed lag tanks 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, NH3, NH4 conc.	Not relevant		Destroyed by FBSR system

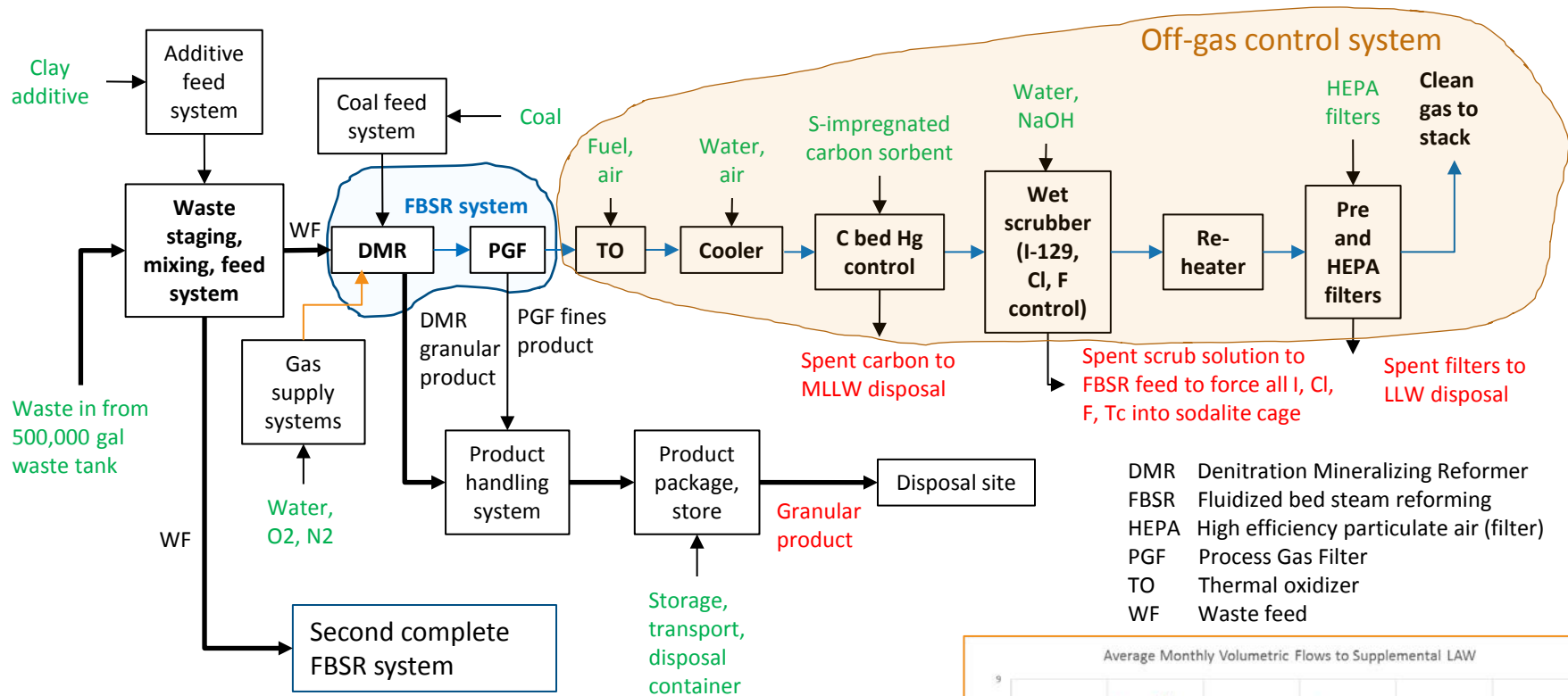


High FBSR mass transfer rates convert the waste feed to a durable aluminosilicate mineralized product and destroys nitrates/NO_x and organics

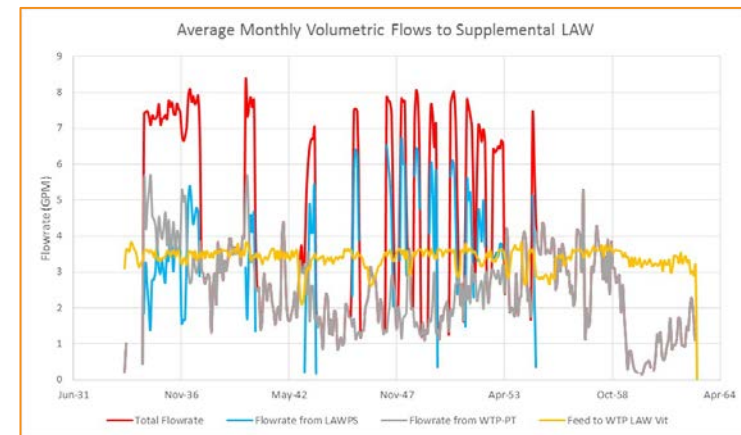
3- part DMR chemistry model: coal reactions, waste feed conversion, and gas-phase reactions



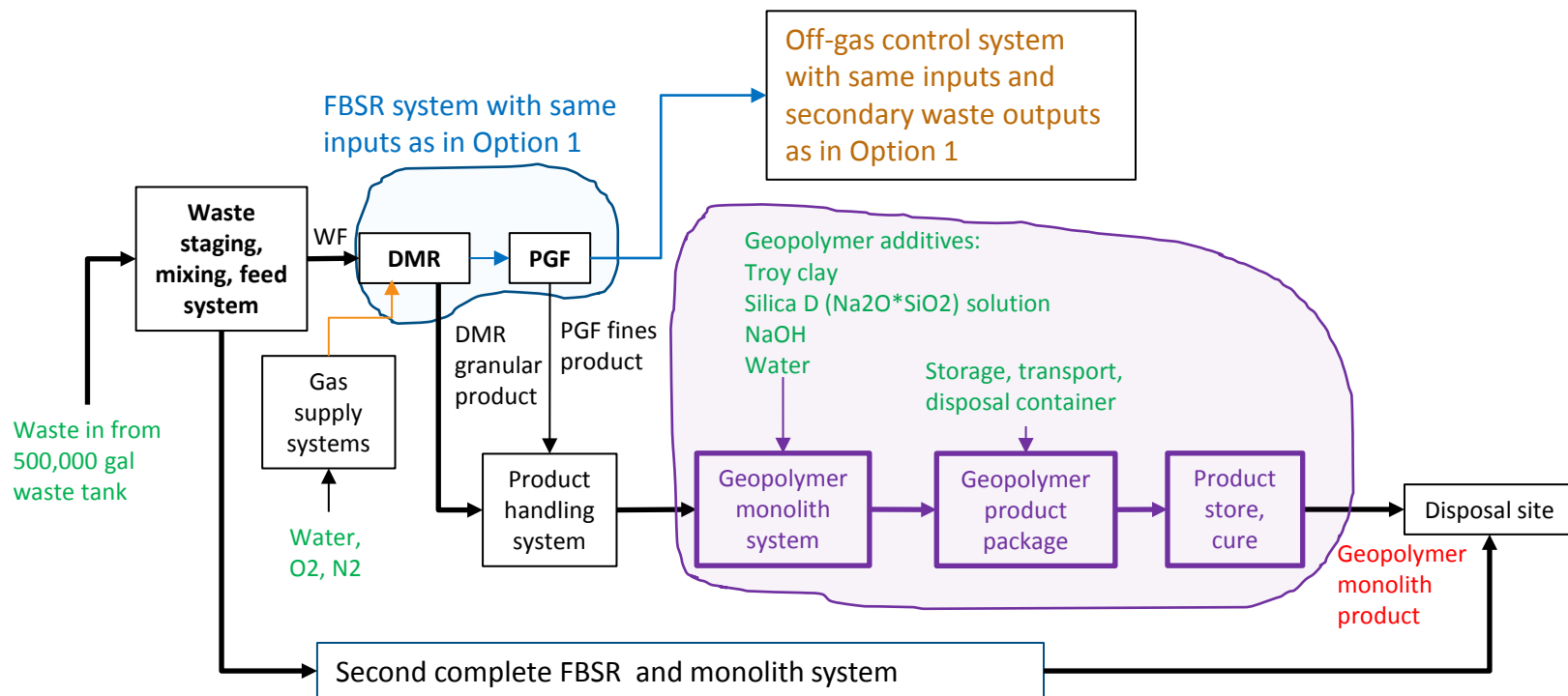
Mineralizing FBSR Option 1: Two DMR systems; dry granular solid product



- Utilize 500,000 gal waste holding tank upstream of the SLAW treatment system
- ~1,000,000 gal additional delay tank + two 250,000 gal waste feed/mix tank capacity needed for first ~3 years of SLAW treatment; throughput decreases afterwards
- Two identical FBSR systems to maximize available capacity in first ~3 yrs
- Shared waste staging, mixing, feed system



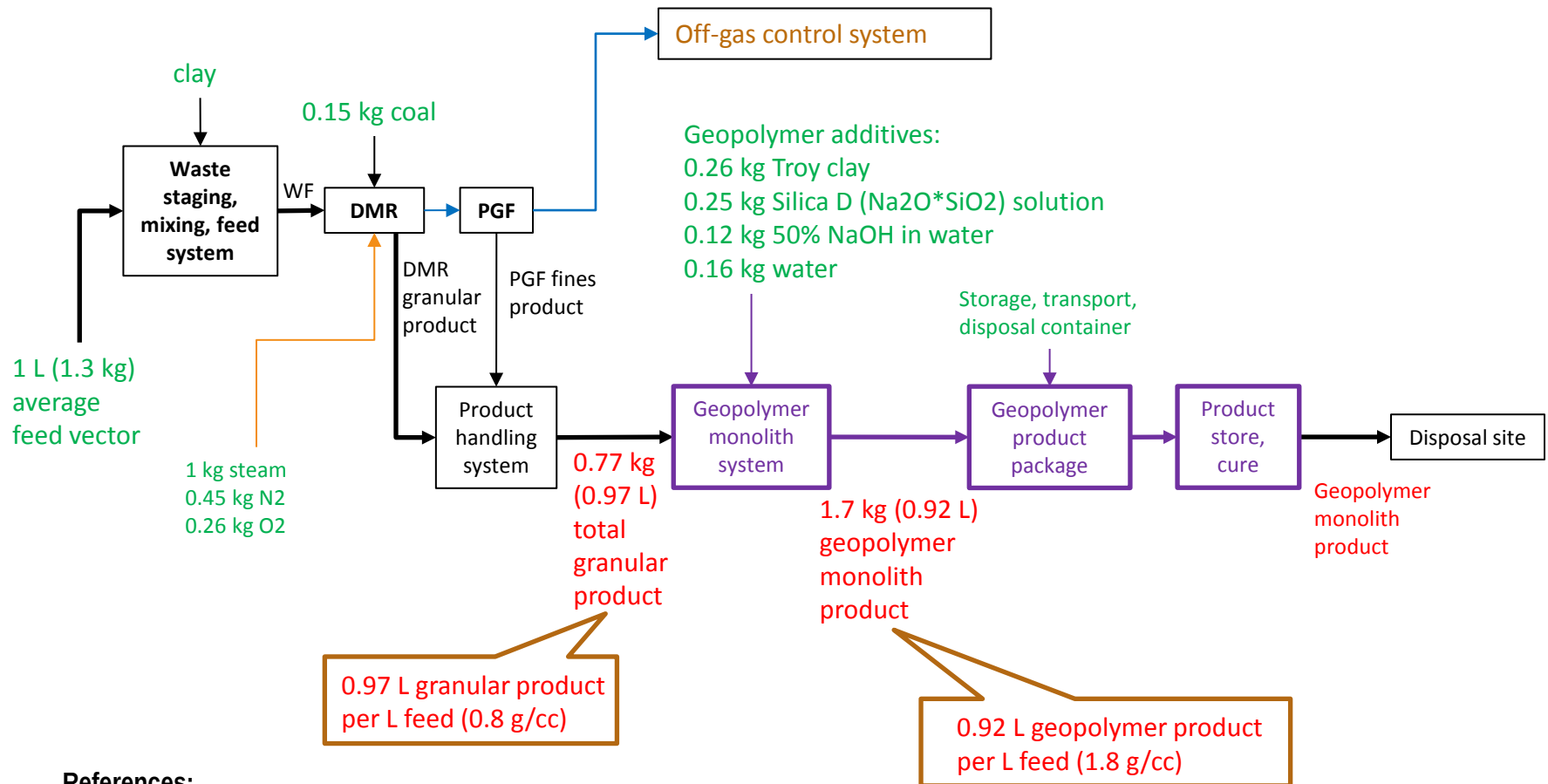
Mineralizing FBSR Option 2: Two DMR systems; solid monolith product



- Eliminates dust, provides more compression strength
- Same waste feed, FBSR, off-gas, and product handing systems as in Option 1
- Two complete identical product monolith systems to maximize available capacity



FBSR preliminary mass balance



References:

- FBSR mass balance for average SLAW feed vector
- 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		



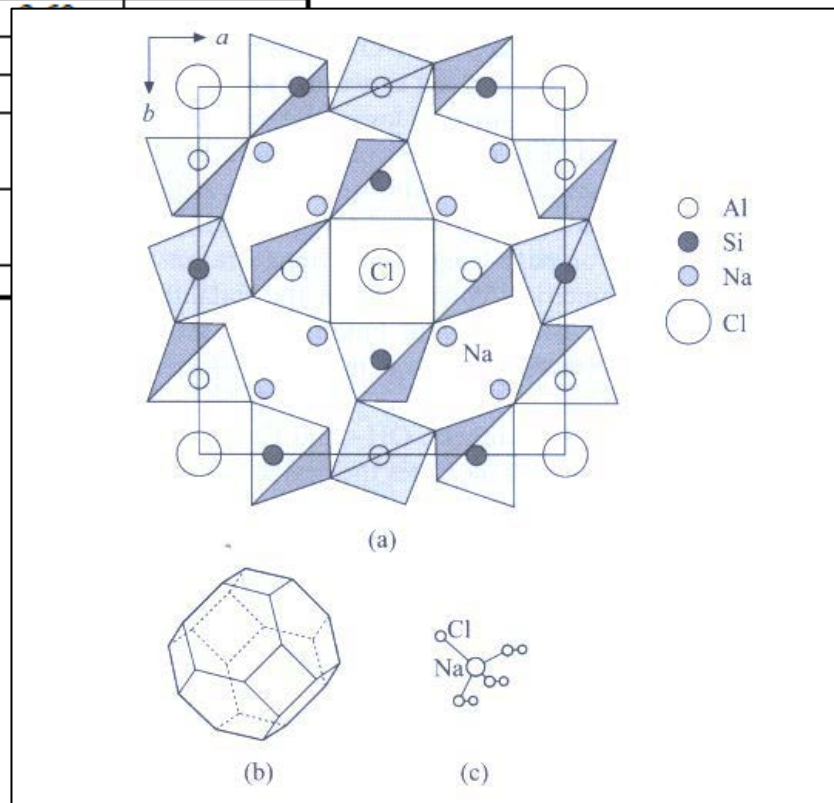
Halogens, S, and Tc-99 can be captured in sodalite and nosean phases in durable “cages”

Element	Mineral Name	Oxidation State	Coordination Number	a(Å)	Space Group	Ionic Radii fom 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).



- **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. 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 ± 0.3) × 10⁻² g/(m²d)] 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)

- ASTM308/ANSI 16.1 test duration was up to 90 days. For the Hanford IDF, the solidified waste is considered effectively treated for IDF disposal if the leach index (LI) for Re and Tc ≥ 9 after a few days and the LI for Na ≥ 6 in 2 hours.
 - 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 fly ash durability
- ASTM308/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.



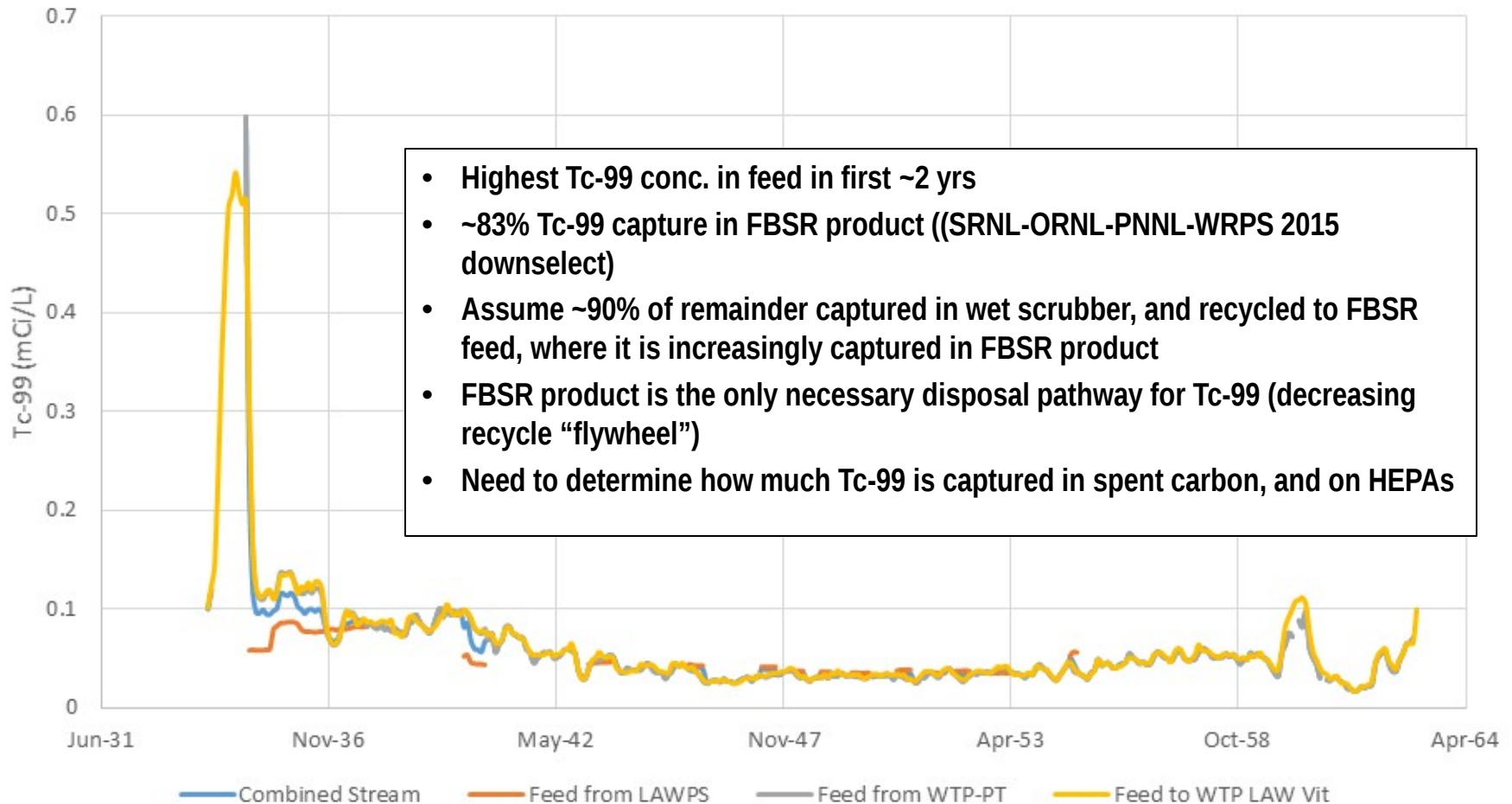
FBSR is expected to meet emission requirements similar to WTP LAW vitrification

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 key radionuclides including Tc-99 and I-129, halogens Cl, F, I, and S are captured to a large degree in the FBSR solid waste form. The total required control efficiency is achieved by >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	$\geq 2.0\text{E}+8$	Estimated minimum combined performance for process gas filter (99%); 90% (wet scrubber); 99% (HEPA prefilters) and 99.95% (HEPAs)
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. 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 $2.0\text{E}+8$.		

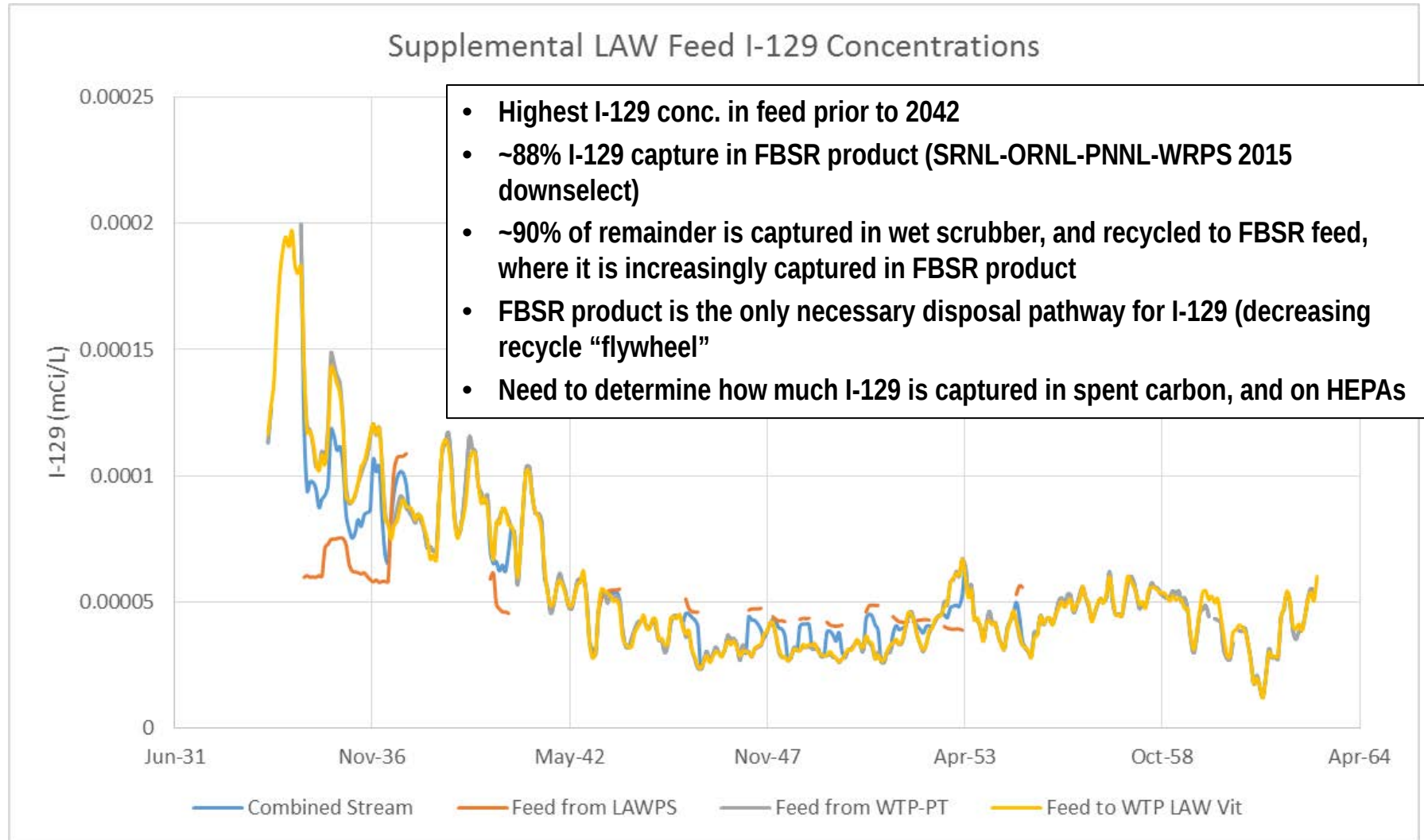


The FBSR product is the only necessary disposal path for Tc-99; but some may also be captured in spent carbon (for Hg control) and in HEPA filters

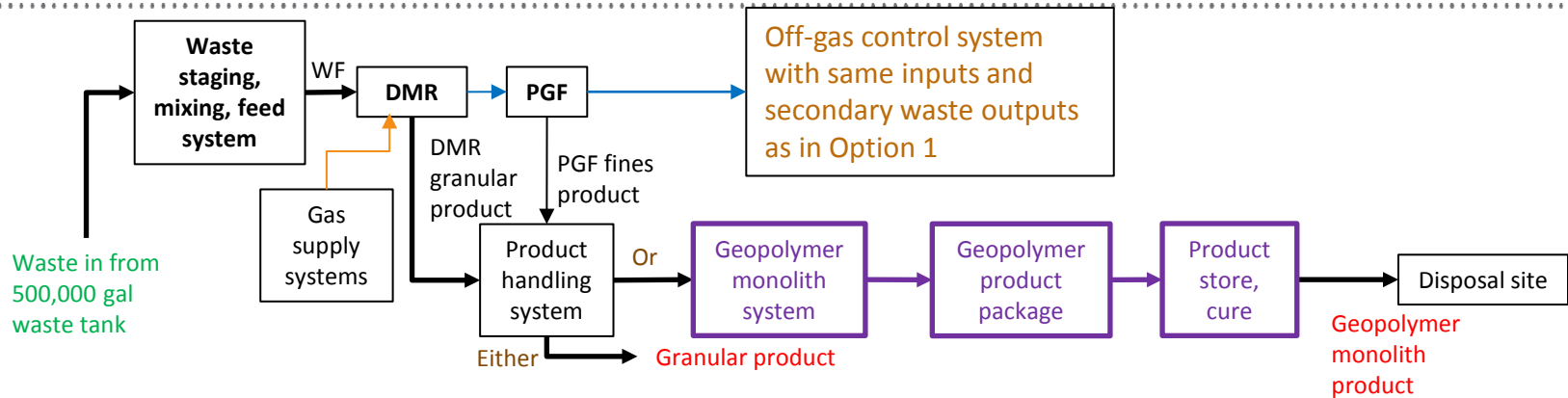
Supplemental LAW Feed Tc-99 Concentrations



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



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



Estimated Technology Readiness Level, assumptions

- Additive, WF systems TRL high
 - Gas supply systems TRL high
 - Not unique to FBSR, common commercial equipment
 - DMR TRL Medium
 - Unique to FBSR
 - Mineralizing flowsheet TRL Medium
 - Coal feed TRL High
 - Product system TRL medium
 - Geopolymer monolith system TRL Medium
 - Can use common commercial equipment
 - Off-gas system TRL high
 - Wet scrubber TRL medium
 - Not unique to FBSR
 - Product cure, store, transport - needs design but TRL high
 - Can use common commercial equipment
- **Integrated FBSR system TRL is medium** 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: 15-in. diameter fluidized bed in the ESTD (Golden, CO)
- **Two full scale FBSR facilities (IWTU for SBW and SPF for LLRW); Studsvik continuing to demonstrate FBSR for various customers**
- **Some pros...**
 - Moderate temperature and pyrolysis in the DMR to destroy organics and NO_x
 - Production of a durable, mineralized waste form using a process control algorithm (MINCALC) developed at SRNL and demonstrated at INL 6-in. FB and Hazen ESTD
 - Retain radionuclides, halogens, and hazardous metals with efficiencies high enough to be the waste form for those elements
 - No liquid secondary wastes – breaks the recycle “flywheel”
 - No volume increase
- **Some cons that can be resolved with applied R&D...**
 - Complex, integrated thermal process
 - Requires design details specific to Hanford SLAW
 - Integrated pilot-scale demonstration of that design; although integration of many of the key components have already been demonstrated in the Hazen ESTD
 - Full-scale demonstration



Work still to do

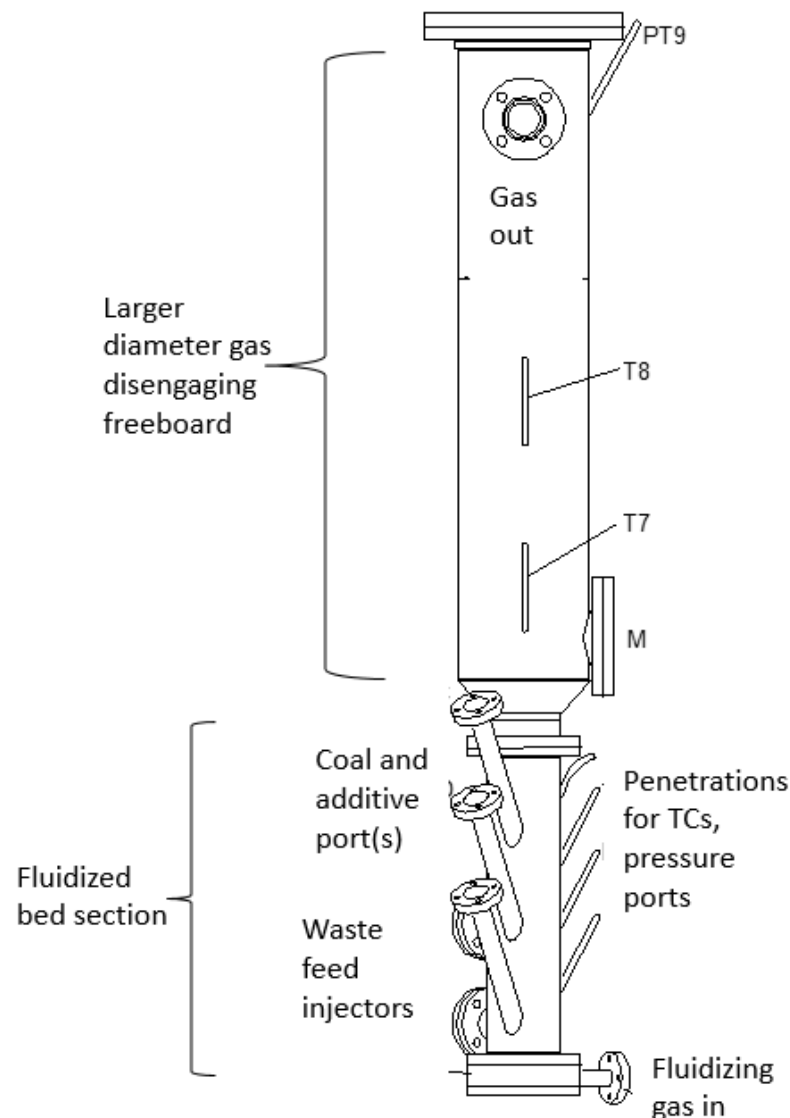
- Refine some details of the FBSR system
- Complete mass balance through product and off gas systems
- Work with FFRDC team on waste packaging, transport, disposal, cost estimate, TRLs, risks and opportunities, etc.
- Respond to comments and questions



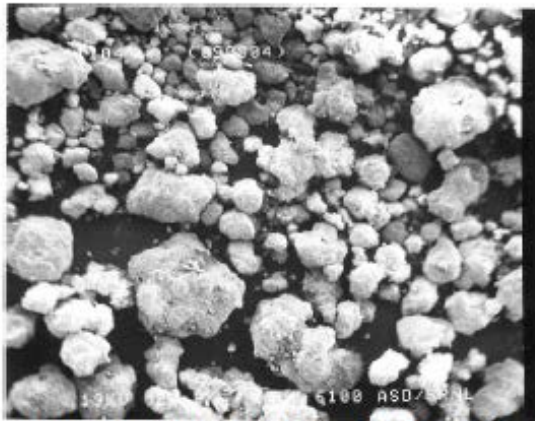
Backup slides

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

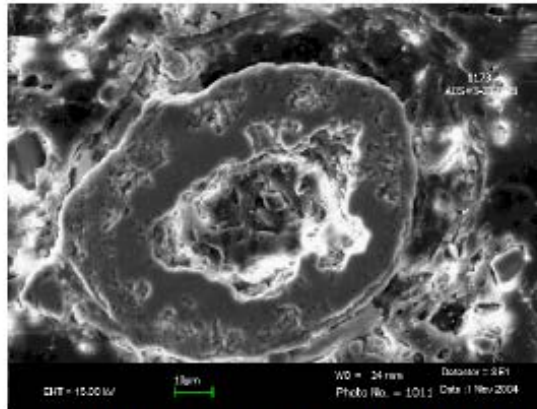
- Haynes 556 alloy or equivalent for strength and corrosion tolerance at temperatures ~750 C (no refractory)
- Steam, O₂, and N₂ fluidizing gas flows up from bottom
- Heated by coal oxidation
- O₂-deficient pyrolysis destroys both organics and NO_x
- N₂, O₂, or air – atomized liquid/slurry waste feed nozzles
- Granular solid product removed from bottom
- Gas discharge out the top
- Sealed thermocouple ports
- Pressure 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



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; Science Applications International Corporation Science and Technology Applications Research (SAIC-STAR) 6 in. diameter FBSR (SRNL-ORNL-PNNL-WRPS down-select).

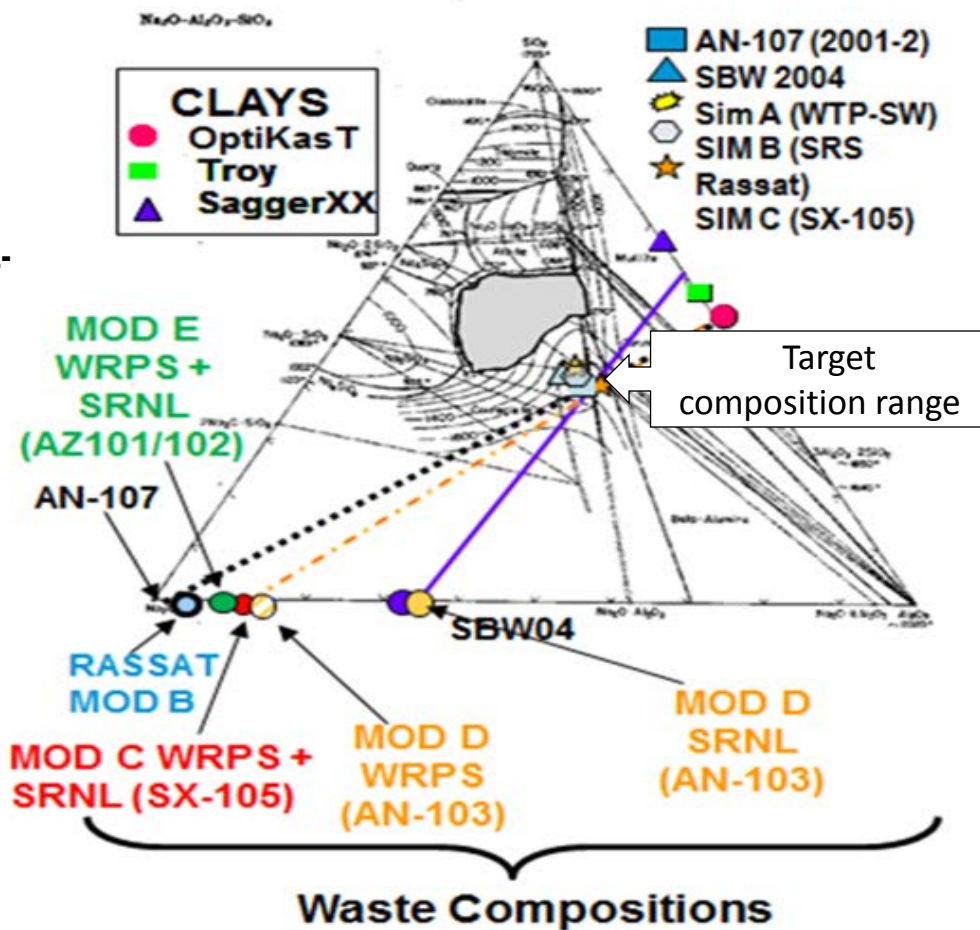


Troy clay geopolymer monolith of Hanford LAW 60% FBSR product (SRNL-ORNL-PNNL-WRPS down-select)



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)



Monolith product analyses and durability tests

Table 9-6. Monolith Testing and Characterization Performed (SRNL-ORNL-PNNL-WRPS 2015 downselect).

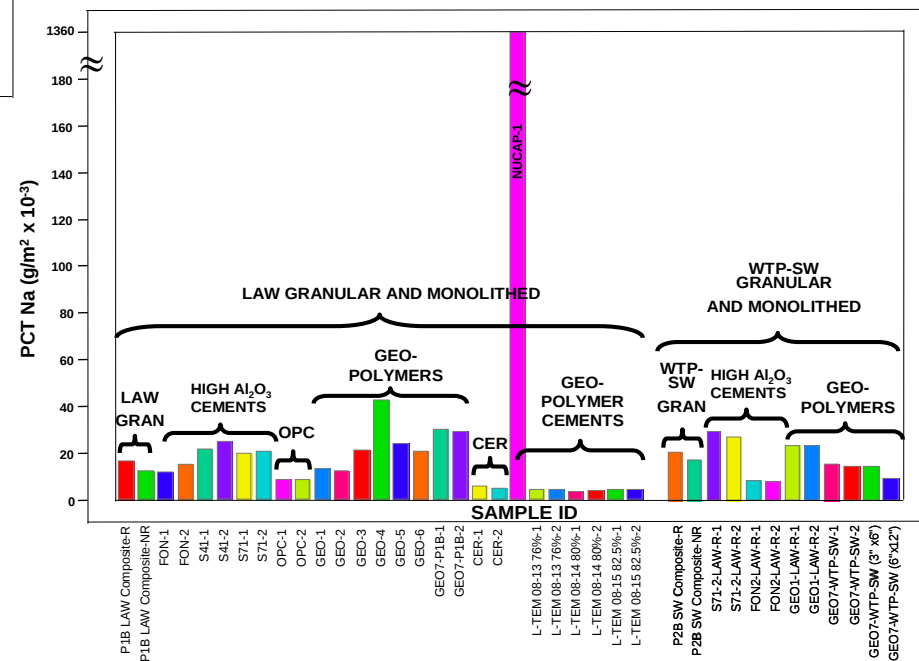
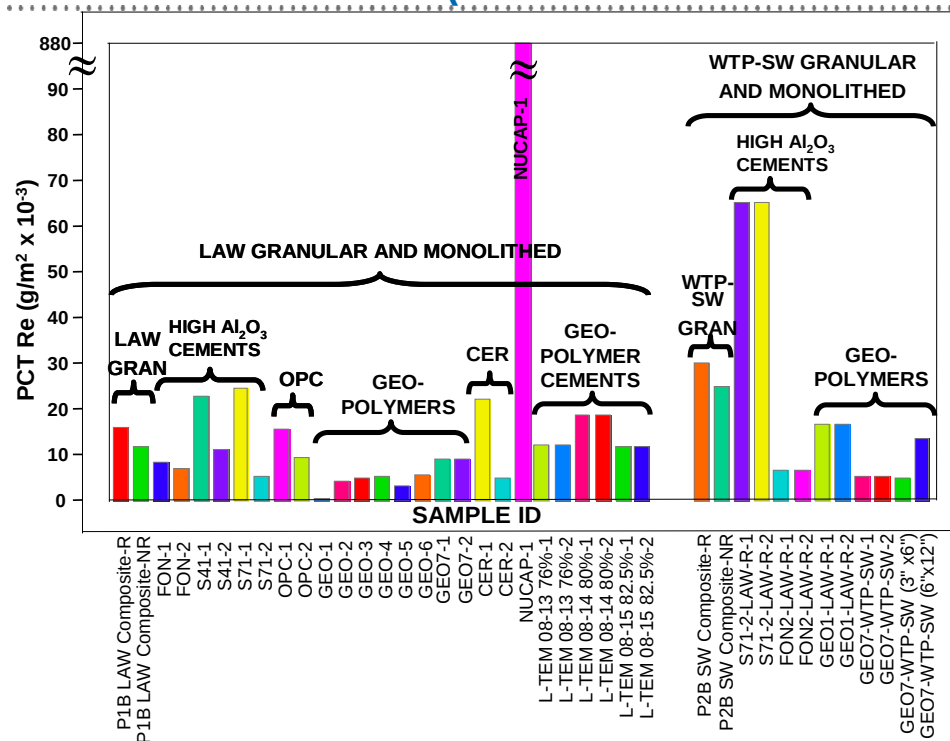
Monolith	As Made Composition	Dry Basis Fbstr Loading (%)	Compress-Ion Tested	XRD Phases	PCT	Analyzed Chemical Composition	TCLP Testing	Bulk Density (G/Cc)	ANSI/ANS 16.1/ ASTM C1308 Leaching	SPFT/PUF Testing
Fly Ash GEO-7 ESTD LAW P-1B	Table 9-1	68	Yes	Yes	Short-Term and Long-Term	Yes	Yes	Yes	Yes	SPFT PUF
Fly Ash GEO-7 Mod B Sim	Table 9-2	68	Yes	Yes	Short-Term and Long-Term	Yes	Yes	Yes	Yes	SPFT
Clay ESTD LAW P-1B	Table 9-3	42	Yes	Yes	No	No ^b	No	Yes	Yes	No
	Table 9-4	65				No ^b	No	No	No	No
Clay Mod B Sim	Table 9-3	42	Yes	Yes	No	No ^b	No	Yes	Yes	No
Clay Mod B Rad	Table 9-5	42	Yes	Yes	Short-Term ^a	No ^b	Yes	No	No	No
	Table 9-4	65			Long-Term ^a	No ^b	Yes	No	No	No

a) Both the 42% WL and the 65% WL Mod B radioactive monoliths made with clay were tested with PCT. The lower 42% WL PCT leachates were archived and the 65% WL PCT leachates were analyzed and reported in this work.

b) Chemical compositions calculated from analyzed granular products and known Na, Al and Si oxide compositions of the binder additives.



PCT elemental release for granular and monoliths compared to other WTP-SW granular and monolith forms(SRNL-ORNL-PNNL-WRPS 2015 downselect)





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Laboratories

NDAA 3134 Supplemental Low Activity Waste FFRDC Approach to “Other Options”

Tom Brouns

Regulatory Lead

Market Sector Manager

Pacific Northwest National Laboratory

Energy & Environment Directorate

NAS Committee Meeting #2

February 28 – March 1, 2018

Pre-Decisional



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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



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.



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
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





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Disposal Facilities Overview, Waste Acceptance Criteria, and Transportation

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*NAS Committee Meeting #2
February 28 and March 1, 2018
Richland, WA*

Pre-Decisional



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- **Overview 2 LLW Disposal Facilities**
- **Waste Acceptance Criteria for Waste Control Specialists**
- **Discuss Off-Site Transportation of Grout Waste Form**



- ➔ • Overview 2 LLW Disposal Facilities
- Waste Acceptance Criteria for Waste Control Specialists
- Discuss Off-Site Transportation of Grout Waste Form



- **Status**
 - Commercial facility operated by Waste Control Specialists LLC
- **Physical Setting**
 - Located in west Texas
 - Sparsely-populated area, semi-arid climate
 - Based on extensive investigation program & 390 monitoring wells:
 - Facility underlain by 600-foot thick red-bed clays
 - No potable groundwater aquifer beneath the site
- **Design of Federal Waste Disposal Cell**
 - Multi-barrier design
 1. Natural site characteristic
 2. Engineered barriers:
 - 2-m thick, multi-layer liner (0.3 m reinforced concrete + RCRA compliant geosynthetic layer)
 - Higher-activity wastes disposed in modular concrete containers (MCCs)



- **Licensing**

- Licensed by Texas, an NRC “Agreement State”
- Licensing process took 5 years (August 2004 - September 2009)
- Licensed for Class A, B & C LLW and Class A, B & C MLLW
- Received first Federal LLW shipment in 2012 – very new facility

- **Related Regulatory Issue**

- NDAA Team developing compliance strategy – for compliance with various RCRA land disposal restrictions

- **Federal Waste Disposal Facility**

- Limits: 737,000 m³ and 5,600,000 curies total
- DOE signed Agreement to take ownership of the Federal Facility after closure



- **Example Disposal Costs**

- Current fee for Class A MLLW - \$1,460 /m³
- Current fee for Class B MLLW - \$7,830 /m³
- Adders and subtractors to base fee (e.g., for Class B, lower cost for waste in B-25 boxes)
- Fee covers: land purchase, site characterization, 5-year licensing process, construction, day-to-day operations, profit, site monitoring, long-term site closure, and assumed risk (this is a fickle business line)
- Fees will be lower for large, multi-year generator with constant waste stream





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



Federal Waste Disposal Facility



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



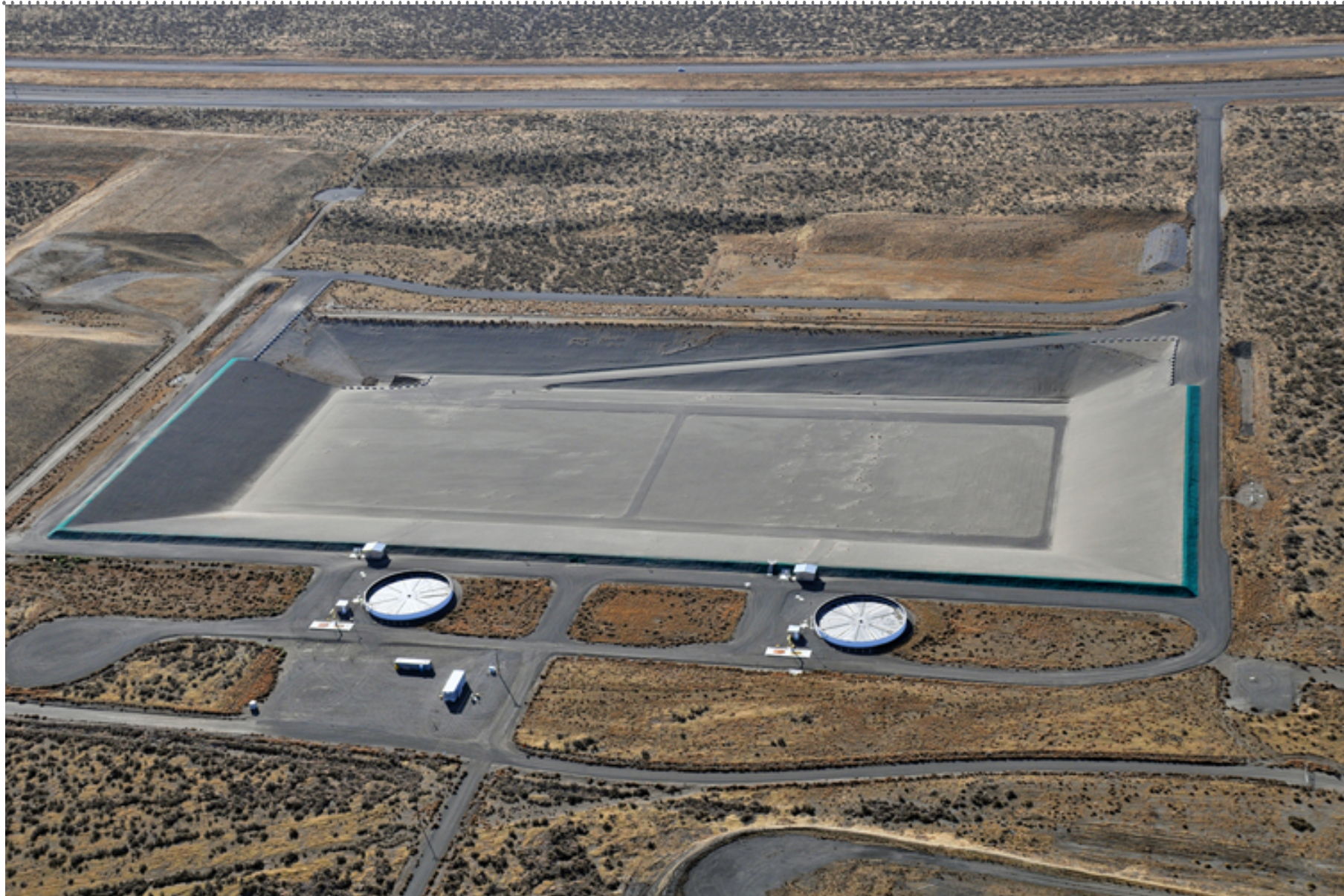
- **Licensing**

- DOE-self regulates LLW disposal
- Final DOE Authorization and Waste Acceptance Criteria not issued
- Department of Ecology has issued a *draft* 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





- Overview 2 LLW Disposal Facilities
- ➔ • Waste Acceptance Criteria for Waste Control Specialists
- Discuss Off-Site Transportation of Grout Waste Form



Waste Acceptance Criteria (WAC) for Disposal

- **The name says it all – WAC are the criteria the waste must meet to be accepted for disposal**
 - WAC based on many factors (Criteria to protect intruder, NRC's Branch Technical Position on Concentration Averaging, operational considerations, license requirements, criteria to ensure characteristics of actual wastes are consistent parameters used to model long-term site-specific performance)
 - **For WCS, focus on:**
 - Packaging criteria
 - Radiological criteria



WAC for Waste Control Specialists (WCS) – Examples of Packaging Criteria

- < 1% free liquids
- < 10% headspace for MLLW packages
- **Containerized Waste** – waste is disposed in the DOT shipping container, usually placed in an MCC
- **Bulk Waste** – waste is disposed without the DOT shipping container & is not disposed in a MCC – must be Class A & dose rate <100 mrem at 30 cm
- **Containerized waste needs to fit in MCC**
 - Several sizes
 - Cylindrical MCC – holds fourteen 200 L drums
 - Rectangular MCC – holds four B-25 DOT shipping containers



Modular Concrete Canisters



**Rectangular MCC holds four
B-25 DOT shipping containers**

**Cylindrical MCC – holds
fourteen 200 L drums**



WCS Radiological Criteria for 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

- 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

- 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)

- Overview 2 LLW Disposal Facilities
- Waste Acceptance Criteria for Waste Control Specialists
- • How we use Feed Vector data, to determine if treated SLAW meets radiological criteria
- Discuss Off-Site Transportation of Grout Waste Form



Review Supplemental LAW Feed Vector Data

- Provides specific activity of feed that goes into the immobilization plant
- 46 nuclides tracked
- Screen shot below – feed from WTP PT for April 2060 (5 nuclides shown)
- Units: mCi/L = Ci/m³ (same as WAC units)
- For example Sr-90 = 0.847 Ci/m³

LAW Supplemental Treatment Feed Vector (Case 3335)_with WTP LAW Feed_with Density Dec 5 2017.xlsx - Excel

Home Insert Page Layout Formulas Data Review View ACROBAT Tell me what you want to do

	A	B	VR	VS	VT	VU	VV	VW	VX	VY	VZ
	Preliminary Draft										
	Transfer Date Range	Liquid Volume kgal	90-Sr Liquid mCi/L	90-Sr Solid mCi/L	90-Y Liquid mCi/L	90-Y Solid mCi/L	93-Zr Liquid mCi/L	93-Zr Solid mCi/L	93m-Nb Liquid mCi/L	93m-Nb Solid mCi/L	99-Tc Liquid mCi/L
	Mar-60										
	Apr-60	7.50E+00	8.47E-01	0.00E+00	0.00E+00	0.00E+00	3.58E-04	0.00E+00	4.12E-04	0.00E+00	8.86E-02
	May-60	7.14E+00	9.81E-01	0.00E+00	0.00E+00	0.00E+00	3.64E-04	0.00E+00	4.19E-04	0.00E+00	8.20E-02
	Jun-60	1.38E+01	9.65E-01	0.00E+00	0.00E+00	0.00E+00	3.03E-04	0.00E+00	3.45E-04	0.00E+00	9.73E-02



Tc-99 and I-129 concentrations in Feed Vector vs. WAC for WCS

	Class C limit (Ci/m3)	Feed Concentration Average (Ci/m3)	Feed Concentration Maximum (Ci/m3)
Tc-99	3	0.054	0.6
I-129	0.08	0.000054	0.0002

- **Average concentration Tc-99 is ~one one-hundredth Class C limit**
- **Average concentration I-129 is ~one one-thousandth Class C limit**

Use Feed Vector to determine if Final Waste meets Radiological WAC for Disposal

- **Need 3 pieces of information, to use Feed Vector data to determine if final waste form meets WAC for disposal:**
 1. Does final processing drive some nuclides to secondary waste form?
 2. 1 liter of feed = how many liters of final waste form?
 3. Density of final waste form?
- **Hand-calculations using feed vector data and WAC for WCS**
- **Early hand-calculations assuming 2.5 L grout per 1 L feed, and density of 1930 kg/m³**



Example Calculations Long-lived (WTP PT April 2060, for grout, 2.5 L per L feed)

Table 1 Limit		Specific Activity in Feed Vector Ci/m3	Change specific activity due to treatment	Specific Activity in Final Waste Form Ci/m3	Conversion to nCi/gram	Fraction of limit
Nuclide	Limit Ci/m3					
C-14	8	2.20E-03	x 0.4	8.8 E-4		1.1 E-4
Tc-99	3	8.86E-02		3.54 E-2		1.18 E-2
I-129	0.08	4.33E-05		1.73 E-5		2.17 E-4
	Limit nCi/gram				nCi/gram [Ci/m3 x 518]	
Pu-241	3500	2.19E-04		8.76 E-5	4.54 E-2	~0
Cm-242	20000	3.78E-05		1.51 E-5	7.83 E-3	~0
Ra-226	100	2.37E-09		9.48 E-10	4.91 E-7	~0
Summed alpha-emitting TRU half-life > 5 years	100					
Np-237		7.88E-06	x 0.4	3.15 E-6	1.63 E-3	
Pu-238		1.03E-04		4.12 E-5	2.13 E-2	
Pu-239		1.62E-03		6.48 E-4	3.36 E-1	
Pu-240		3.54E-04		1.42 E-4	7.33 E-2	
Am-241		4.14E-03		1.66 E-3	8.58 E-1	
Am-243		1.86E-06		7.44 E-7	3.85 E-4	
Cm-243		4.96E-07		1.98 E-7	1.03 E-4	
Cm-244		5.35E-06		2.14 E-6	1.11 E-3	
Summed TRU's					1.29	1.29 E-2
Summed Fraction for all Table 1 nuclides						0.025

sum of fractions < 0.1, so Class A for long-lived



Example of Calculations for Short-lived (WTP PT April 2060, grout, 2.5 L per L feed)



Table 2 Limits for Class A		Specific Activity in Feed Vector Ci/m3	Change specific activity due to treatment	Specific Activity in Final Waste Form Ci/m3	Fraction of limit
Nuclide	Limit Ci/m3				
H-3	40	7.17E-05	x 0.4		
Co-60	700	2.93E-07			
Ni-63	3.5	5.55E-03			
Sr-90	0.04	8.47E-01		3.39E-1	8.47
Cs-137	1	4.90E-03			
Total all nuclides with half-life < 5 years	700				
Y-90		0			
Ru-106		3.80E-22			
Sb-125		4.08E-10			
Cs-134		3.81E-15			
Ba-137m		4.90E-03			
Summed activity all nuclides with half-life < 5 years					
Summed Fraction for all Table 2 Class A nuclides					> 8.47

exceeds Class A →
for short-lived

Table 2 Limits for Class B		Specific Activity in Feed Vector Ci/m3	Change specific activity due to treatment	Specific Activity in Final Waste Form Ci/m3	Fraction of limit
Nuclide	Limit Ci/m3				
H-3	unlimited	7.17E-05	x 0.4		0
Co-60	unlimited	2.93E-07			0
Ni-63	70	5.55E-03		2.22E-3	3.2E-5
Sr-90	150	8.47E-01		3.39E-1	2.26E-3
Cs-137	44	4.90E-03		1.96E-3	4.4E-5
Total all nuclides with half-life < 5 years	unlimited				0
Y-90		0			
Ru-106		3.80E-22			
Sb-125		4.08E-10			
Cs-134		3.81E-15			
Ba-137m		4.90E-03			
Summed activity all nuclides with half-life < 5 years					0
Summed Fraction for all Table 2 Class B nuclides					2.26E-3

meets Class B →
for short-lived



Automation of WAC Calculations and Input Data for Grout

- EXCEL workbook setup to perform calculations on all Feed Vector Data and compare resulting concentrations to WAC
- Current calculations based on following:

Hypothetical Grout	
Nuclides in secondary waste	none
1 liter feed	1.8 liters grout
Specific weight final waste form (WF)	1770 kg/m ³ (110 lb/ft ³)

Results and Insights from Automation of WAC Calculations

- **Feed Vector data based on monthly averages - results are based on monthly averages**
- **For hypothetical grout (1.8 liters of grout per 1 liter of feed)**
 - *408 months of output will produce Class B MLLW, but for 33 months with Class C MLLW*
 - What makes Class B for 408 months – Sr-90
 - What makes Class C for 33 months?
 - Long-lived nuclides
 - All from WTP PT
- **For hypothetical grout, if we remove Sr-90, all wastes Class A MLLW, but for 33 months from WTP PT with Class C MLLW**
 - Save > \$1 billion in disposal costs at WCS
 - If Class A, then could consider another commercial disposal facility nearer Richland



- Overview 2 LLW Disposal Facilities
- Waste Acceptance Criteria for Waste Control Specialists
- • Discuss Off-Site Transportation of Grout Waste Form



Off-site Transportation – How much final waste form to ship?

- Feed Vector data, cumulative volume (2034-2063) is: 54 Mgal = 205,000 m³
- If final Waste Form (WF) volume = feed vector volume: average: **7,000 m³/yr**
- If hypothetical grout (factor 1.8), total = 369,000 m³, average: **~12,600 m³/yr**
- How much is 7,000 m³/yr?
 - WIPP averaged 6,000 m³/yr 1999 – 2014
 - Commercial LLW facility in Clive Utah received: ~70,000 m³/yr in 2011 and in 2012



Off-site Transportation – Regulatory

- Radioactive materials are transported routinely and safely every day
- For example - DOE/EM completed ~ 5,500 shipments of radioactive materials in FY 2016 with no reportable accidents (Office of Packaging and Transportation Annual Report FY2016)
- 49 CFR 171-173 regulates: Highway routing, Placarding, Occupational exposure and working conditions
- 10 CFR 71 governs “Packaging and Transportation of Radioactive Material”
 - Ensures safe transport under normal conditions of transport and hypothetical accident conditions
 - Uses a graded approach for shipping containers, for normal form materials
 - Low Specific Activity (LSA) materials are exempt
 - Type A container – if specific activity > LSA limit & radiological content < A_2 limit
 - Type B cask – if specific activity > LSA limit & radiological content > A_2 limit
 - Type A container ~ inexpensive, Type B cask is ~ expensive





Type A containers
B-25 boxes
weight ~ 800 lb & carry 6,000 lb
(IP-1, Container Products Corporation)



Type B Cask
HalfPACT cask (left side of trailer)
Contact-handled, 30 watts max
Weigh ~ 10,500 lb & carry 7,000 lb



Off-site Transportation – Regulatory

- “A₂” content (= Type A Quantity)
 - For normal form materials (dispersible in accident)
 - A₂ limit for each nuclide in Appendix A to 10 CFR 71
 - **A₂ is maximum number of curies of a nuclide allowed in Type A container, normal form**
 - Example, for Sr-90 A₂ limit is 8.1 curies in container
 - If container has < 8.1 Ci of Sr-90, then Type A container
 - If container has > 8.1 Ci, then Type B cask
 - With 46 nuclides in Feed Vector - use sum of fractions

Pt. 71, App. A

10 CFR Ch. I (1–1–10 Edition)

TABLE A-1—A₁ AND A₂ VALUES FOR RADIONUCLIDES—Continued

Symbol of radionuclide	Element and atomic number	A ₁ (TBq)	A ₁ (Ci) ^b	A ₂ (TBq)	A ₂ (Ci) ^b	Specific activity	
						(TBq/g)	(Ci/g)
Sb-124		6.0×10 ⁻¹	1.6×10 ¹	6.0×10 ⁻¹	1.6×10 ¹	6.5×10 ²	1.7×10 ⁴
Sr-89		6.0×10 ⁻¹	1.6×10 ¹	6.0×10 ⁻¹	1.6×10 ¹	1.1×10 ³	2.9×10 ⁴
Sr-90 (a)		3.0×10 ⁻¹	8.1	3.0×10 ⁻¹	8.1	5.1	1.4×10 ²
Sr-91 (a)		3.0×10 ⁻¹	8.1	3.0×10 ⁻¹	8.1	1.3×10 ⁵	3.6×10 ⁶



Example Calculating A_2

- Feed Vector WTP PT for April 2060
- **For this example:**
 - 1 liter of feed - 2.5 liters grout
 - all nuclides in final WF
 - Volume shipping container is 1.25 m³ (B-12 box)



GROUT

Nuclide	A ₂ Limit Ci	Specific Activity Feed Vector Ci/m ³	Change specific activity due to treatment	Specific Activity Final Waste Form Ci/m ³	Total activity in container Ci	Fraction of the limit
Ru-106	5.4	3.80 E-22	0.4	1.52 E-22	1.95 E-22	3.60 E-23
Cd-113m	14	8.56 E-5		3.42 E-5	4.38 E-5	3.13 E-6
Sb-125	27	4.08 E-10		1.63 E-10	2.09 E-10	7.74 E-12
Sn-126	11	9.93 E-5		3.97 E-5	5.08 E-5	4.62 E-6
I-129	unlimited	—		—	—	unlimited
Cs-134	19	3.81 E-15		1.52 E-15	1.95 E-15	1.03 E-16
Cs-137	16	4.90 E-3		1.96 E-3	2.51 E-3	1.57 E-4
Ba-137m	Not listed	—		—	—	0.00
C-14	81	2.20 E-3		8.80 E-4	1.13 E-3	1.39 E-5
Sm-151	270	2.28 E-2		9.12 E-3	1.17 E-2	4.32 E-5
Eu-152	27	7.09 E-7		2.84 E-7	3.63 E-7	1.34 E-8
Eu-154	16	3.93 E-6		1.57 E-6	2.01 E-6	1.26 E-7
Eu-155	81	8.46 E-8		3.38 E-8	4.33 E-8	5.35 E-10
Ra-226	8.10 E-2	2.37 E-9		9.48 E-10	1.21 E-9	1.50 E-8
Ac-227	2.40 E-3	2.21 E-7		8.84 E-8	1.13 E-7	4.71 E-5
Ra-228	0.54	1.22 E-8		4.88 E-9	6.25 E-9	1.16 E-8
Th-229	1.40 E-2	7.77 E-9		3.11 E-9	3.98 E-9	2.84 E-7
Pa-231	1.10 E-2	7.62 E-7		3.05 E-7	3.90 E-7	3.55 E-5
Th-232	unlimited	—		—	—	unlimited
U-232	2.70 E-1	1.59 E-7		6.36 E-8	8.14 E-8	3.02 E-7
U-233	2.4	1.60 E-5		6.40 E-6	8.19 E-6	3.41 E-7
U-234	2.4	1.07 E-5		4.28 E-6	5.48 E-6	2.28 E-6
U-235	unlimited	—		—	—	unlimited
U-236	1.60 E-1	2.40 E-7		9.60 E-8	1.23 E-7	7.68 E-7
Np-237	5.40 E-2	7.88 E-6		3.15 E-6	4.04 E-6	7.47 E-5
Pu-238	2.70 E-2	1.03 E-4		4.12 E-5	5.27 E-5	1.95 E-3
U-238	unlimited	—		—	—	unlimited
Pu-239	2.70 E-2	1.62 E-3		6.48 E-4	8.29 E-4	3.07 E-2
Pu-240	2.70 E-2	3.54 E-4		1.42 E-4	1.81 E-4	6.71 E-3
Am-241	2.70 E-2	4.14 E-3		1.66 E-3	2.12 E-3	7.85 E-2
Pu-241	1.60 E-1	2.19 E-4		8.76 E-5	1.12 E-4	7.01 E-5
Cm-242	2.40 E-2	3.78 E-5		1.51 E-5	1.94 E-5	8.06 E-4
Pu-242	2.70 E-2	4.11 E-8		1.64 E-8	2.10 E-8	7.79 E-7
Am-243	2.70 E-2	1.86 E-6		7.44 E-7	9.52 E-7	3.53 E-5
Cm-243	2.70 E-2	4.96 E-7		1.98 E-7	2.54 E-7	9.41 E-6
Cm-244	5.40 E-2	5.35 E-6		2.14 E-6	2.74 E-6	5.07 E-5
H-3	Not listed	—		—	—	0.00
Ni-59	unlimited	—		—	—	unlimited
Co-60	1.10 E-1	2.93 E-7		1.17 E-7	1.50 E-7	1.36 E-8
Ni-63	8.10 E-2	5.65 E-3		2.22 E-3	2.84 E-3	3.51 E-6
Se-79	5.40 E-1	4.91 E-4		1.96 E-4	2.51 E-4	4.66 E-6
Sr-90	8.10 E-1	8.47 E-1		3.39 E-1	4.34 E-1	5.35 E-2
Y-90	8.10 E-1	0		0	0	0.00 E-0
Zr-93	unlimited	—		—	—	unlimited
Nb-93m	8.10 E-2	4.12 E-4		1.65 E-4	2.11 E-4	2.60 E-7
Tc-99	2.40 E-1	4.86 E-2		3.54 E-2	4.54 E-2	1.89 E-3

Trace K₂Cr₂O₇ 1-4-18

Total: 1.75 E-1



Se-79	5.70 E 1	4.91 E -4		1.96 E -4	2.51 E -4	4.66 E -6
Sr-90	8.10 E 0	8.47 E -1		3.39 E -1	4.34 E -1	5.35 E -2
Y-90	8.10 E 0	0		0	0	0.00 E 0
Zr-93	Unlimited	—		—	—	Unlimited
Nb-93m	8.10 E 2	4.12 E -4		1.65 E -4	2.11 E -4	2.60 E -7
Tc-99	2.40 E 1	8.86 E -2		3.54 E -2	4.54 E -2	1.89 E -3

Total: 1.75 E -1



Automation of A₂ Calculations

- EXCEL workbook setup to perform calculations on all Feed Vector Data and compare radiological content to A₂ limit
- Results presented as monthly output averages, because Feed Vector is monthly average
- Output from WTP PT and LAWPS

Hypothetical Grout	
Nuclides in secondary waste	none
1 liter feed	1.8 liters grout
Specific weight final WF	1770 kg/m3 (110 lb/ft3)



Results and Insights from Automation of A_2 Calculations for Grout

- For hypothetical grout (factor 1.8) average: 369,000 m³ total = **~12,600 m³/yr**
- **For hypothetical grout in special B-25 boxes (modified to hold 10,000 lb)**
 - Can use B-25 boxes for 366 output months, and A_2 is exceeded for 75 output months
- **For hypothetical grout in B-12 box**
 - Can use B-12 boxes for 411 output months, but for 30 output months
- **For hypothetical grout in 200 L (55 gallon) drum**
 - Can use 200 L drums for all output months
- **Simple off-the-shelf program for off-site transport of hypothetical grout**
 - B-25 boxes for 366 monthly outputs, plus
 - B-12 boxes for 45 months outputs, plus
 - 200 L drums for 30 months of output

Off-site Shipping Mode for Grout

- **Hypothetical grout** (1.8 L grout per 1 L feed) = **~12,600 m³/yr for 29 years**
- Need “lag-storage facility to average-out volume shipped
- For trucks & railcars, weight, not volume, governs analysis
- **For tractor trailers**
 - 12,600 m³/yr = 5,040 B-25 boxes/yr = 101 boxes /week (50 weeks)
 - B-25 box weighs ~ 11,000 lb -> **3 boxes per tractor-trailer**
 - ~ 34 tractor-trailers/week
 - ~ **7 tractor-trailers/day** @ 5 days/week, grand average
- **Railroad**
 - 12,600 m³/yr = 5,040 B-25 boxes/yr = 420 boxes /month
 - B-25 box weighs ~ 11,000 lb -> **18 boxes per gondola car**
 - ~ **24 gondolas on train/month**, grand average



On-site Shipping

- Not on public roads
- Short distance (few km)
- Low-speed
- Analysis - TBD

Summary of Entire Presentation and Early Insights

- **WCS LLW Disposal Facility**

- Disposal of Tc-99 and I-129 not an issue (well below disposal limits)
- WCS can accept total inventory of grouted waste based on radiological criteria (RCRA land-disposal restrictions need resolution)
- If Sr-90 removed, most final wastes Class A, could save significant \$

- **IDF LLW Disposal Facility**

- Based on past analyses, Tc-99 and I-129 are important contributors to IDF performance
- Current IDF WAC and permit are draft – and include limitations on long-lived radionuclide inventory through release rates (WAC) or “risk budget tool” (permit) requirements
- Both immobilized LAW & secondary waste have been shown to contribute to IDF performance

- **Off-Site Transportation Grout:**

- In aggregate, ship significant quantities waste: 7,000 to 12,600 m³/yr for 29 years
- But daily & monthly averages not significant (e.g. 7 tractor-trailers/day)
- Based on Feed Vector and hypothetical grout, most wastes OK in Type A special B-25 box, but 75 months need B-12 box or 200 L drums



Area of Softness and Future Work

- **Softness**
 - Feed Vector data is foundation for analysis of waste classification and the A_2 calculations
- **Future Work**
 - Grout
 - Need transportation routing and costing for road and rail
 - Need to define a “lag-storage” facility to even-out shipments
 - Steam Reforming and Vitrification
 - Have not completed WAC analysis
 - Have not started transportation analysis
 - Some vitrified waste form packages may not be suitable for off-site transportation
 - IDF
 - Need draft WAC for analysis
 - Need to define the on-site transportation program
 - Regulatory – compliance with various RCRA land disposal restrictions requires additional analysis





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NDAA 3134 Supplemental Low Activity Waste FFRDC Analysis Approach and Methodology

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NAS Committee Meeting #2

February 28 and March 1, 2018

Richland, WA

Pre-Decisional



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- **“(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*



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***



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 ³) - Total volume - Inventory per container	- NEPA - Long Term Environmental Impacts - Env. Permits - Address concentration (Ci/cm ³) - Total volume - Inventory per container - PA compliance	- Decon - Removal - Entombment



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



FFRDC Team Approach to Risk Assessment

- **NDAA 3134 Study**
 - Domains: Project, Environmental, and Safety Risks
 - Methods: Semi-quantitative
 - Application: Alternatives analysis
- **LOIs and Expert Elicitation**
 - Risks (threat, consequence, probability or likelihood) considered explicitly for each LOI, where appropriate
 - Risk Analysis SME to support Team's elicitation and evaluation process
 - Explicit consideration of project-, operational execution-, and technology maturation-risks (scope/schedule/budget, environmental, and safety risks)
 - Assumptions and considerations documented for each alternative's evaluation



Waste Form Performance for On-Site Disposal

Hanford Integrated Disposal Facility (IDF)

- **IDF WAC not finalized**
 - Draft criteria mostly comparable to offsite disposal site WAC
 - Draft WAC contains a “release rate limit (Ci/yr)” for LAW waste forms informed by past IDF performance assessment (PA) analysis
 - Draft IDF Permit contains a “risk budget tool” requirement
- **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*



IDF Disposal Performance

- 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).
- Range of assumptions and parameter values will be considered, to the extent practical, to assess uncertainty



- **Technology Readiness Level (TRL)**

- Assess whether the disposition option requires additional development prior to deployment
 - *Past assessments of TRL for each technology will be reviewed*
 - *Utilize EM guide to determine a TRL level for each disposition technology*

- **Complexity**

- Assess the level of difficulty in operating and maintaining required facilities and unit operations for each disposition technology
 - *Number and type of unit operations*
 - *Expected life of processing equipment*
 - *Secondary waste generation / disposition*
 - *Packaging operations*
 - *Ability to handle process upsets (such as off-spec products)*



- **Assess the relative safety of the process to disposition the waste for each proposed disposition technology**
 - Nuclear safety
 - *Criticality control, radionuclide containment, worker dose, etc.*
 - Process safety
 - *Hazardous chemical handling, pressurized systems, high temperatures, etc.*
 - Number of controls required
 - Processes considered
 - *Pretreatment*
 - *Immobilization*
 - *Packaging*
 - *Transportation*
 - *Disposal*



Robust Operational Flexibility

- **Assess ability of disposition technology to handle entire range of feeds to be processed as well as variability of feed and uncertainty in composition/physical properties**
 - Number of stream components that challenge disposition technologies
 - *e.g. sulfur and chromium for glass; organics and ammonia for grout*
 - Percentage of feeds that challenge limits of the disposition technology
 - *i.e. fraction of feed vector not compatible*
 - Ability to handle turndown in feed flowrates
 - Impact on Pretreatment Requirements
 - *Any additional treatment required beyond filtration/cesium removal*



Cost Lifecycle and Annual

- **Assess cost of each disposition technology**
 - Capital project cost
 - Operation/Maintenance cost
 - *Facility operations*
 - *Disposal cost*
 - *Transportation cost*
 - Total cost and annual costs considered
- **Will review previous estimates for each disposition technology**
 - Evaluate previous methods and assumptions
- **Compare to current EM baseline liability cost profile**
- **Utilize net present value for cost estimates**



Schedule

- **Assess the time needed to implement each disposition technology**
 - Compare against current baseline assumptions
 - Evaluate opportunities to improve schedule with each option
- **Will review previous estimates for each disposition technology**
 - Evaluate previous methods and assumptions



Risks and Opportunities

- **Assess the risks and opportunities associated with each disposition technology**
 - Regulatory risks
 - *Could the disposition technology fail to meet a regulatory commitment?*
 - Schedule risks
 - *Can the disposition technology accelerate the baseline schedule?*
 - *How likely is meeting the estimated schedule?*
 - Cost risks
 - *Could the disposition technology be less costly than the baseline?*
 - *How likely are cost overruns?*
 - Safety risks
 - *Will the process be safer than the baseline*
 - *Could the process result in excessive worker dose?*
 - Process risks
 - *Could the process fail to make acceptable immobilized product?*
 - Product out of specification
 - *Throughput not met*
 - *Generation of excessive secondary wastes*



Regulatory Considerations – Disposal

- **Radioactive Waste Management (DOE O 435.1)**
 - Waste incidental to reprocessing
 - Solid physical waste form not exceeding Class C LLW limits
 - Meet safety requirements comparable to performance objectives in 10 CFR Part 61, Subpart C
- **RCRA/TSCA (40 CFR 261 & 268/40 CFR 761 and WAC 173-303)**
 - Hanford tank waste is a radioactive mixed waste (non-wastewater) subject to land disposal restrictions (LDR)
 - Disposal requires compliance with State and Federal regulations including meeting applicable treatment standards for metals and organics
 - *D001-D043 Characteristic Wastes*
 - *F001-F005 Solvents*
 - *Underlying Hazardous Constituents (UHCs)*



Waste Form Performance

- **Waste form must meet disposal site's Waste Acceptance Criteria (WAC)**
 - Radiological criteria – waste classification and dose
 - *Limits on specific activity (Ci/m^3 and nCi/gram for transuranics)*
 - *"Summed contributions of each nuclide" needed to classify waste for disposal (e.g., as Class C) and many nuclides in ILAW*
 - Waste package requirements – e.g., compressive strength
 - Waste form chemical and physical criteria
 - *e.g. RCRA, LDR compliance*
- **Disposal Site-specific considerations**
 - Off-site disposal: Compliance with established disposal site WAC
 - On-site disposal: Compliance with draft IDF WAC



Secondary Wastes Impacts for On-Site Disposal - Previous Studies

- 2003 SLAW Risk Assessment; 2014 Tank Closure & Waste Management EIS
- Thermal treatment may drive volatile nuclides such as technetium and iodine to secondary wastes
- Long-lived radionuclides ^{99}Tc , ^{129}I in *secondary wastes were primary risk drivers* to IDF performance predictions
- Secondary wastes include:
 - Liquid effluents from LAW and HLW processing (e.g., off-gas condensates)
 - Solid secondary wastes (e.g., spent HEPA filters)
- Consideration of both primary and secondary waste forms important to overall risk assessment

TC&WM EIS (2014)

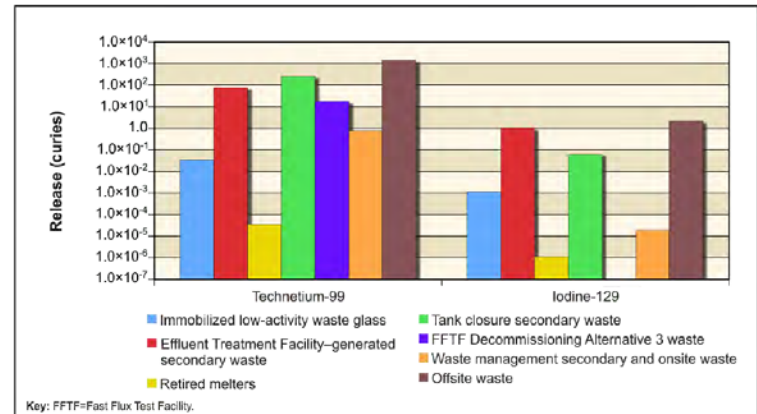


Figure 5-383. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, Radionuclide Releases from 200-East Area Integrated Disposal Facility to Groundwater

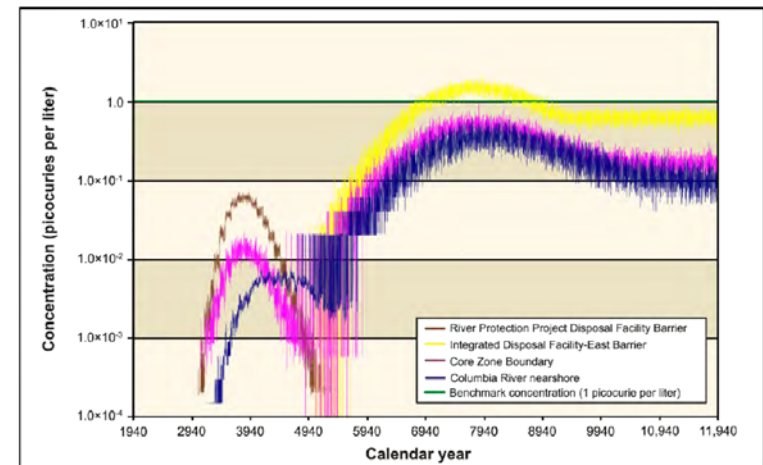


Figure 5-393. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, Iodine-129 Concentration Versus Time

Regulatory Considerations – Processing

- **RCRA/LDR Requirements**

- Treatment Standards for Hazardous Wastes – technology, total waste, or waste extract standards, as applicable.
- Determination of Equivalent Treatment or Alternate Treatment Standards (variance)

- **Air Emissions**

- Controls for New Sources of Toxic Air Pollutants (WAC 173-460) – e.g., Volatile Organic Compounds (VOCs), nitrogen oxides (NOx), mercury

- **Secondary Effluents and Solid Wastes**

- Liquid LLW from processing (e.g., off-gas scrubber, process condensate)
- Solid waste (e.g., spent HEPA filters, resins or sorbents)

- **RCRA TSD licensing**

- **Material Balance – Splits of contaminants of concern between waste form, secondary waste, air emissions**

- Long-lived radionuclides – e.g., volatile species into waste form, off-gas filters, off-gas scrubber
- Volatile metals



Regulatory Considerations – Shipping Off-Site

- **10 CFR 71 Packaging and Transportation Of Radioactive Material**
 - Additional DOE requirements for shipping
- **Type A or Type B shipping containers?**
 - Exact shipping container – e.g., B-12 box for Type A shipping
- **Over-the-road or railroad?**
- **Large volumes, over 30 years, long distances**
 - NEPA requirements

Cost Estimating Methodology

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Cost Estimating Lead

Project Management Professional

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NAS Committee Meeting #2

February 28 and March 1, 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, SRNL 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



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

1. Identification / Utilization of Analog Facility for Primary Process

<i>Vitrification</i>	<i>WTP-LAW (w/ EMF), DWPF</i>
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<i>Grout</i>	<i>SRS-Saltstone, West Valley</i>
--------------	-----------------------------------

<i>FBSR</i>	<i>IWTU</i>
-------------	-------------

2. Systems approach Cost Estimate sheets (based on recent DOE activity) for ancillary facilities including,

<i>Pre-Process</i>	<i>will WTP-PT suffice?</i>
--------------------	-----------------------------

<i>New Unit Operations</i>	<i>required capability for analog facility comparison</i>
----------------------------	---

<i>Post-Process</i>	<i>Transport / Logistics as needed</i>
---------------------	--

<i>Balance of Facilities</i>	<i>support services (based on current WTP)</i>
------------------------------	--

<i>Control Room</i>	<i>additive to WTP or new?</i>
---------------------	--------------------------------

<i>Laboratory</i>	<i>additive to WTP or new?</i>
-------------------	--------------------------------

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

<i>D&D</i>	<i>estimated as function of capital and operations</i>
----------------	--

<i>G&A</i>	<i>overhead and general services</i>
----------------	--------------------------------------

- **Process initiated. First iteration with process leads complete. Key initial target was identification of potential analogs and major gaps. Multiple iterations and refinements incorporating SME guidance required. Status summarized in provided sheets.**

1. Analog Facility for Primary Process (comments)

<i>Vitrification</i>	<i>WTP-LAW is excellent basis for technical comparison</i>
<i>Grout</i>	<i>Container processing / decon added to Saltstone (ex). Logistics planning underway</i>
<i>FBSR</i>	<i>Multiple lines may be required – balance against significant redesign and size increase</i>

2. Ancillary facilities (comments)

<i>Vitrification</i>	<i>WTP Balance of Facilities is excellent basis</i>
<i>Grout</i>	<i>Simpler process requirements, may need additional PT, more challenging volume (for support)</i>
<i>FBSR</i>	<i>Likely more akin to glass versus grout</i>

3. Key Points

- *Ensure up-front development costs are included, where necessary*
- *Estimating via effort level – not just percentage of capital*
- *Current value versus extrapolated cost across such a long timespan*
- *Consistent with Association for the Advancement of Cost Engineering, International (AACEI) guidance*
- *Technical and Operations expertise required throughout process*

Summary and Next Steps

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NAS Committee Meeting #2

February 28 and March 1, 2018

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Pre-Decisional

Summary and Next Steps

- **Initial Flowsheets Developed**
 - Variants Still Evolving
- **Next Steps**
 - Formalize Review Meeting Logistics
 - FFRDC Team Meeting to Review and Document using LOI Table
 - Draft Report