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

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

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

It is important for readers to understand that much of what is presented in these working draft documents has not been peer reviewed or technically edited and is not intended to imply any final conclusions or represent a complete analysis.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

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

Bill Bates

FFRDC Team Lead

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NDAA 3134 Supplemental Low Activity Waste

Introduction of FFRDC Team Study

Bill Bates
FFRDC Team Lead
Deputy Associate Laboratory Director
SRNL Nuclear Materials Management Programs Directorate

NAS Committee Meeting #4
November 29 and 30, 2018
Richland, WA

SRNL-MS-2018-00222

Introduction of FFRDC Team Study

- **Overview of Team Approach**
  - o 6 National Laboratories – EM National Laboratory Network
  - o Evaluation per 2017 NDAA Section 3134
    - ▪ *Processing to Remove Long-lived Constituents (Tc-99, I-129)*
    - ▪ *Vitrification, Grouting, Steam Reforming, and Other Approaches*
    - ▪ *Risks, Benefits, Costs, Schedules, Regulatory Compliance, and Obstacles to Pursuit*
  - o Interface with NAS Committee
- **Establishing Cases for Comparison**
  - o 22 Cases for Initial Screening
  - o Analytical Hierarchy Process (AHP) to Review Initial Cases (May 1-3, 2018)
  - o 12 Cases Selected for Further Maturation
  - o 5 Cases Selected & Refined for Comparison (1 Vit, 2 Grout, 2 Steam Reforming)
    - ▪ *Focus in Main Body of Report*
    - ▪ *Evaluated in Risk Review (October 16-17, 2018)*

FFRDC Team Status

- **Progress Since July**
  - Initiated IDF Disposal Performance Evaluation
  - Developed Risk Register
  - Developed Comparative Analysis Summary

NDAA PARAMETERS	VITRIFICATION	GROUT	STEAM REFORMING
COST	$19B-$40B	$2B-$10B	$8.5B-19B
SCHEDULE	10-21 Years	5-10 Years	10-15 Years
BENEFITS	• Current baseline • Most technically mature for SLAW feed • Thermal LDR organic/nitrate destruction • Lowest primary waste volume	• Lowest temperature process (less offgas, stop/start flexibility, safety) • Least complex process • Utilizes vast international experience • Lowest secondary waste volume	• Lowest cost thermal LDR organic/ nitrate destruction • Medium primary & secondary waste volume
REGULATORY COMPLIANCE	• Primary wasteform compliant for onsite disposal (IDF) • Secondary grout wasteform & onsite disposal (IDF) pending	• High likelihood to meet DOE Technical Performance Criteria for onsite disposal (IDF) • Secondary solid wasteform & onsite disposal (IDF) pending **All wasteforms are compliant with offsite transport and disposal (WCS).**	• High likelihood to meet DOE Technical Performance Criteria for onsite disposal (IDF) • Secondary solid wasteform & onsite disposal (IDF) pending
RISKS/ OBSTACLES (Technical)	• Most dependent on integrated facility performance (DFLAW, WTP, TF) ○ Most complex ○ Highest throughput risk ○ Most impacted by feed rate variability • Highest secondary waste volume (liquid and solid)	• May require System Plan feed adjustments or pretreatment to address organic peaks • Highest primary waste volume • Additional validation/demonstration of wasteform performance needed	• Lowest technical maturity • Latest waste form performance tests show promise, but more needed for regulator/stakeholder acceptance
RISKS/ OBSTACLES (Programmatic)		• Potential lack of stakeholder/ regulator acceptance for onsite disposal (IDF) **All technologies require significant concurrent Line Item and operations funding (> $1.5B/yr).**	• Potential lack of regulator/stakeholder acceptance for onsite disposal (IDF)

FFRDC Team Status, continued

- **Focus Areas Based on Feedback from NAS Review #2**
  - Present for Ease of Comparison
    - *Cost, Schedule, Benefits, Regulatory Compliance, Risks/Obstacles*
  - Develop Report Executive Summary and Main Body in non-technical Form
  - Recognize Potential Other Approaches (Hybrid, Changes from System Plan, etc.)
  - Highlight Areas for Further Analysis/Study
  - Recognize the acceptance of non-glass as a programmatic risk

- **Schedule**
  - 11/29-30/2018 NAS Public Meeting
  - Final Draft Report to NAS 12/21/2018
  - Anticipate NAS Report Feedback in 3/2019
  - Issue Report

FFRDC Team Presentation Agenda

Introduction of FFRDC Team Study	Bill Bates
Process Overview & Major Assumption/Bases	Michael Stone
Pertinent Pre-Treatment Technologies & Maturities	Bob Jubin
Vitrification Baseline Case (1)	Alex Cozzi
Grout Base Cases (2)	George Guthrie
Steam Reforming Cases (2)	Nick Soelberg
Onsite Disposal Performance Evaluation (IDF)	Tom Brouns
Offsite Disposal and Transportation (WCS)	John Cochran
Risk Analysis	Steve Unwin
Estimate & Schedule Summary	William Ramsey
Wrap-Up & Next Steps	Bill Bates

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Process Overview & Major Assumptions/Bases

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Pre-Decisional

Overview

- NDAA Scope
- Feed Vector Basis and Relationship to System Plan 8
- Feed Vector Variability
- “Flywheels”
- Other Factors

NDAA Scope

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

2017 NDAA, Sec 3134

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

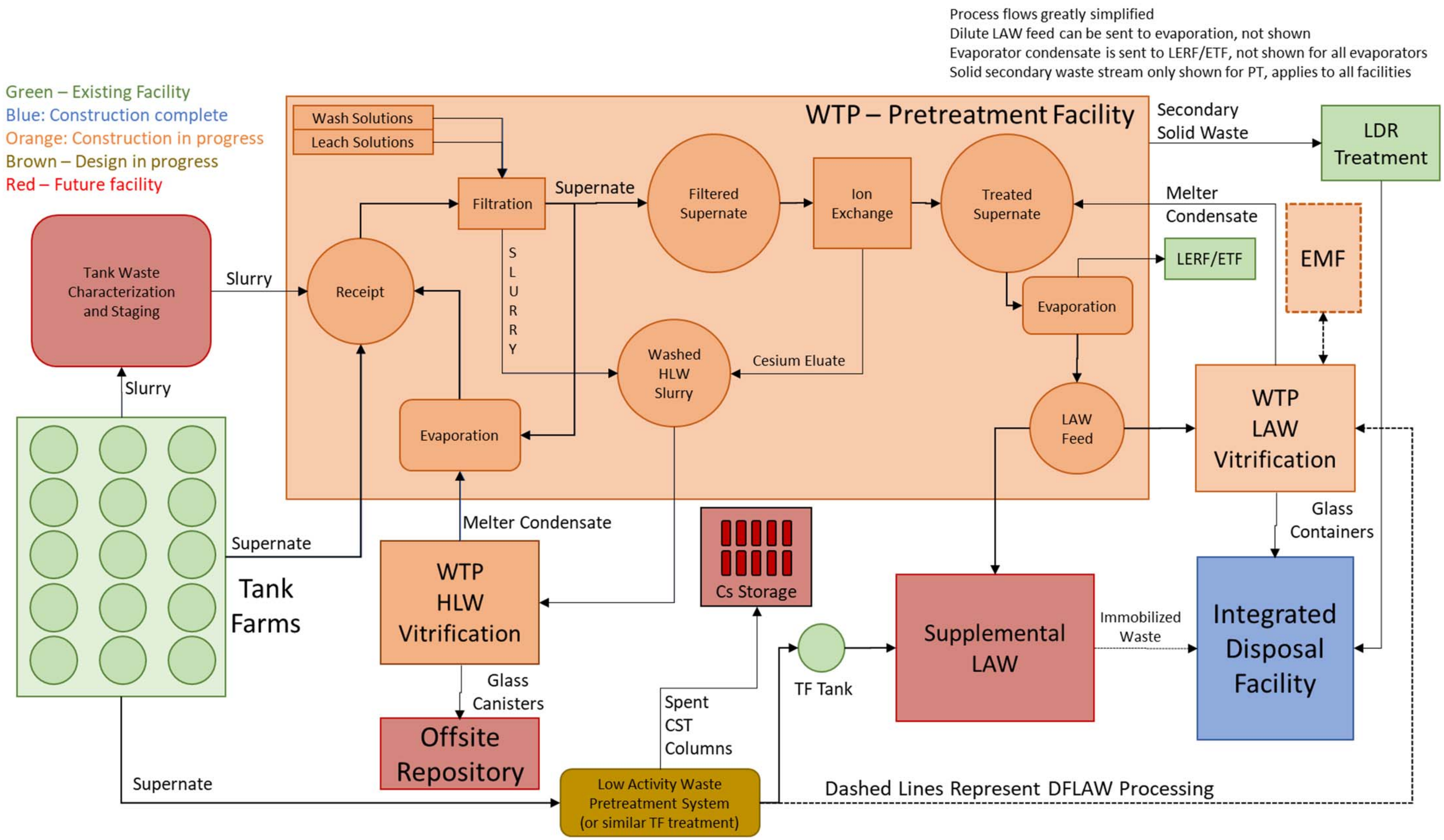
One System Integrated Flowsheet

- **The Integrated Flowsheet is the only current estimate of the feed vector for Supplemental LAW**
  - o System Plan 8 assumptions used for Revision 2 of Integrated Flowsheet
  - o "Best Available Data"
  - o HTWOS model used for Revision 1 of Integrated Flowsheet does not allow extraction of detailed feed vector for Supplemental LAW
    - ▪ *Mission averages are the only data available; not sufficient to evaluate Supplemental LAW processes*
- **Past studies RPP-RPT-55960, Supplemental Immobilization of Hanford Low-Activity Waste: Cast Stone Screening Tests**
  - o *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
  - o SVF-2006 / SVF-2007 determined a Supplemental LAW feed vector for use in RPP-RPT-48333
  - o 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**
  - o Also to account for incidental blending in tank farms during transfer to treatment facility

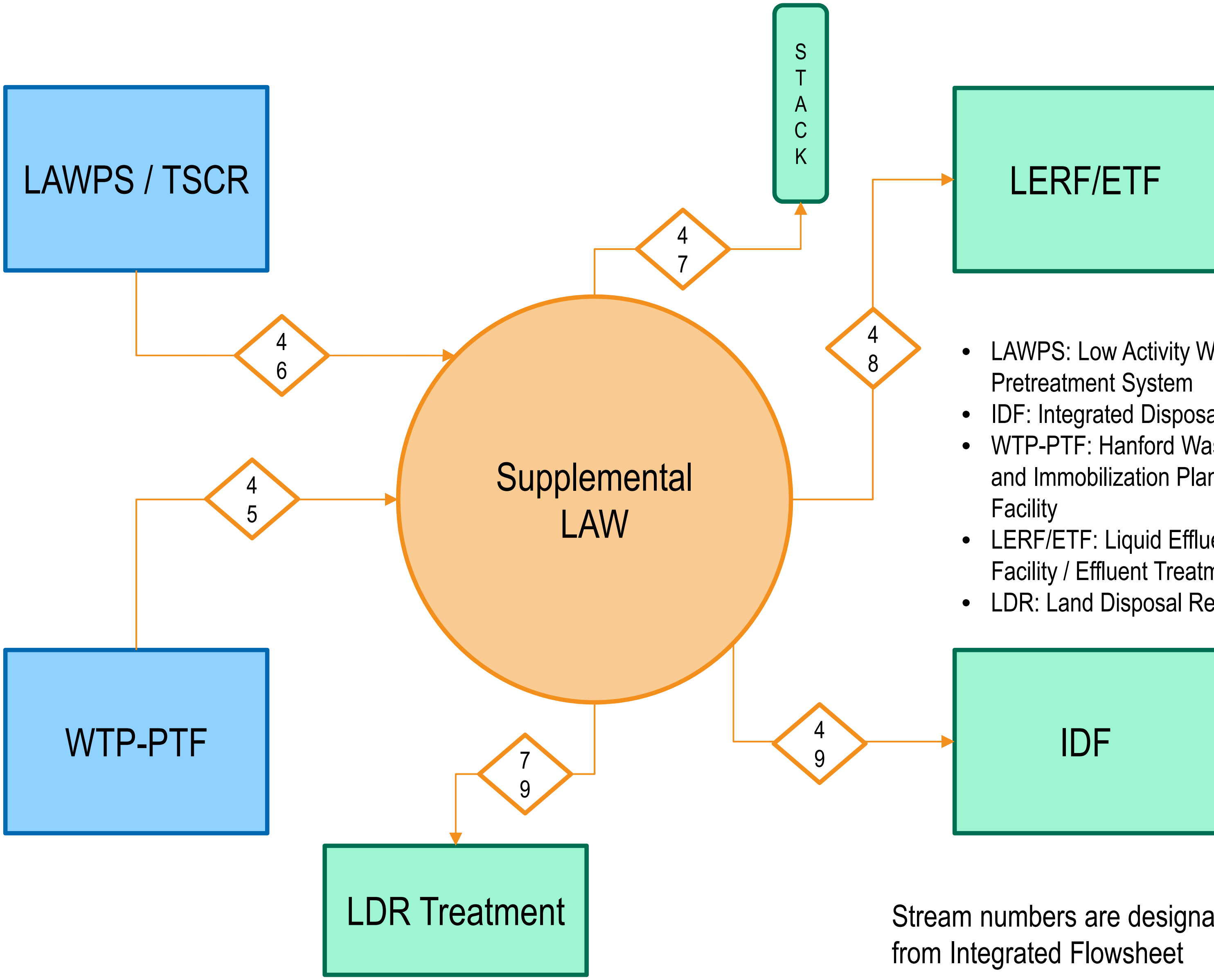
Feed Vector Basis

- **The Integrated Flowsheet is based on the System Plan 8 "Baseline" case**
- **Feed vector from the model output from the Integrated Flowsheet provided by WRPS as requested by the FFRDC team**
  - o Excel file sent from WRPS; data is not explicitly reported in Integrated Flowsheet report
- **Provided by WRPS to the team as monthly averages with two streams**
  - o WTP-PT to Supplemental LAW
  - o LAWPS to Supplemental LAW
  - o Calculations performed by the FFRDC team
    - ▪ *Combined stream calculated from two streams*
    - ▪ *Unit conversions performed to obtain concentrations*

WTP Baseline Process



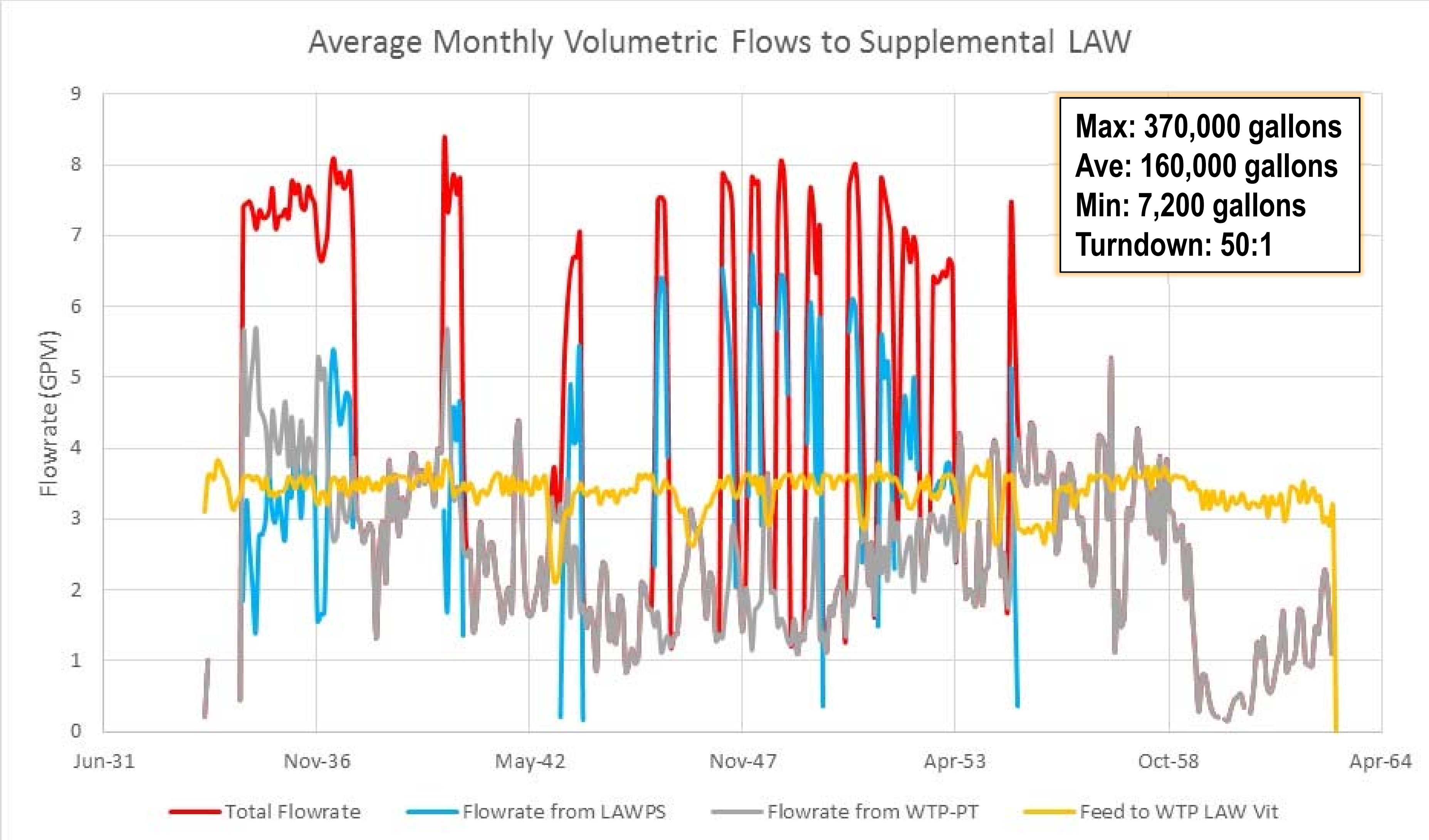
Integrated Flowsheet: Baseline Process Flows to/from Supplemental LAW



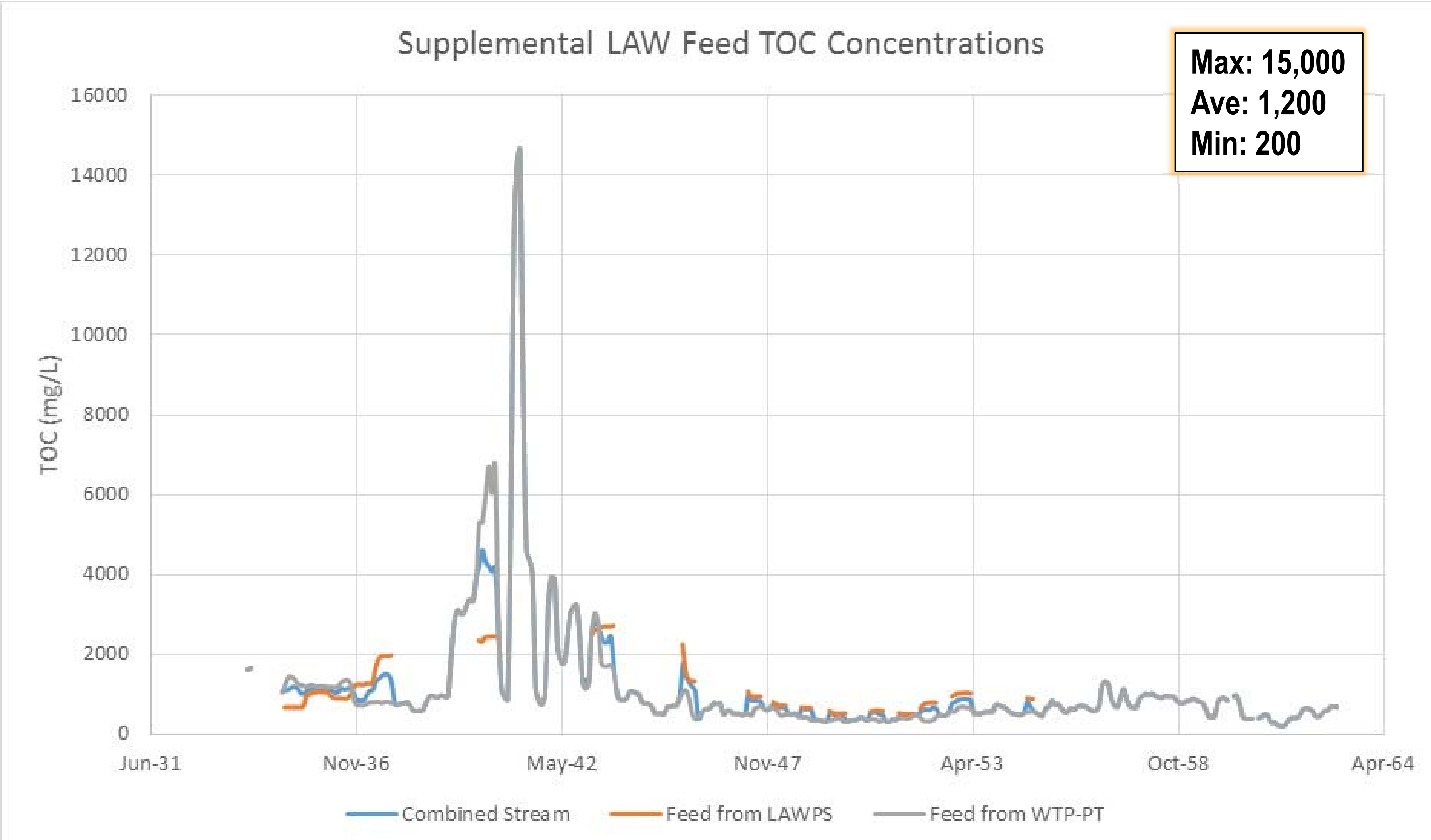
- LAWPS: Low Activity Waste Pretreatment System
- IDF: Integrated Disposal Facility
- WTP-PTF: Hanford Waste Treatment and Immobilization Plant Pretreatment Facility
- LERF/ETF: Liquid Effluent Retention Facility / Effluent Treatment Plant
- LDR: Land Disposal Requirements

Stream numbers are designated stream ID from Integrated Flowsheet

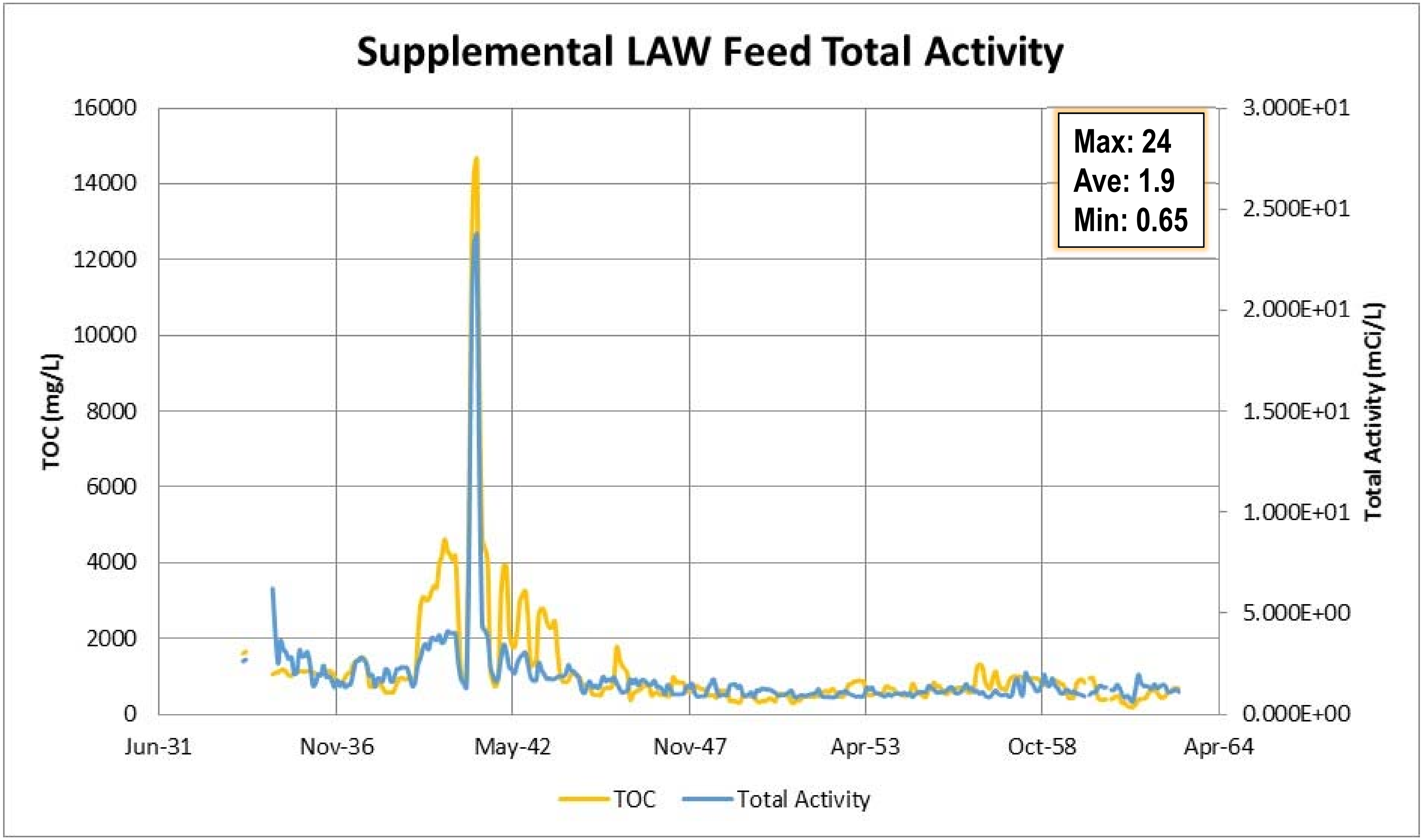
Feed Vector: Flowrates



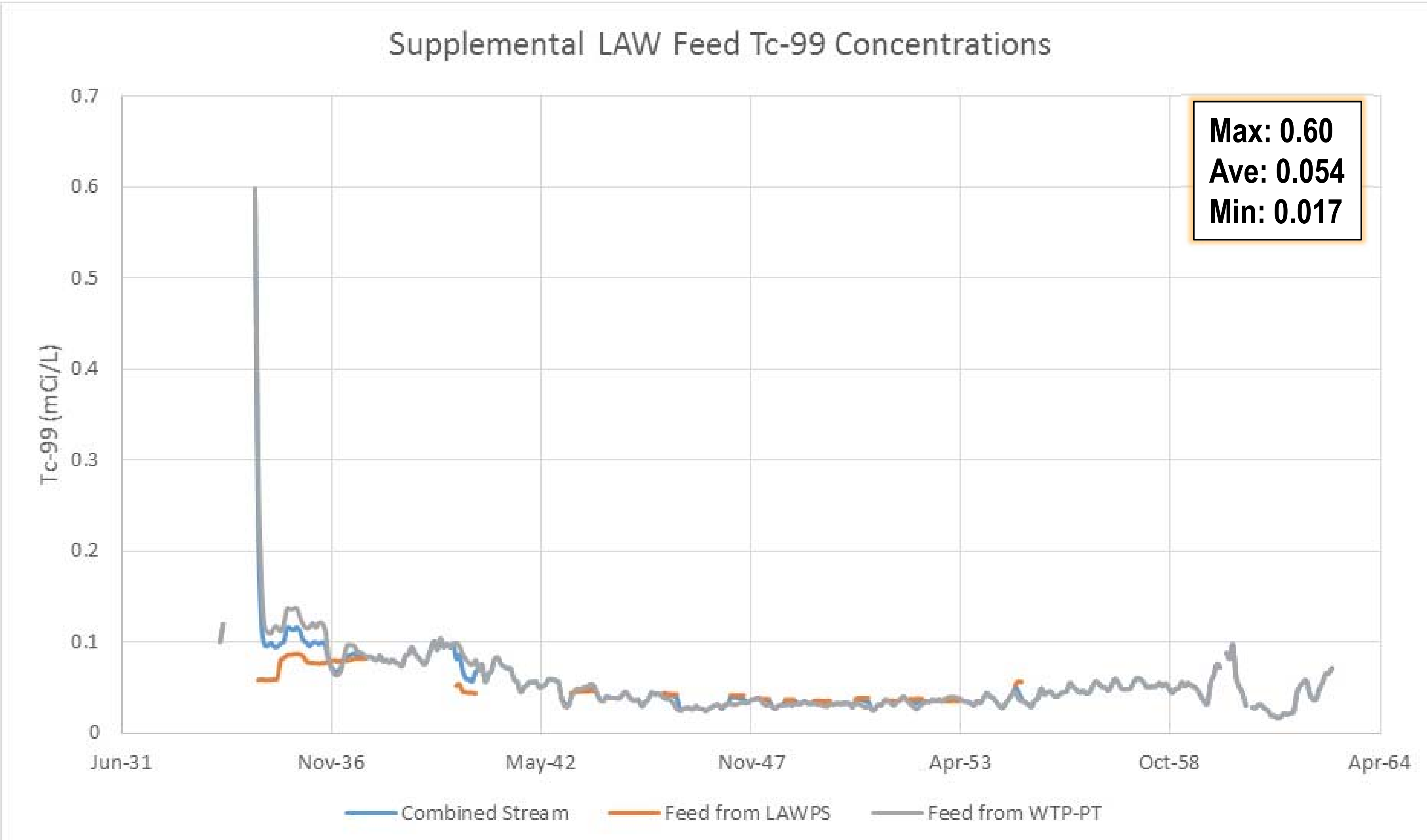
Feed Vector: Total Organic Carbon Concentrations



Feed Vector: Total Activity per Liter



Feed Vector: Technetium-99 Concentrations



Feed Vector: Flowrate and Composition Variation

- **Flow variations**
  - o SLAW combined feed rate increases when "direct-feed" paths (TSCR/LAWPS) to SLAW are operating in addition to the feed to SLAW from the WTP PT facility
    - *Direct-feed path operate when "excess" LAW supernate available from retrieval operations above the LAW supernate fed to WTP PT*
    - *When direct feed operations are performed, the flowrate from the "direct-path" is adjusted to stabilize overall SLAW feed rate*
    - *Variation in flow from PT result from intentionally setting PT operations to consistently feed HLW*
      - – Flowsheet modeling during Integrated Flowsheet did not place any constraints on SLAW feed vector
    - *Processing available supernate from DSTs provides tank space for additional waste retrievals and SST tank closures*
- **Compositional Variations**
  - o Result from the differences in Hanford tank waste and the sequence of waste retrievals
  - o Waste feed retrieval and staging have multiple, competing objectives and many constraints
    - *SST closure plans, available DST space, 242-A evaporator campaigns, transfer routing availability, simultaneous staging of LAW and HLW wastes*
    - *SSTs are operationally isolated – require upgrades to allow retrieval*
    - *DST system upgrades also needed to complete mission*

Comparison of Supplemental LAW to WTP-LAW Production

LAW Facility in June 2009

- **Glass Produced**
  - o Supplemental ILAW:
    - *Revision 1: 576 million kg*
    - *Revision 2: 281 million kg*
  - o WTP-ILAW:
    - *Revision 1: 309 million kg*
    - *Revision 2: 267 million kg*
- **Volume of LAW treated**
  - o Supplemental LAW:
    - *Revision 1: 62.2 million gallons*
    - *Revision 2: 54 million gallons*
  - o 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.

Uncertainties

- **System Plan 8 Assumptions**
  - Funding
  - Retrieval Rates
- **Feed Vector**
  - Composition
    - *BBI uncertainty and data availability; TOPSim simplifications*
    - *Entire tank farm feed is processed, so feed vector should allow a reasonable comparison between technologies to be made*
  - Volume
    - *TOPSim simplifications*
    - *Dependent on funding / policy decisions, other "non-technical" factors*
    - *Results should be scalable, so more important to have consistency between flowsheets versus accuracy in scale of facilities*
- **IDF Performance Assessment**
  - Still in draft form, but nearly finalized
- **Cost Estimation**
  - Comparison of costs between sites is challenging
    - *Different regulatory environment, etc.*

Uncertainties – System Plan 8 Details

- **Assumptions to meet required mission duration**
  - *Funding profile*
    - Flat funding profile is inadequate for WTP PT and HLW completion, TWCSF, Supplemental LAW, WRFs, TF upgrades, etc. as described
    - Significant changes could be required
      - *WTP-PT not restarted – Preparations in progress to restart*
      - *DFHLW*
      - *Modular systems for West area treatment*
  - *Retrieval rates may not be realistic*
    - West-East transfer line availability
    - TF evaporator operation
    - TF operations culture change
      - *Number of transfers in a year increased by orders of magnitude once processing starts*
    - SST tanks at Hanford are out of service and were isolated by cutting piping.

Uncertainties – Feed Vector Composition Details

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

Uncertainties – Best Basis Inventory Details

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

Uncertainties – Feed Vector Volume Details

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

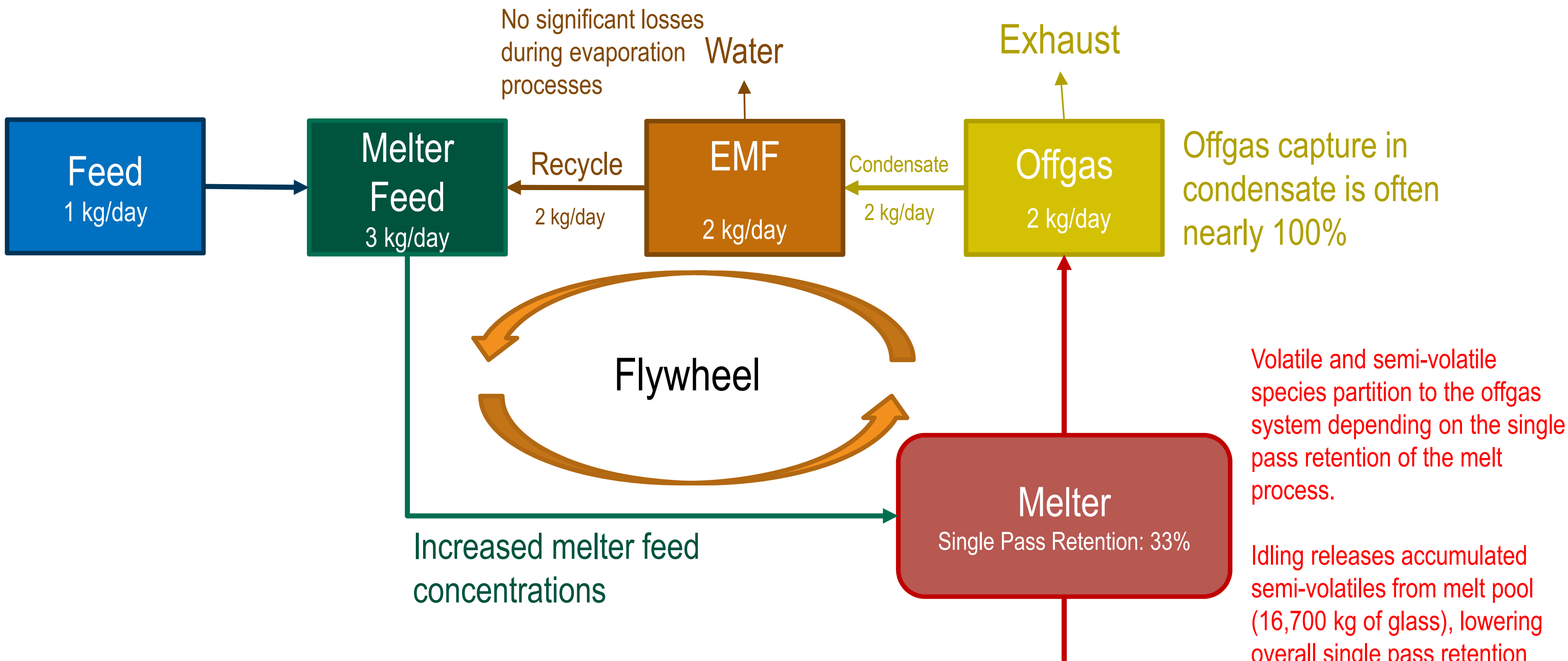
Uncertainties – Integrated Flowsheet Details

- **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*

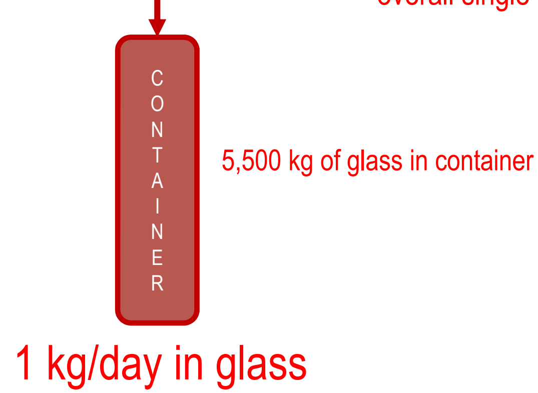
Uncertainties – TOPSim Model Details

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

Flywheel Example: Steady State Operation



Volatile and Semi-volatile species can “flywheel” when offgas condensates are recycled. The increase in feed concentrations are dependent on melter single pass retention, offgas capture efficiency, and EMF partitioning.



LAW Flywheels: Cl, Cr, F, Hg, I, S, and Tc

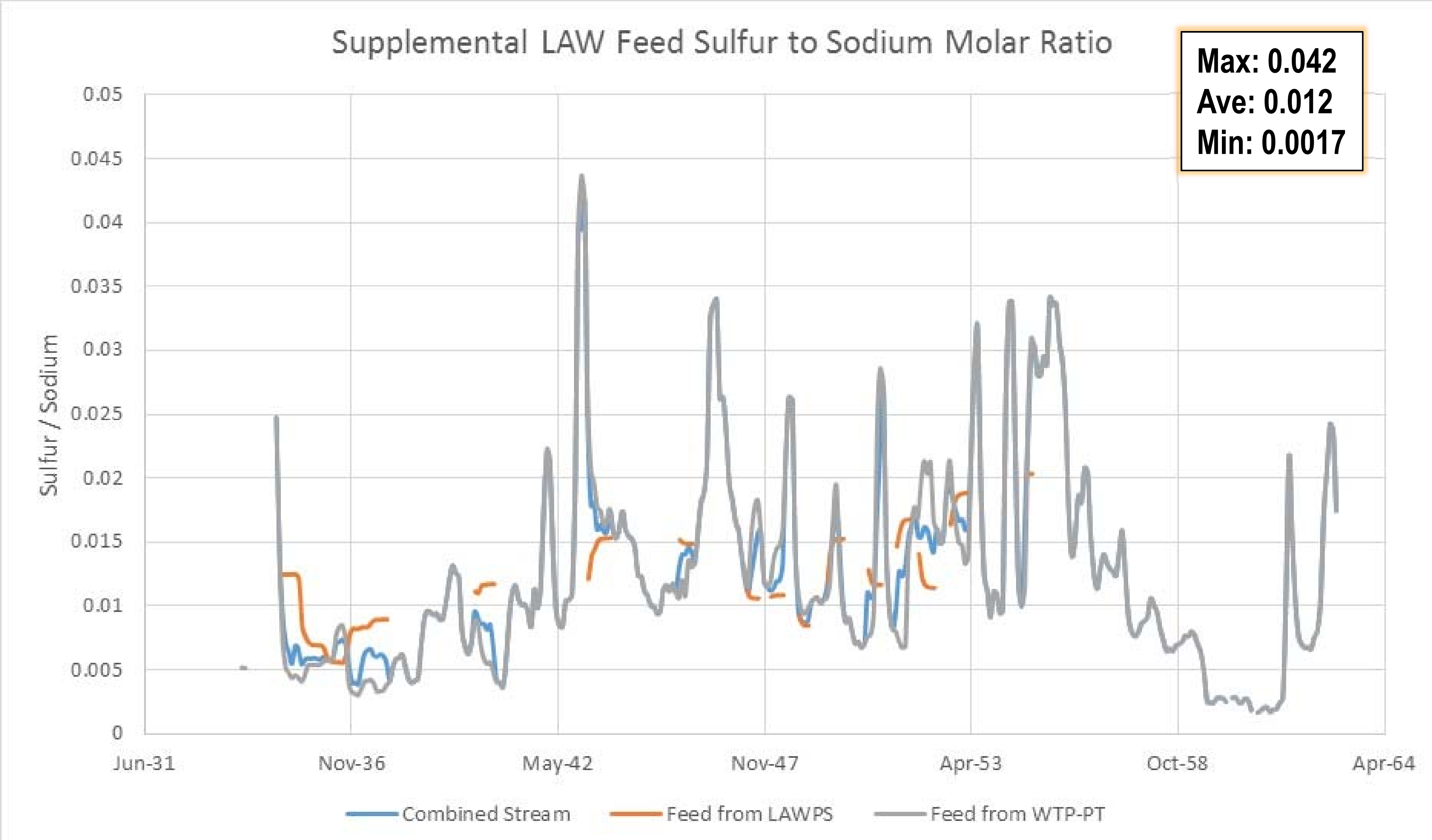
Other Factors for Feed Vector to SLAW

- **Uncertainty in the SLAW Feed Vector is high**
  - Many proposals and initiatives currently under consideration could significantly impact the SLAW feed vector both in volume of waste to be processes and the composition of wastes to be processed
    - *At-tank treatment programs– e.g. Test Bed Initiative*
      - Removes LAW waste treated from projected SLAW feed
    - *West area treatment proposals*
      - Potentially removes LAW waste treated from projected SLAW feed
    - *Direct Feed High Level Waste proposals*
      - Changes timing and flowrates to SLAW
    - *High Level Waste definition clarifications*
      - Could dramatically change entire flowsheet for treating Hanford tank waste
  - SLAW could be completely eliminated or expanded depending on decisions made for processing Hanford tank waste
  - Excess capacity in SLAW to immobilize LAW if constructed for maximum monthly flowrate
- **NDAA scope is specific on the SLAW mission to be evaluated**
  - Not later than 60 days after the date of the enactment of this Act, the Secretary of Energy shall enter into an arrangement with a federally funded research and development center to conduct an analysis of approaches for treating the portion of low-activity waste at the Hanford Nuclear Reservation, Richland, Washington, that, as of such date of enactment, is intended for supplemental treatment.

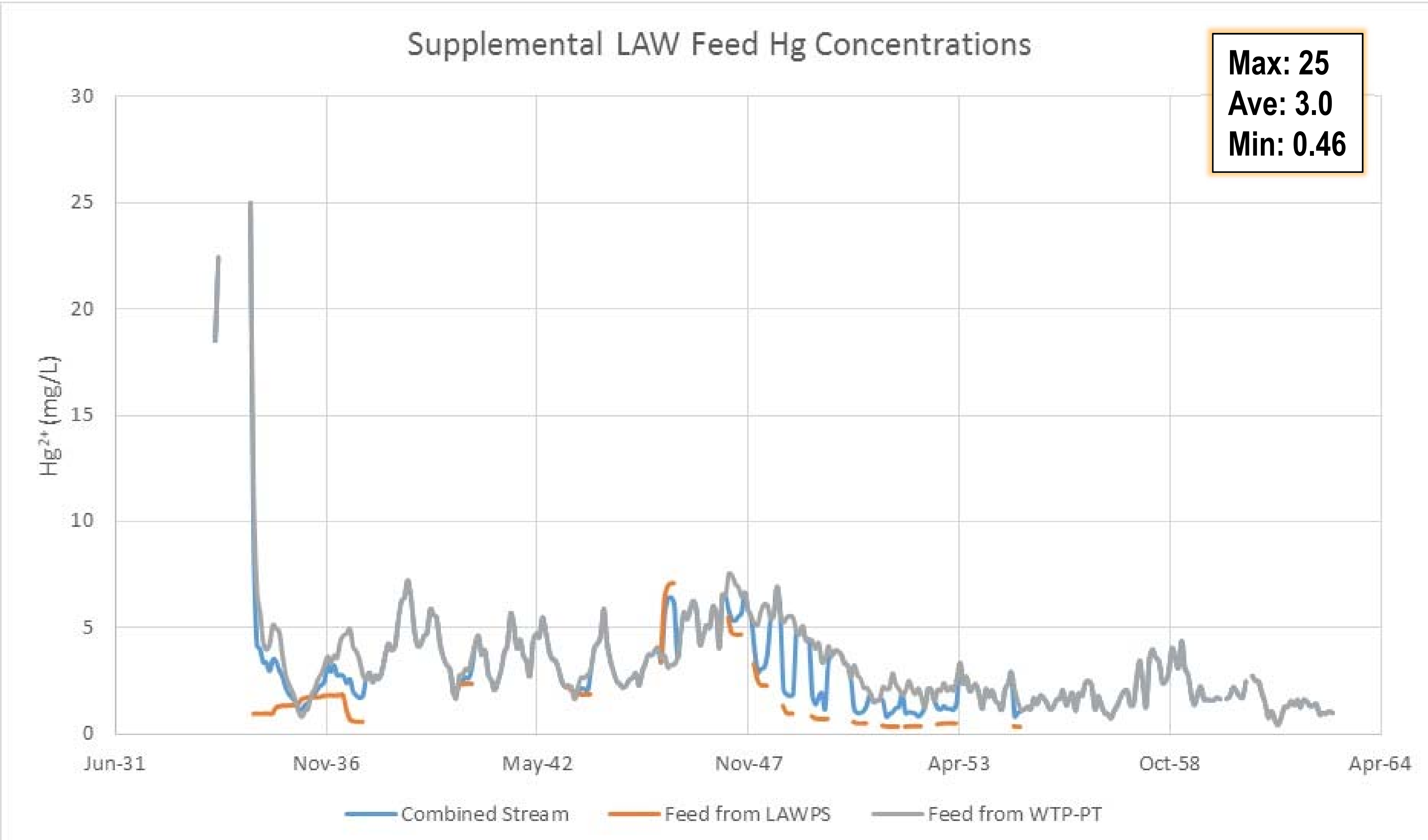
Key Question:
How is the technology selection impacted by scale and composition changes?

Backup Slides

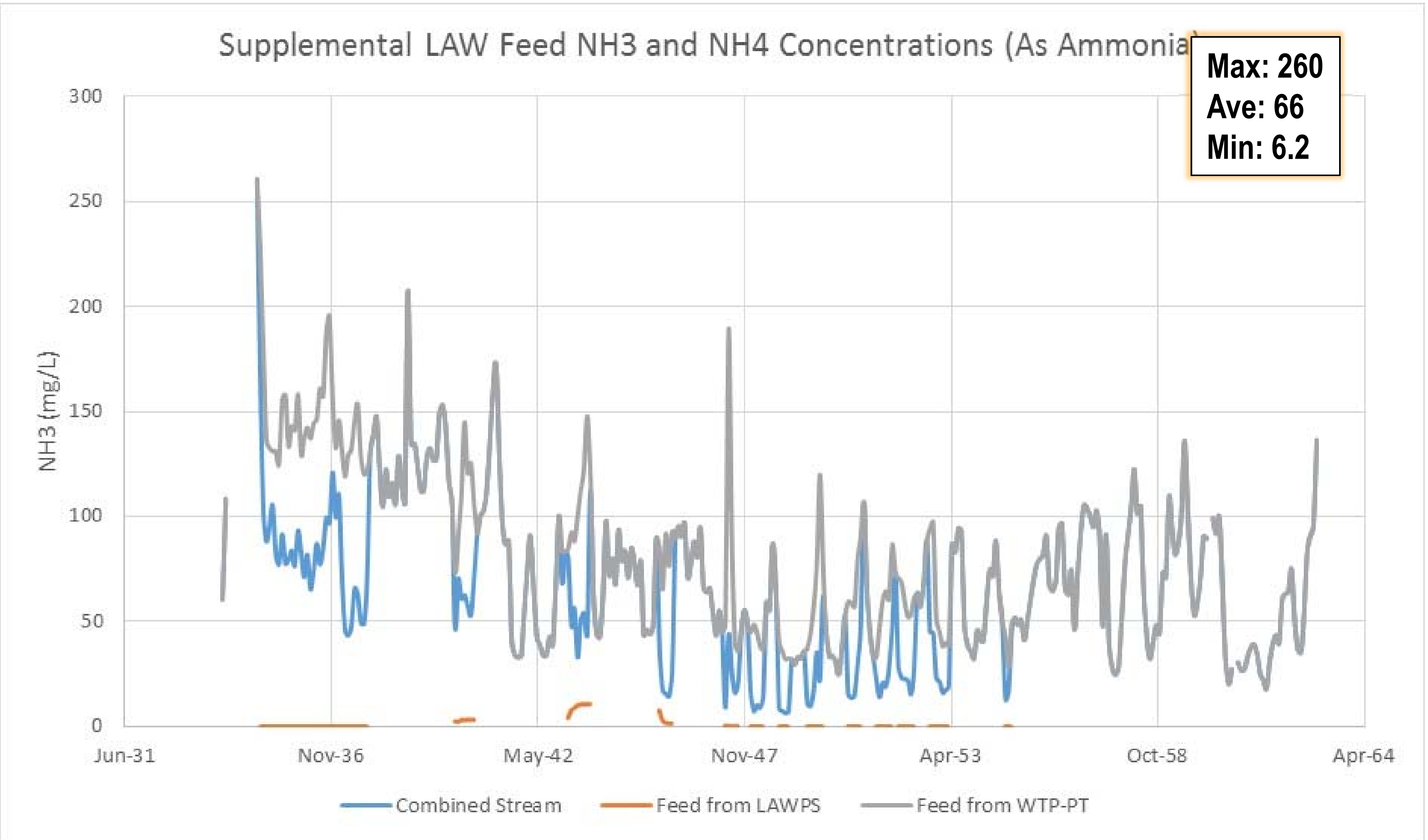
Feed Vector: Sulfur to Sodium Ratio



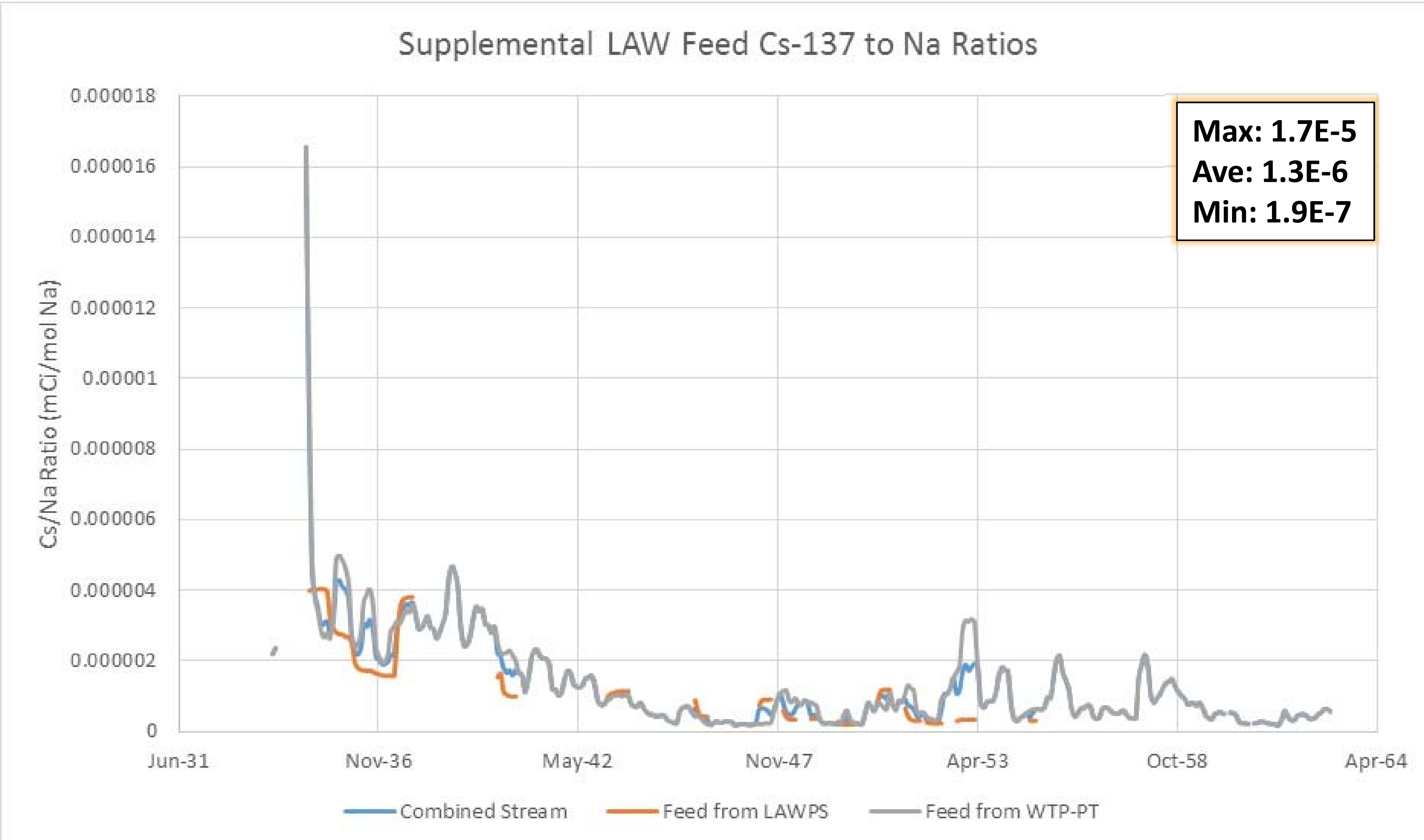
Feed Vector: Mercury Concentrations



Feed Vector: Ammonia Concentrations



Feed Vector: Cesium-137 Ratio to Sodium



HLW and LAW Processing Closely Coupled in Baseline Process

- **HLW and LAW feed paths are intertwined in PT**
  - o 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*
  - o Supernate and solids recombined in PT
  - o 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)*
  - o Cesium removed from LAW combined with HLW solids
  - o 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*
  - o LAW vitrification condensate combined with treated LAW in PT

Integrated Flowsheet: RPP-RPT-57991

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

Integrated Flowsheet, Rev 1

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

Integrated Flowsheet, Rev 2

2.1.3.1 LAW Supplemental Treatment Facility

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

HLW and LAW Processing Closely Coupled in Baseline Process

- **Impact on LAW stream**
  - o Enrichment in species washed and leached from solids
    - *Al, Cr, Na (added to prevent aluminum reprecipitation)*
  - o 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*
  - o Addition of GFC components to LAW stream from melter condensate recycle
  - o Enrichment in cerium from HLW canister decon (and sodium added to neutralize)
- **Impact on LAW flowrate**
  - o Integrated flowsheet operates to optimize HLW canister production rate
  - o LAW generated from HLW processing (concentration, washing, leaching, melter condensate recycle, etc.) is greater than LAW vitrification facility capacity when added to the LAW processed as needed to complete mission at same time as HLW (40 years)
    - *Generates need for supplemental treatment for LAW*

Supplemental LAW in Current Baseline

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

Technical Challenges

- **Immobilization technology viability evaluation**
  - Information from previous testing with Hanford waste or simulants along with information from analog facilities will be utilized to perform the evaluation
    - *Hanford Waste Testing*
      - Vitrification
        - *Numerous tests with Hanford waste*
        - *Numerous pilot scale tests with simulants*
      - Grout
        - *Tests with Hanford waste*
        - *Pilot scale tests with simulants*
      - Steam Reforming
        - *Tests with Hanford waste*
        - *Pilot scale tests with simulants*
    - *Technologies in use at other sites*
      - Vitrification of HLW at SRS and West Valley
      - Grouting of LLW at SRS in large storage vaults
      - Grouting of LLW at West Valley in containers
      - Fluidized bed steam reforming of sodium bearing waste at INL in final startup testing
  - Long term performance
    - *Identify when compositions are outside the bounds of previous evaluations of the technology*
- **Cost Estimation**
  - Significant issues in DOE complex with accuracy of cost estimates for large projects

Conclusions from Feed Vector Evaluation

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

Other Assumptions

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

LAW Processing Acceleration Notes

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

ISM Evaluation – (RPP-RPT-53089)

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

Good predictions	Poor predictions	Additional data required			
		Trending well	Trending poorly	Varied trending	No trending
^{99}Tc	Al	Plutonium isotopes	Uranium isotopes	Ba	Category 1 (except ^{99}Tc and ^{137}Cs)
^{137}Cs	Cr	Ag	$^{59}Ni/^{63}Ni$	Bi	^{129}I
$^{90}Sr/Sr$	F	Nd	Ta	Ca	Te
Cl	PO_4	Ni		Cd	
C_2O_4		V			
Na		$^{90}Y/Y$			
NO_2					
NO_3					
OH					
SO_4					
CO_3					
Fe					

^{90}Sr had accurate ISM predictions in all tanks reviewed, but the ISM poorly predicted its concentration in the saltcake dissolution studies. However, since ^{90}Sr is a Category 2 component, the ISM should predict the correct dominant phase not necessarily the correct concentration to a factor of 2. ^{90}Sr is highly insoluble and it is easy for the liquid concentration to change dramatically when the major phase is still picked accurately. In addition, ^{90}Sr is subject to the carbonate concentration, which could be subject to assumption made during mass balancing and experimental data reconciliation. The ISM ^{90}Sr concentration predictions in saltcake dissolution may not be within a factor of 2, but the dominant phase is accurately predicted.

Concentration values predicted within a factor of 2 were considered good

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Pertinent Pretreatment Technologies and Maturities

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NAS Committee Meeting #4
November 29 and 30, 2018
Richland, WA

Pre-Decisional

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Overview

- Pretreatment Concepts
- Approach
- Requirements
- Technology Options
- Status of Technologies

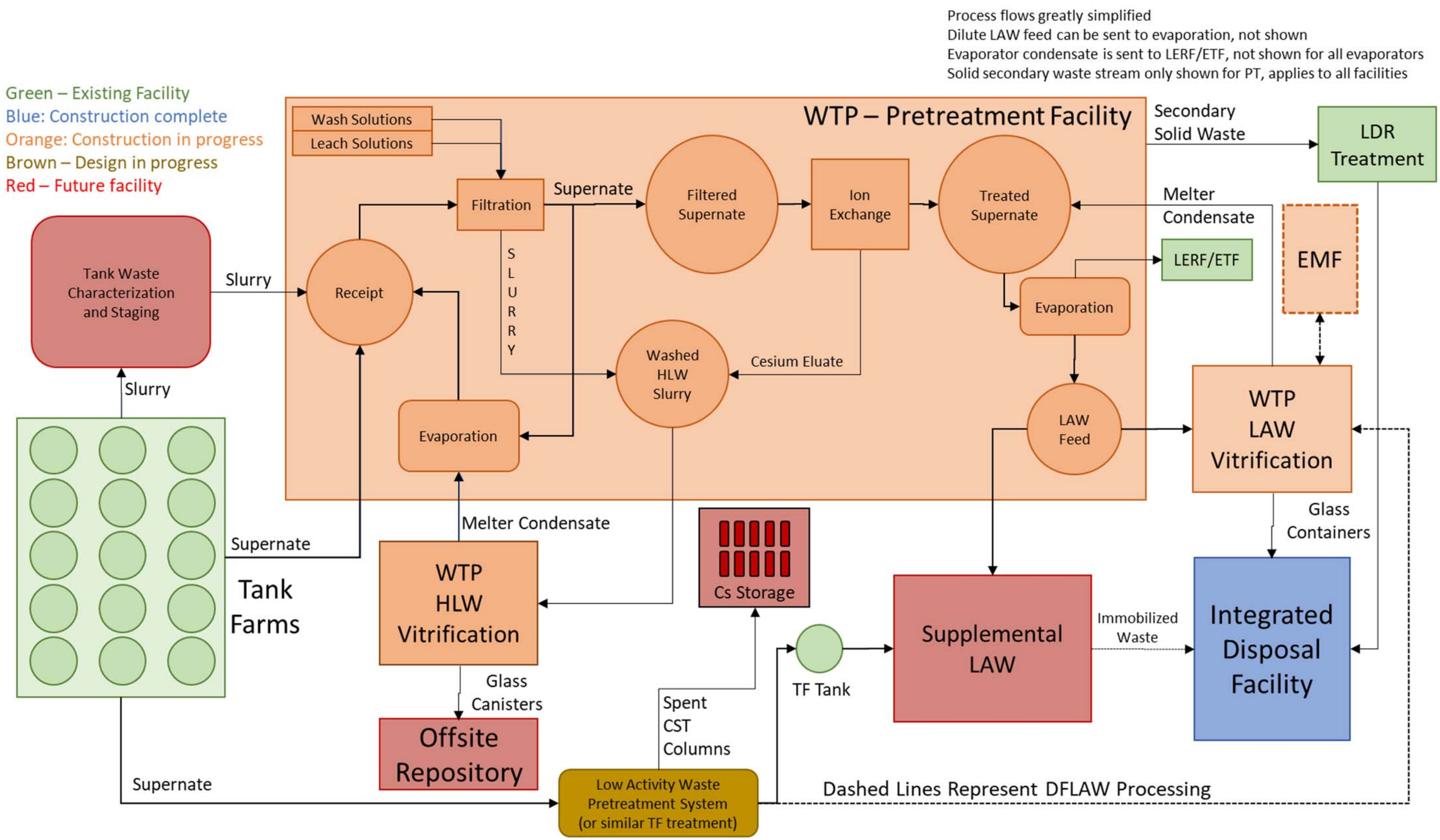
Sec. 3134 "Further Processing"

- **"(1) An analysis of <u>at a minimum</u>, the following approaches for treating the low-activity waste …:**

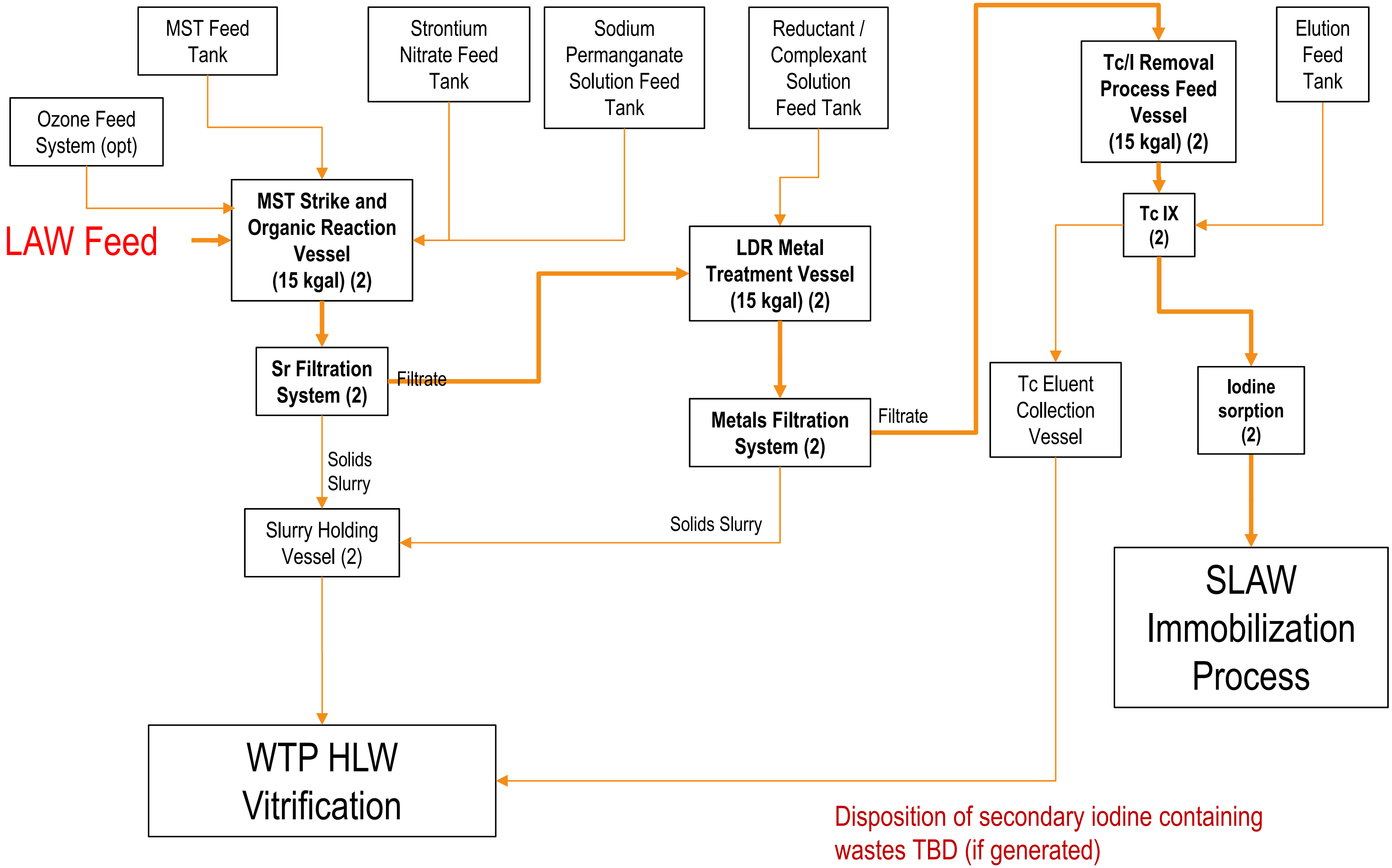
  (A) *<u>Further processing</u>* of the low-activity waste to remove long-lived radioactive constituents, particularly *<u>technetium-99 and iodine-129</u>*, for immobilization with high-level waste.

- **In response, the FFRDC Team is identifying and analyzing:**
  - Further processing alternatives that reduce the levels of:
    - *Iodine*
    - *Technetium*
    - *Could change the waste class (strontium)*
    - *Could address Land Disposal Restrictions*

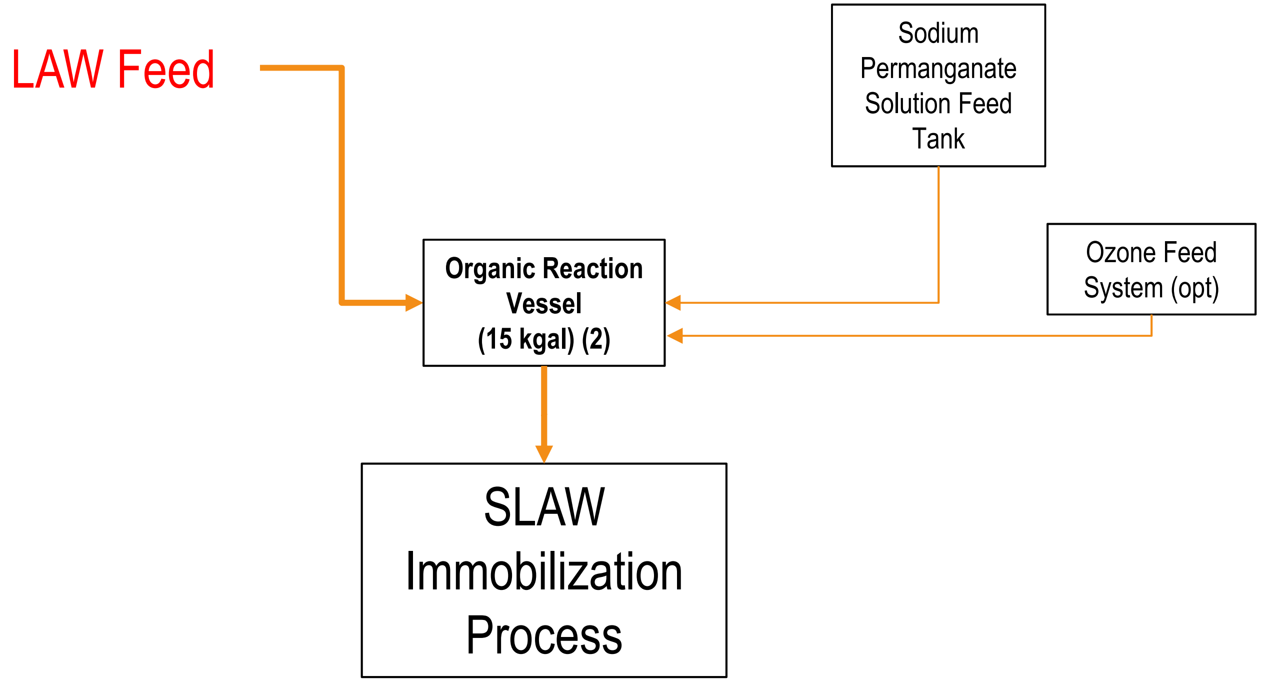
WTP Baseline Process as Defined in Integrated Flowsheet



Supplemental LAW Pretreatment Concept



Supplemental LAW Pretreatment Concept: LDR Organic Treatment Only



Methodology for Identification and Analysis of Further Processing Approaches

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

Removal Requirements

- **Tc Removal Target:**
  - *Primary Basis - 2017 IDF PA, Extracted summary plots from Pat Lee presentation to NAS committee, 2/27/18*
  - *Assumptions:*
    - *LSW grout is conservative relative to performance of ILAW grout*
    - *LSW performance extrapolation linear to much higher Tc inventories*
    - *Fraction of Tc inventory for SLAW is 50%*
  - *Based on these assumptions and ground water Maximum Contaminant Level (MCL) of 900 uCi/L* to meet groundwater resource protection performance measures an overall Tc removal of 92% is required*
  - *To limit the ground water concentration to 100 µCi/l an overall Tc removal of 99% is required*
- **Iodine Removal Target:**
  - *Primary Basis - 2017 IDF PA, Extracted summary plots from Pat Lee presentation to NAS committee, 2/27/18*
  - *Assumptions*
    - *LSW grout is conservative relative to performance of ILAW grout*
    - *LSW performance extrapolation linear to iodine inventories*
    - *Fraction of iodine inventory for SLAW is 50-60%*
  - *Based on these assumptions and a ground water MCL of 1 uCi/L to meet groundwater resource protection performance measures an overall iodine removal of 48 – 57% is required*
  - *To limit the ground water concentration to 0.05 µCi/l an overall iodine removal of 97 – 98.8% is required*

** MCL is 4 millirem/year for beta particle and photon radioactivity from man-made radionuclides in drinking water. The average concentration of Tc-99 which is assumed to yield 4 mrem/yr is 900 pCi/L*

Removal Requirements, continued

- **Strontium Removal Targets for Grouted Waste Form**

Grout (1770 kg/m3, all nuclides retained and 1.8 multiplier)					
% Sr-90 removal	GTCC (months)	Class C (months)	Class B (months)	Class A (months)	Notes
None	0	33	408	0	TRU's from WTP PT cause Class C
90% removal	0	33	338	70	
95% removal	0	33	314	94	
99% removal	0	33	2	406	

- **Strontium Removal Targets for Glass or Steam Reforming (NOT CURRENTLY PLANNED)**

Glass (or Steam Reformed?) (2600 kg/m3, all nuclides and 1.0 multiplier)					
% Sr-90 removal	GTCC (months)	Class C (months)	Class B (months)	Class A (months)	Notes
None	0	42	399	0	TRU's from WTP PT cause Class C
90% removal	0	42	399	0	
99% removal	0	42	1	398	

Methodology to Assess LDR Organics

- **Hanford tanks are suspected of containing a wide range of LDR organics, as documented in the Part A RCRA Permit for both SSTs and DSTs.**
- **Significant characterization of radionuclides and inorganics in the liquid and solid phases of the tank waste has been conducted and is continuing**
  - However, there is much more limited data on presence and concentration of LDR organics in the SLAW feed.
- **Recent organics characterization of a very limited set of tank waste samples has identified some LDR organics, but most at very low levels, and this limited data cannot be extended to the broader set of tanks.**
- **There is a more robust set of organics data from headspace and tank farm exhauster stack emissions sampling.**
- **Maximum potential organic content in the tank liquid wastes was approximated by converting maximum tank headspace and exhauster measurements of all LDR organics actually detected in historic sampling to liquid waste concentrations using Henry's Law Constants for each organic.**
  - This was a screening-level analysis, designed to assess whether there was a potential for LDR organics to greatly exceed LDR total waste standards that would indicate treatment was required.

Methodology to Assess LDR Organics

		Henry's Law	AW-106 R	AW-106 NR
Chemical Name	CAS Number	Exceedance of Total Waste Standard (from Max Headspace Vapor Conc.) (Cmax / Cstd)	Exceedance of Total Waste Standard (Cmax / Cstd)	Exceedance of Total Waste Standard based on reporting / detection limits (Cmax / Cstd)
Propane, 2-nitro-	79-46-9	N/A*		
Phenol	108-95-2	2060	0.000	**23.0**
1,2-Benzenedicarboxylic acid, bis(2-ethylhexyl) ester	117-81-7	1140	0.000	1.16
Ethanone, 1-phenyl-	98-86-2	687	0.000	0.00
Phenol, 2-methyl-	95-48-7	483	0.000	8.50
1,2-Benzenedicarboxylic acid, diethyl ester	84-66-2	235	0.000	2.67
Morpholine, N-nitroso-	59-89-2	137	0.000	2.01
2-Propanone	67-64-1	126	0.105	0.00
Methanamine, N-methyl-N-nitroso-	62-75-9	113	**4.530**	2.30
2-Butanone	78-93-3	104	0.035	0.00
1-Butanol	71-36-3	95.9	0.000	0.73
Pyridine	110-86-1	75.5	0.000	77.10
Methanol	67-56-1	49.1	0.000	0.00
Acetic acid ethyl ester	141-78-6	40.4	0.000	0.01
Propanenitrile	107-12-0	34.1	0.000	0.00
Acetonitrile	75-05-8	7.6	0.000	0.00
1-Propanol, 2-methyl-	78-83-1	5.5	0.000	0.29
Dichloromethane	75-09-2	5.1	0.000	0.01
2-Pentanone, 4-methyl-	108-10-1	4.9	0.000	0.03
9H-Fluorene	86-73-7	2.1	0.000	13.60
2-Propenal	107-02-8	1.5	0.000	0.00
1-Propanamine, N-nitroso-N-propyl	621-64-7	1.5	0.000	2.50

* 2-nitro-propane has treatment based standard rather than concentration based standard

Methodology to Assess LDR Organics

- **LDR Organic Summary**
  - o 114 relevant LDR organics that are known or suspected to be present in tank waste based on results of a regulatory data quality objectives process
  - o 61 of these LDR organics detected in tank headspace or tank farm exhausters above detection levels
  - o 22 of these LDR organics have the highest potential to exceed LDR total waste standards, based on approximate tank waste concentrations estimated from maximum vapor concentrations.

- **LDR Organics Removal Target:**
  - o Cast Stone (CS) process does not meet the definition of HLVIT to address suspected organics.
  - o As a stabilization technology, CS is a less likely candidate for a determination of equivalent treatment (DET), and is generally not an acceptable treatment technology for organics.
  - o However, chemical oxidation is and is routinely used in conjunction with grouting
  - o *Assumptions:*
    - *Some organic treatment / destruction will be required.*
    - *Requirement / treatment variable between tanks*
    - *Required removal / destruction specific organics could range from 50% to 99.9% for selected tanks.*

LDR Removal Requirements, continued

- **LDR Metals Removal Targets:**
  - RCRA metal content indeterminant based Feed Vector / Tank chemical analysis.
  - Tank / batch specific waste form TCLP results needed to determine if tank or batch-specific conditions would require additional pretreatment to assure that final waste form would meet LDR requirements.
  - *Assumptions:*
    - *Some metal removal / complexation will be required.*
    - *Selected RCRA metal removal / complexation may be required for selected tanks*

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

Sr Removal Options

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

Tc Removal Options

- **A number of options have been identified and developed to various degrees:**
  - *Solvent Extraction*
    - *SrTALK (DI+butylcyclohexano)-18-crown-6) in TBP:Isopar*
      - Moyer's group developed a process (SrTalk) for removing Sr and Tc from wastewater in the late '90s. The Sr part doesn't work in high alkalinity, but the Tc part worked well.
  - *Ion-Exchange*
    - *Numerous materials tested as part of Tank Waste Remediation System (TWRS) program (see table below)*
    - *SuperLig-639®, (a polystyrene matrix resin with a crown-ether based organic linker covalently attached), has the best adsorption separation capacity under realistic conditions. (DF of ~100 for wastes without significant amounts of organic complexants)*
- **Complications**
  - *Batch contact and laboratory-scale ion exchange column tests have indicated that 1 to 5 percent of the technetium present in samples of non-complexed tank wastes is not present as the pertechnetate anion and cannot be extracted using SuperLig 639 resin.*

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

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

Iodine Removal Options

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

LDR Organics and Metals Management Options

- **Organic Management**
  - *Chemical Oxidation (CHOXD)*
    - *Permanganate – could be added in the field to the tanks or in the pretreatment facility*
    - *Peroxides*
    - *Ozone (in selected cases) – has the advantage of not adding additional chemicals and also dissipates fairly quickly, so it is less likely to interfere with later processes*
  - *Recovery of Organics (RORGS)*
    - *Carbon adsorption*
    - *Liquid / Liquid Extraction*
    - *Physical phase separation / centrifugation*
- *Metals Management*
  - *Chemical Reduction*
  - *Admix to waste form*
- *Complications*
  - *Oxidation rates for permanganate are slower than peroxide and ozone reactions.*
  - *99.+% destruction of some organics may be very difficult in bulk treatment.*
  - *Generation and injection/distribution of sufficient ozone.*
  - *Analytical limitations / detection limits.*

Status of Technologies

- **TRL**
  - Strontium removal using MST – TRL 6 (Medium)
  - Tc removal using Superlig 639 – TRL 5-6 (Medium)
  - Iodine removal using AgNP – TRL 2-3 (Low)
  - LDR organic using permanganate – TRL 6 (Medium)
  - LDR organic using ozone – TRL 3-5 (Low to Medium)
  - LDR metal complexation – TRL 4 (Medium)
- **Cost of implementing these as standalone options is still being refined**
- **Schedule**
  - Directly tied to the supported treatment option(s)
  - Pretreatment steps add slightly to the schedule due to additional processing steps and analytical
- **Benefit**
  - In the suite of options evaluated, pretreatment is only utilized with the grout options
  - Provides a broader range of options for the treatment and disposal options for SLAW
- **Risk (Technical)**
  - For each of these pretreatment unit operations there are the following risks:
    - *The selected technology is unable to achieve the desired decontamination factor with some feed streams.*
    - *The selected technology fails to achieve required decontamination factor or cannot be matured successfully*
      - With the exception of iodine, it was assumed that technologies can be matured successfully prior to start-up and without impacting schedule
    - *Five specific risks have been identified and are shown on the following slide*

Pretreatment Risks

Case	Cause	Mitigation	Unmitigated Consequences	Mitigated Consequences
Grout Cases 2d, 2e1, 2e2, 2f, 2g2 (LDR Organic Oxidation)	During operation it is determined that for a range of tank compositions non thermal oxidative methods do not result in sufficient LDR organic destruction	Divert problematic waste streams to LAW VIT - able to swap other waste to balance SLAW and LAW VIT - no impact on schedule.	Diverts to LAW VIT, but more waste causes delay in schedule, inability to balance SLAW and LAW VIT	Cost of vitrifying fraction of LAW stream that was planned to go to grout
Grout Cases 2e1, 2e2 (Tc/I Seps [to HLVIT or WCS])	After start up, found >5% of Tc in SLAW is non-pertechnetate and cannot be removed by SuperLig 639 resin	Modify/replan feed sequence to direct non-pertechnetate to LAW VIT	Ship non-compliant SLAW to offsite disposal	Cost of vitrifying fraction of LAW stream that was planned to go to grout
Grout Cases 2e1, 2e2 (Tc/I Seps [to HLVIT or WCS])	Method to effectively remove 50 to 98% of the iodine in the tank waste is not developed in time	Pursue negotiations with WA for disposal acceptance	2G2 - offsite disposal	Negotiation
Grout Case 2f (Class A target)	At start up of operations it is determined that the Sr-90 removal system does not have the expected removal efficiency	Improve Sr90 strike efficiency through development/testing	Cost and delays associated with pursuit of alternative non-grout technology - extended operation of LAW and HLW Vit	Cost and schedule of development testing improvement of Sr-90 strike and potential HLW canisters
Grout Cases 2d, 2e1, 2e2, 2f, 2g2 (LDR Organic Oxidation)	During operation it is determined that for a range of tank compositions non thermal oxidative methods do not result in sufficient LDR organic destruction	Divert problematic waste streams to LAW VIT - able to swap other waste to balance SLAW and LAW VIT - no impact on schedule.	Diverts to LAW VIT, but more waste causes delay in schedule, inability to balance SLAW and LAW VIT	Cost of vitrifying fraction of LAW stream that was planned to go to grout

Status of Technologies

- **Areas requiring further analysis and / or R&D**
  - Improved analytical methods to quantify levels of LRD organics in the feed vector
  - Maturation of each of the primary technologies to TRL 8
  - Significant work remains to demonstrate the removal of iodine from caustic waste streams.
  - Development of an iodine waste form compatible with the removal method
  - Demonstration of large scale ozonation system
  - R&D is needed to demonstrate the oxidization of the full range of LDR organics either with ozone alone or in combination with permanganate.
    - *Determine mixing parameters, residence time, oxidation rates, etc.*
  - Demonstration / confirmation that grout formulations will pass TCLP as is, or with additional pretreatment, for LDR metals

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

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SRNL Environmental Stewardship Directorate

NAS Committee Meeting #4
November 29 and 30, 2018
Richland, WA

Pre-Decisional

Outline

- **Glass Waste Form Overview**
- **Updated vitrification flow diagram**
- **Cost**
- **Schedule**
- **Benefits**
- **Regulatory Compliance**
- **Potential Risks/Obstacles**
  - o Technical
  - o Programmatic

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

Vitrified Waste Forms

- **Vitrified waste forms are used for solidifying high-level waste**
- **Vitrified waste forms have been demonstrated for (1) Solidifying low activity waste (2) Stabilizing toxic waste, and (3) Repurposing hazardous waste into commercial products (fiber).**
- **Vitrification technology is Best Demonstrated Available Technology for high-level waste**
- **Vitrified waste forms**
  - o Volume decrease from liquid waste to glass waste 1 L waste to ~ 0.4 L glass;
    - ~>2 L secondary waste (SRS DWPF ~ 6-7 L)
  - o Robust, but complicated, formulation design (ingredients and proportioning)
  - o Continuous operation (melter idling, start up and shut down undesirable)
  - o Commercially available reagents
  - o DOE and international experience for HLW (UK, Belgium, Germany, Japan, and France)
- **Glass waste form—using the same glass models as the WTP LAW —tailored for sodium-salt wastes;**
- **Demonstration of glass stabilization with legacy Hanford waste**
  - o In 2000, SRNL produced 25 pounds of glass from 7.5 L of AN-102
  - o In 2018, PNNL produced 20 pounds of glass from LAW using the current glass models

Vitrification Case Process Flow Diagram—Disposal at IDF (WA)

- **Process Summary**
  - Glass composition based on WTP LAW facility
  - Glass poured in 2.59 m^3 stainless steel containers, which are transported for disposal at IDF
  - Liquid secondary waste process through EMF and ETF, grouted for disposal at IDF. Solid secondary waste grouted for disposal at IDF.

- **Technology Maturation**
  - Overall process is fairly mature – TRL 7
    - Materials handling equipment off the shelf
    - Waste handling method and equipment not unique
    - Melter design demonstrated at smaller scale
    - Most offgas system components in use at other facilities
  - Additional R&D underway to develop glasses with higher waste loading while maintaining acceptable performance

- **Primary Risk Considerations**
  - *Risk:* WTP LAW throughput (70% TOE) not achieved in actual operations. (REG ID#VIT2)
  - *Mitigation Strategy:* Redesign of SLAW vit baseline to meet throughput requirements.

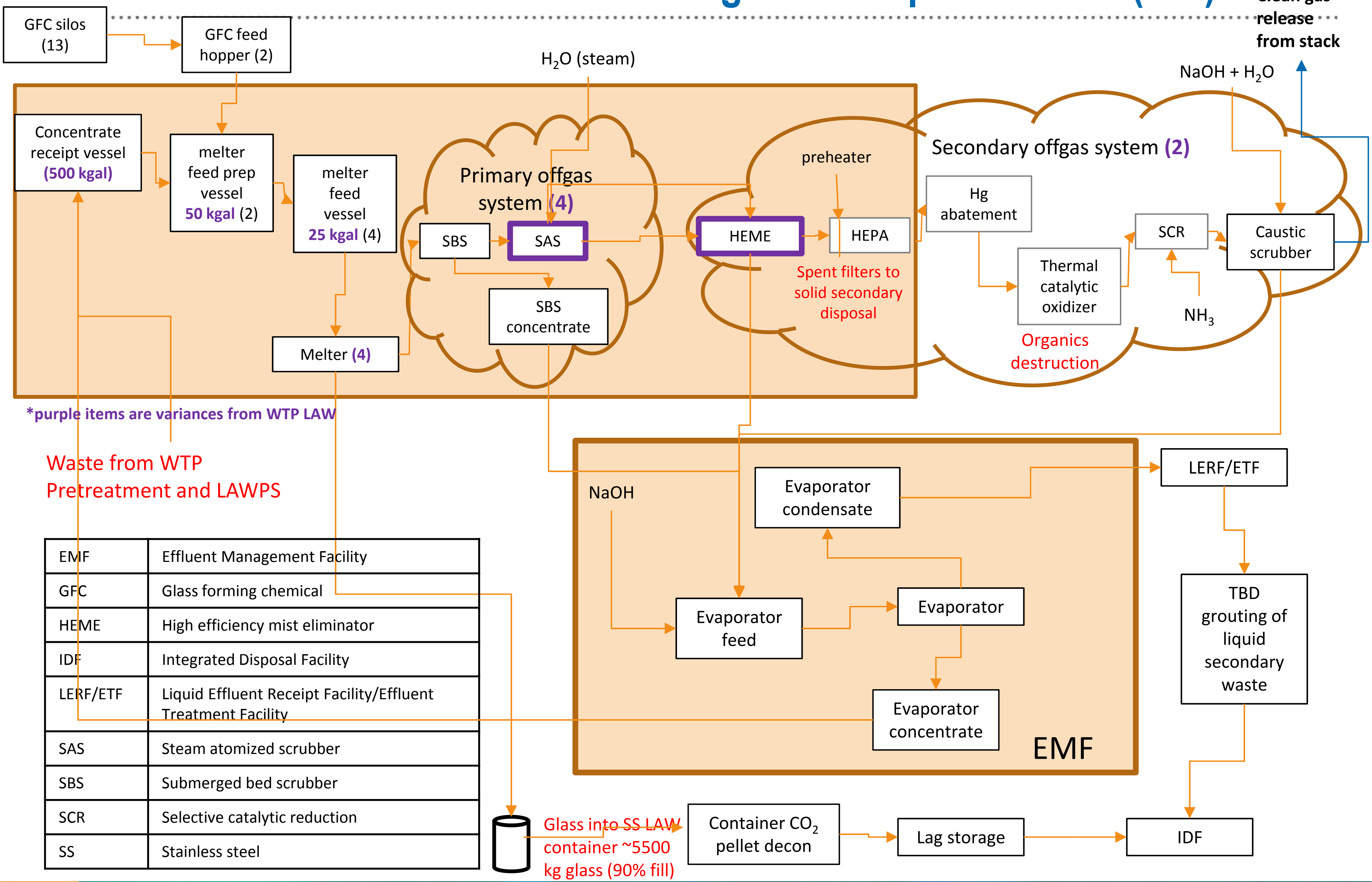
- **Potential Opportunities**
  - Apply lessons learned from WTP LAW start up for design and operations

Vitrification - Basis

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

- **Waste concentrate received from LAWPS or WTP PT (88 gpm)**
- **Waste is analyzed (time for sample collection, transport, and analysis is 10.5 hr) to select and add GFCs LAW Glass Shells v3.0 (2013 glass models) perform the following steps:**
  1. Take stream data and convert it to glass oxide values that are usable in the calculations
  2. Estimate a probable mass and glass chemistry for a batch
  3. Determine the glass properties for the batch using glass property models
  4. Adjust the glass additives, as necessary, to bring the glass properties to within prescribed limits
  5. Determine the amounts of glass former minerals to supply glass additives
  6. Determine impurities and their amounts that accompany the glass additives in the glass forming minerals
- **Blended feed (concentrate plus GFCs) are fed to the Melter Feed Vessel (50 gpm)**
  - Feed rate to the two melters is determined by composition and properties of the waste.
- **Glass is poured into containers that are then cooled and decontaminated**
  - Containers are disposed of in IDF
- **Melter offgas treated via primary and secondary unit operations**
  - Contaminated portion of offgas condensate is returned to front end
  - Liquid secondary wastes treated at LERF/ETF, grouted and disposed of in IDF
  - Solid secondary wastes are grouted and disposed of in IDF

Vitrification Case Process Flow Diagram—Disposal at IDF (WA)



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 Case

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

Modifications to WTP LAW flowsheet for SLAW baseline:

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

Cost and Schedule—Vitrification

Cost Estimate: $19–40 B

Technology Development	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replacement	D&D	Total Program Cost*
$340M – $1560M	$1,000M – $2,600M	$6,800M – $15,600M	$1M – $2.6M	$8500 – 15,100	N/A	$770M – $2100M	$TBD	$19,000M – $40,000M

* Values rounded

Schedule Estimate: >10 years to hot start up

- Highest cost option
- Longest lead schedule
- Cost and schedule estimates informed by WTP LAW
- Cost and schedule estimates include R&D associated with validating retention properties of Cast Stone and with conducting formal performance assessment

Benefits—Vitrification

- **Most studied waste form**
  - o VSL, PNNL, and SRNL have studied LAW glass for decades
- **Same waste form as the WTP LAW glass**
  - o Already demonstrated to be acceptable at IDF
- **Same process as the WTP LAW glass**
  - o Facility design complete with exception of lessons learned
  - o Unforeseen processing issues identified out by WTP LAW
- **Volume reduction of primary waste stream**

Regulatory Compliance—Vitrification

- High likelihood to meet DOE technical performance criteria for onsite disposal (IDF) (e.g., DOE 435.1)
- Permitting of glass at IDF expected
- Grouted secondary solid waste form and secondary liquid waste form for onsite disposal pending

Overall Risks/Obstacles—Vitrification

- **Technical**
  - Total Operational Efficiency (TOE) of 70% required to meet throughput requirements for System Plan 8 intended mission life is optimistic for a vitrification facility integrated with several other facilities
  - Liquid secondary waste waste form in early stages of development
  - Advance glass compositions being developed to meet SP8 throughput, do not meet Ecology performance expectations/permitting requirements
  - Melter idling during actual operations of SLAW significantly decreasing waste loading (S and halides) and increases LSW volume and Tc99 levels

- **Programmatic**
  - Applying Lessons Leaned from WTP LAW may delay start up

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

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Richland, WA

Pre-Decisional

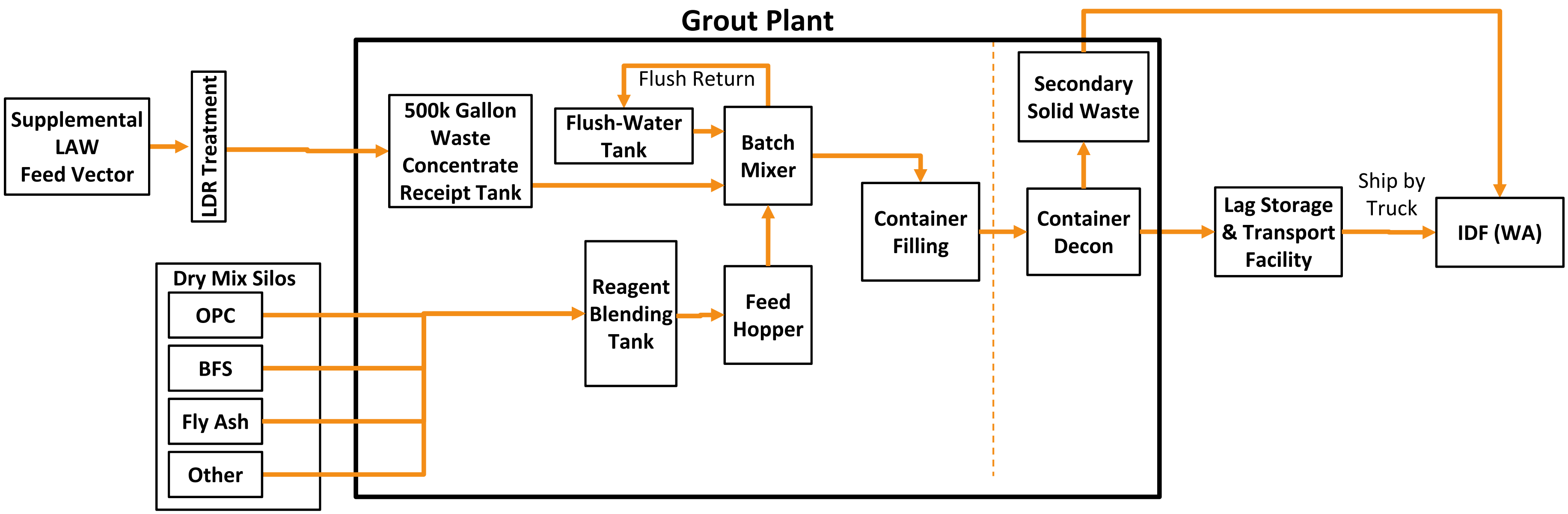
Outline

- Grout Waste Forms Overview
- Updated process flow diagrams
  - o Grout Case I (disposal at IDF)
  - o Grout Case II (disposal at WCS)
- Cost/Schedule
- Benefits
- Regulatory Compliance
- Potential Risks/Obstacles (technical and programmatic)
- Areas for Further Analysis

Grout Waste Forms (Cement-Based Technology)

- **Cement-based waste forms are used for: (1) Solidifying aqueous waste, (2) Stabilizing selected RCRA and radioactive 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**
  - Volume increase from liquid waste to grouted waste ~1.8X (TBD based on final mix); for Supplemental LAW, 204,400 m^3 => ~370k m^3 grouted waste
  - Ambient temperature process—limited secondary waste (minimal off gas); does not inherently destroy organics
  - Personnel safety — spills, movement of monoliths, no high temperature concerns
  - Operational flexibility (quick start up and shut down, one to three shifts/day, easily scaled)
  - DOE, commercial, and international experience (UK, France, Spain, EU utilities, Russia, South Korea)
- **Cast Stone—similar to SRS Saltstone—tailored for solidification of high pH sodium-salt wastes; new data on Cast Stone suggest improved performance relative to 2003 EIS**
- **Cast Stone waste form demonstrated with 3 gallons of decontaminated Hanford waste**
  - Perma-fix prepared Cast Stone plus proprietary reducing agent; passed TCLP
  - Containers shipped to WCS for disposal, along with 1 container of secondary waste

Grout Case I Process Flow Diagram—Disposal at IDF (WA)



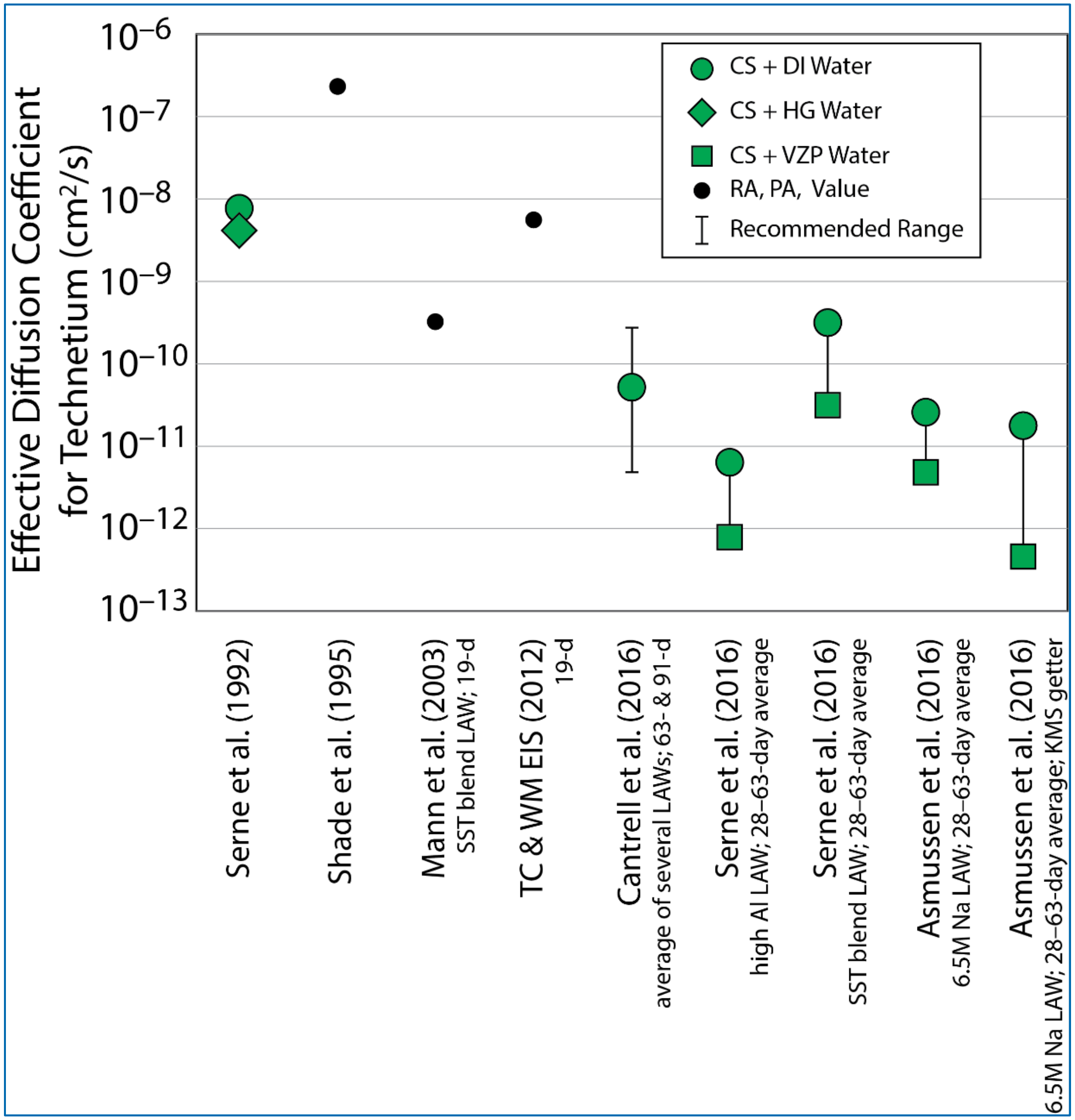
Process Summary

- Pre-treatment (organics & metals) to meet land disposal restrictions (LDR)
- Mix design based on Cast Stone
- Grout cast in 10 m^3 containers, which are transported for disposal at IDF
- Secondary waste (minimal)
  - o Low temperature process minimizes off gas

Technology Maturation

- TRL for overall grout process is high (7–10), based on similarities to other operations (e.g., SRS Saltstone)
- TRL for LDR organics is medium (4–6)
- TRL for Cast Stone performance is medium (4–6)
  - o Additional R&D is needed to confirm understanding of the retention characteristics over a range of potential LAW compositions and to incorporate new data into formal performance assessment

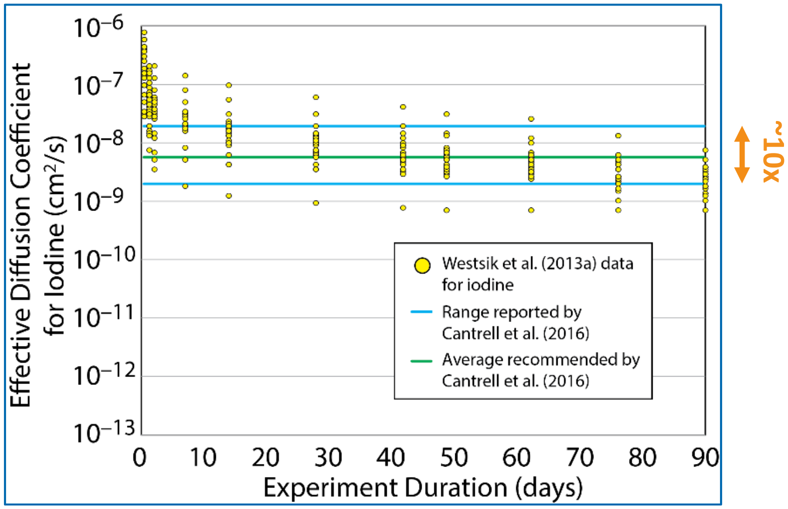
Grout Case I: Evolution of Diffusion Coefficients & Retention

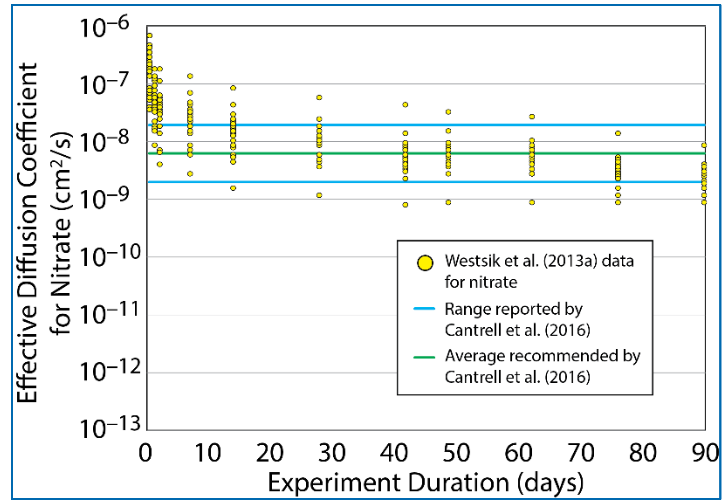


- Effective diffusion coefficients measured on early formulations are higher than those measured on Cast Stone based formulations.
- Cast Stone based data are generally lower than those used in earlier assessments.
- Lowest values reported for Cast Stone based data are 10–1000x are lower than values used in earlier assessments.

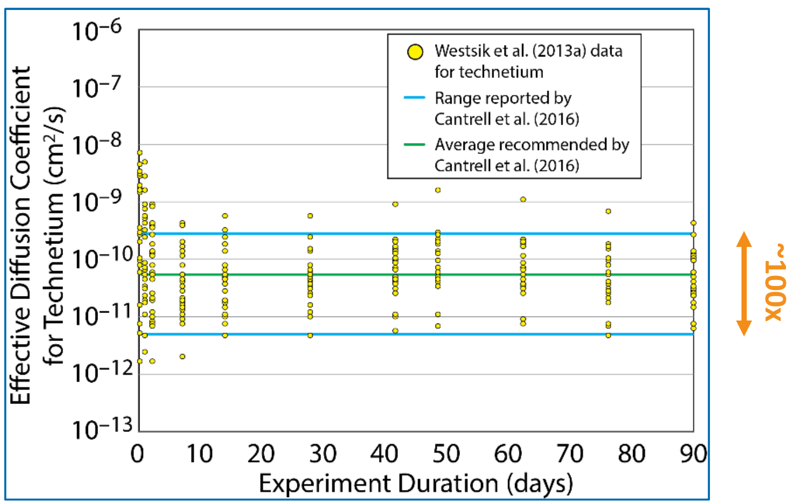
Grout Case I: Evolution of Diffusion Coefficients & Retention

Physical Processes Only



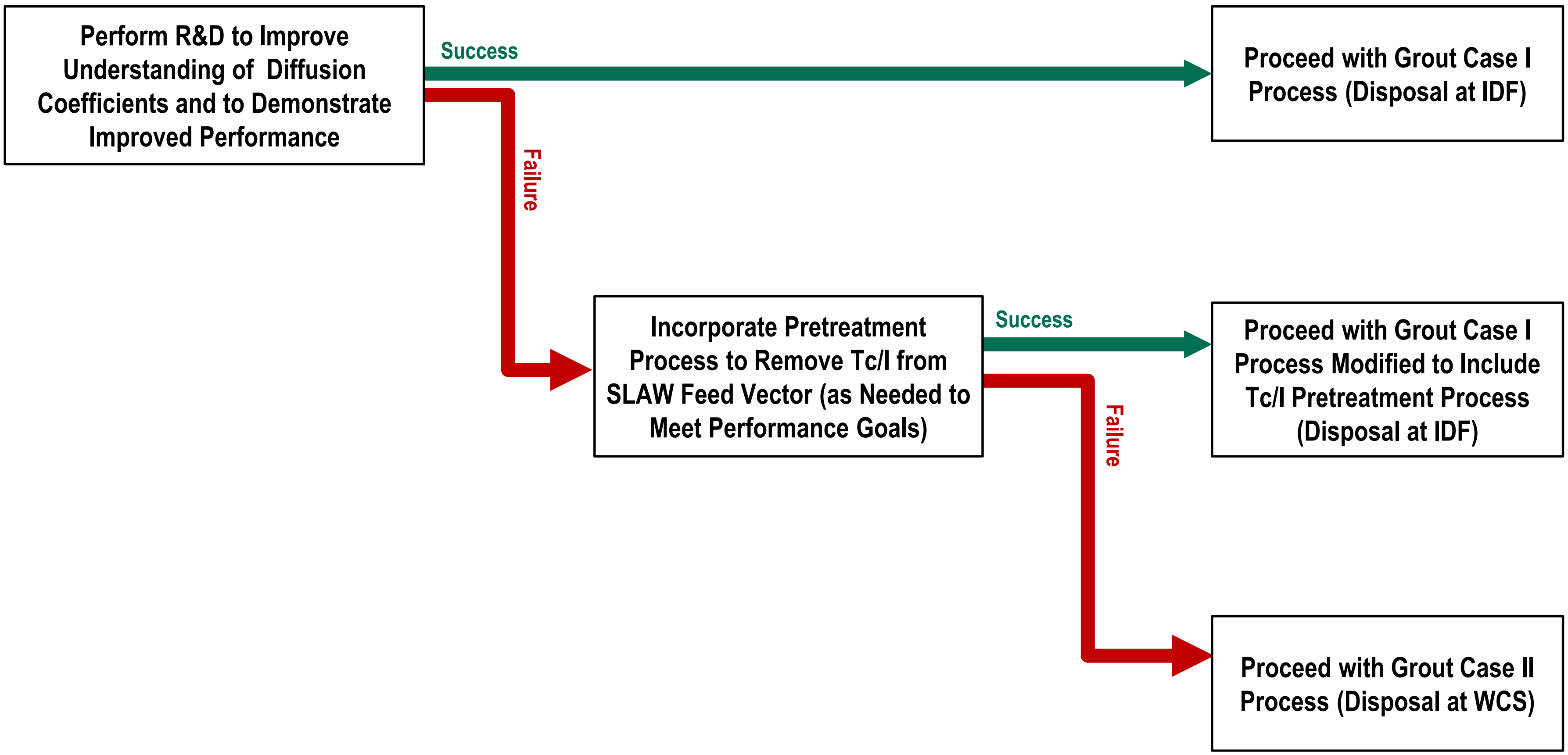


Physical & Chemical Processes

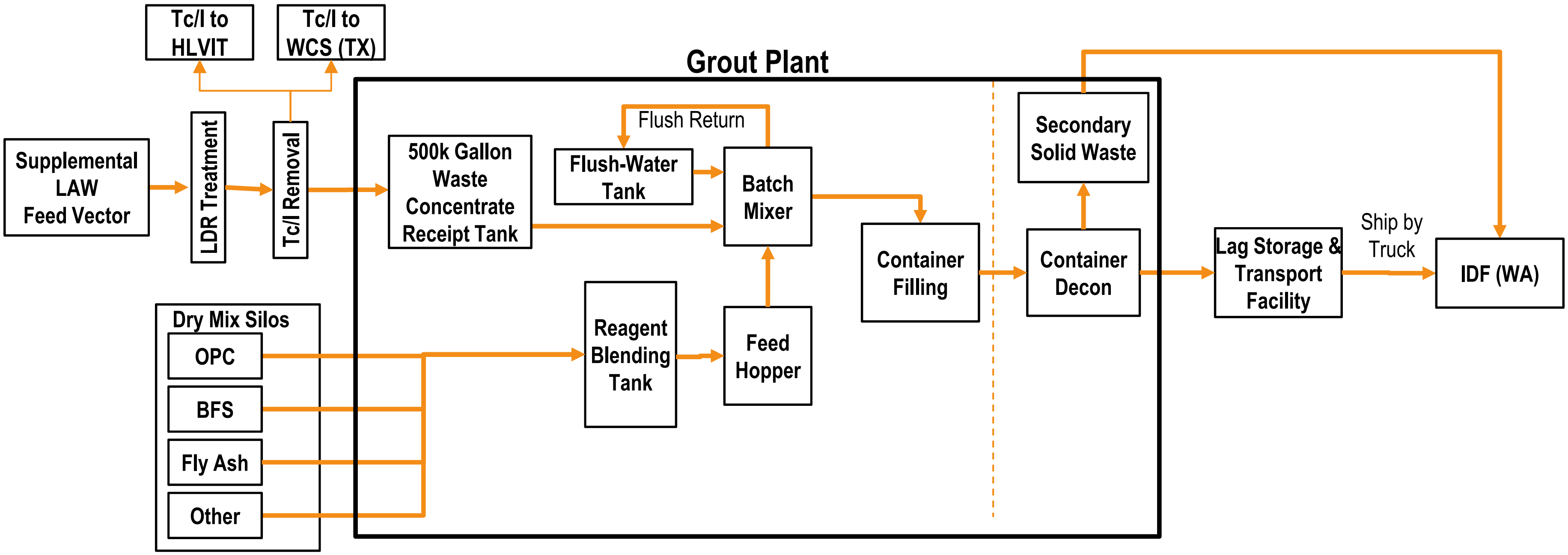


- Data from Westsik et al. (2013) were used in data package reported by Cantrell et al. (2016)
- Effective diffusion coefficients for iodine were comparable to nitrate (a non-sorbing species) and exhibited ~10x variability across test matrix
- Effective diffusion coefficients for technetium were lower than iodine and nitrate and exhibited ~100x variability across test matrix
- Westsik et al. (2013) test matrix included:
  - Sodium molarity (5M & 7.8M), reagent sources, w:d-m (0.4 & 0.6), liquid-waste simulant composition (average LAW, high SO_4, high Al, SST blend)

Grout Case I—Generalized Strategy to Mitigate Uncertainty in Waste-Form Performance



Grout Case I Risk Mitigation Option—PT with Disposal of Grouted SLAW at IDF (WA)



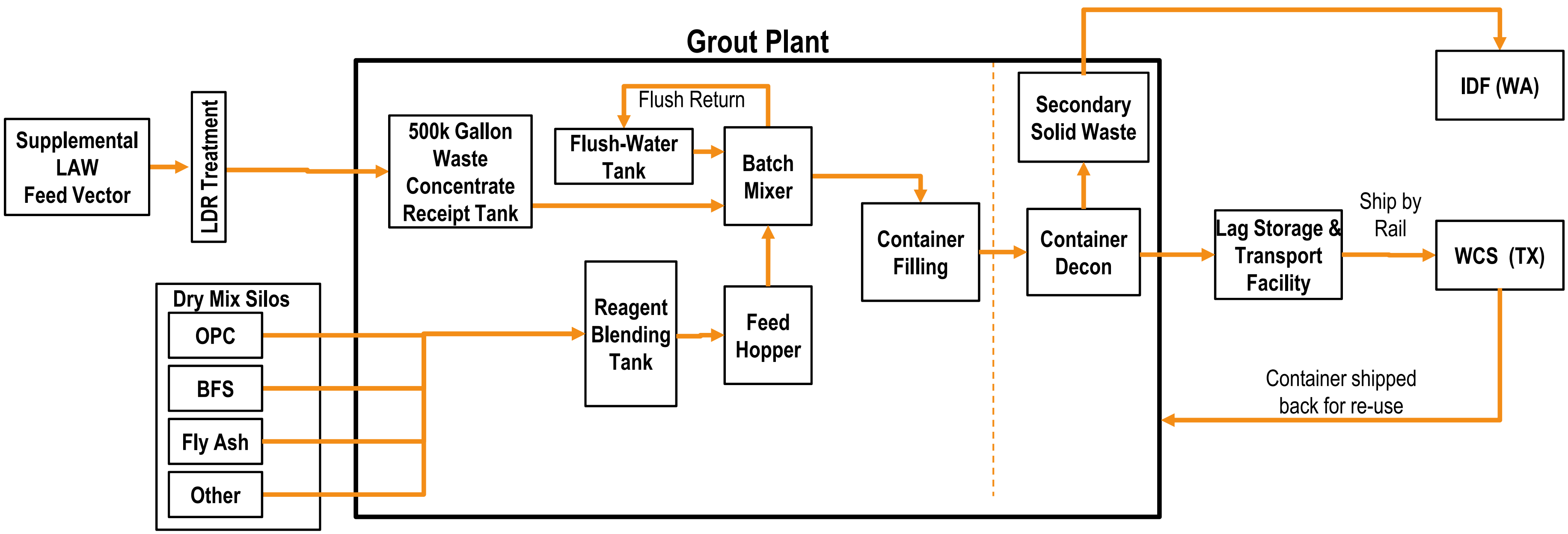
Addition of Process Step for Pretreatment (PT) to Remove Tc/I

- Requires additional technology evaluation and selection, new facility design, and additional secondary waste stream
  - o TRL for Tc is medium (4–6)
  - o TRL for I is low (0–3)
- Removed radionuclides have two possible disposal paths:
  1. Radionuclides sent to high level vitrification
  2. Radionuclides sent to WCS facility
  3. Secondary waste to IDF or WCS

Grout Case I: Risks

Risk	Mitigation
1. Grout unable to meet Tc performance expectations/State permitting requirements - given DOE requirements are met	i. Mature grout formulation and getters to demo acceptable grout performance, PA special analysis, container credit ii. Pursue Pretreatment for Tc/I iii. Dispose of waste at WCS
2. During operation it is determined that for a range of tank compositions non thermal oxidative methods do not result in sufficient LDR organic destruction	i. Divert problematic waste streams to LAW VIT - able to swap other waste to balance SLAW and LAW VIT - no impact on schedule.
3. Key grout reagents become unavailable in the future	i. Stockpile components ii. Conduct additional R&D to certify substitutes

Grout Case II Process Flow Diagram—Disposal of Grouted SLAW at WCS (TX)



Process Summary

- Pre-treatment (organics & metals) to meet land disposal restrictions (LDR)
- Mix design based on Cast Stone
- Grout cast in polypropylene bags in10 m^3 containers; containers are returned after disposal of bagged grouted monolith at WCS
- Secondary waste (minimal)
  - o Low temperature process minimizes off gas

Technology Maturation

- TRL for overall grout process is high (7–10), based on similarities to other operations (e.g., SRS Saltstone)
- TRL for LDR organics is medium (4–6)

Grout Case II: Risks

Risk	Mitigation
1. Due to changing political considerations, Texas regulator blocks WCS from accepting Hanford wastes	i. Negotiations with WA, TX, or alternate to secure viable disposal options
2. Political opposition, in major city, on rail route following a rail accident. Result may be that DOE temporarily abandon rail shipping. Occurs after shipping has started.	i. Change/renegotiate route, or shift to road/truck shipping, or alternate to secure viable disposal options.
3. During operation it is determined that for a range of tank compositions non thermal oxidative methods do not result in sufficient LDR organic destruction	i. Divert problematic waste streams to LAW VIT - able to swap other waste to balance SLAW and LAW VIT - no impact on schedule.
4. Key grout reagents become unavailable in the future	i. Stockpile components ii. Conduct additional R&D to certify substitutes

Cost and Schedule—Grout (Cast Stone)

Cost Estimate: $2–10 B

Grout Case I: Disposal at IDF*

Technology Development	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replacement	D&D	Total Program Cost
$90M – $210M	N/A	$500M – $1,150M	$1M – $2.6M	$1,120M – $1,680M	N/A	$250M – $1,160M	$TBD	$2,000M – $5,000M

** Cost estimates do not include cost of pretreatment facilities for Tc/I (if needed)*

Grout Case II: Disposal at WCS

Technology Development	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replacement	D&D	Total Program Cost
$120M – $280M	N/A	$650M – $1,464M	$1M – $2.6M	$1,120M – $1,680M	$2,775M – $4,163M	$320M – $1,508M	$TBD	$5,000M – $10,000M

Schedule Estimate: 5–10 years from Construction Start to Hot Start Up

- Lowest cost option
- Schedule comparable to steam reforming but faster than vitrification
- Cost and schedule estimates informed by SRS Saltstone operation

Benefits—Grout (Cast Stone)

- **Most compatible integration with WTP**
- **Non-thermal process**
  - Less off-gas
  - Start/stop flexibility
  - Worker safety
- **Least-complex process of three options considered**
- **Lowest secondary waste volume**
  - Minimal off-gas treatment
  - No liquid secondary waste stream

Regulatory Compliance—Grout (Cast Stone)

- **High likelihood to meet DOE technical performance criteria for onsite disposal (IDF) (e.g., DOE 435.1) based on Cast Stone data**
- **Grouted waste is not currently permitted at IDF**
  - Permitting of grouted secondary wastes needed for vitrification
  - Onsite disposal of primary grouted wastes will require permitting
- **Grouted waste forms are compliant with offsite transport (Low-Specific-Activity III material)**
- **Grouted waste forms are compliant with disposal at WCS (TX) (licensed to accept Class A, B, C low-level waste and low-level mixed waste)**

Overall Risks/Obstacles—Grout (Cast Stone)

Technical

- Potential for LDR organics in feed vector (both IDF and WCS)
  - Only feed wastes without LDR organics to grout process—may require system plan feed adjustments to address organic peaks
  - Pretreat wastes to destroy/remove LDR organics—may require R&D of process to remove organics without impacting long-term performance of grouted waste form
- Need to demonstrate acceptable performance
  - Requires (i) additional R&D to confirm retention characteristics of Cast Stone across relevant feed vector compositions and (ii) formal performance assessment (IDF only)
  - May require identification and testing of alternative mix components to mitigate uncertainties in future availability (both IDF and WCS)

Programmatic

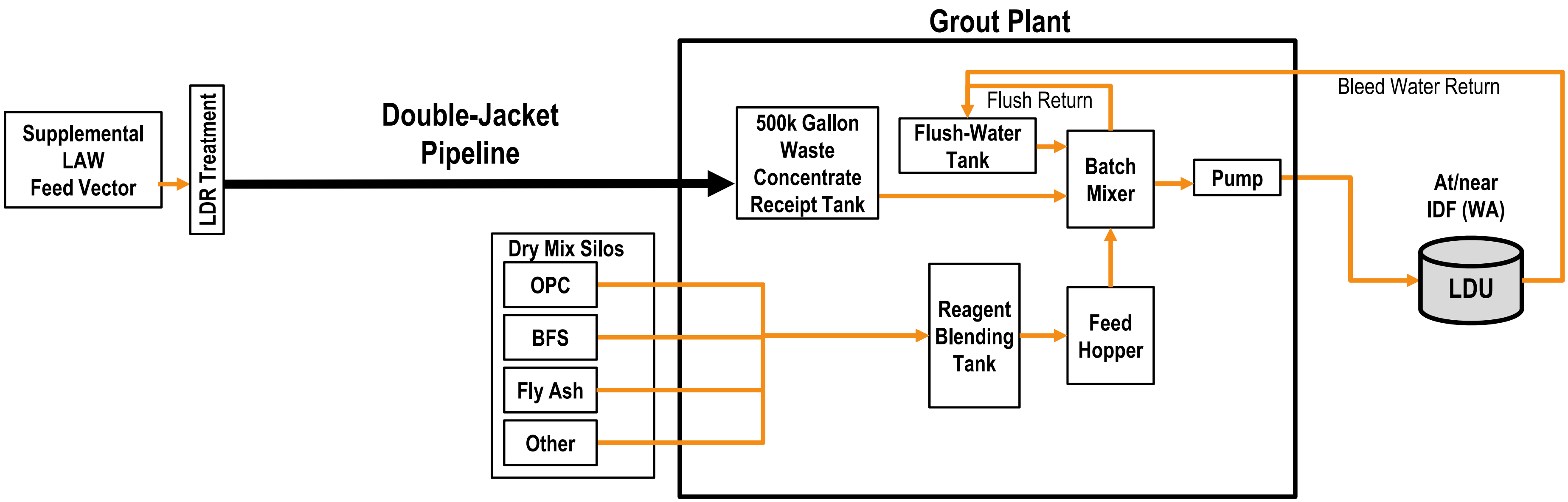
- Potential lack of regulator acceptance for onsite disposal (IDF only)
- Requires significant concurrent line-item & operational funding (all options/processes)

Grout—Areas for Further Analysis

- **Evaluate options for handling LDR-organic-bearing wastes relative to supplemental Cast Stone (both IDF & WCS)**
- **Retention characteristics of Cast Stone formulations (IDF only)**
  - Improve understanding of factors that control retention behavior—reagent source, w:d-m ratio, LAW composition, oxidation rate, Tc/I getters, leach-water composition, time
  - Identify/evaluate reagent options (e.g., natural pozzolans)
  - Include supplemental Cast Stone in IDF performance assessment using peer-reviewed, updated data
- **Demonstrate pilot-scale processing (both IDF & WCS)**
- **Initiate (conceptual) design for full-scale processing options (both IDF & WCS)**

Grout Backup Slides:
Process Flow Diagrams for Potential Opportunities

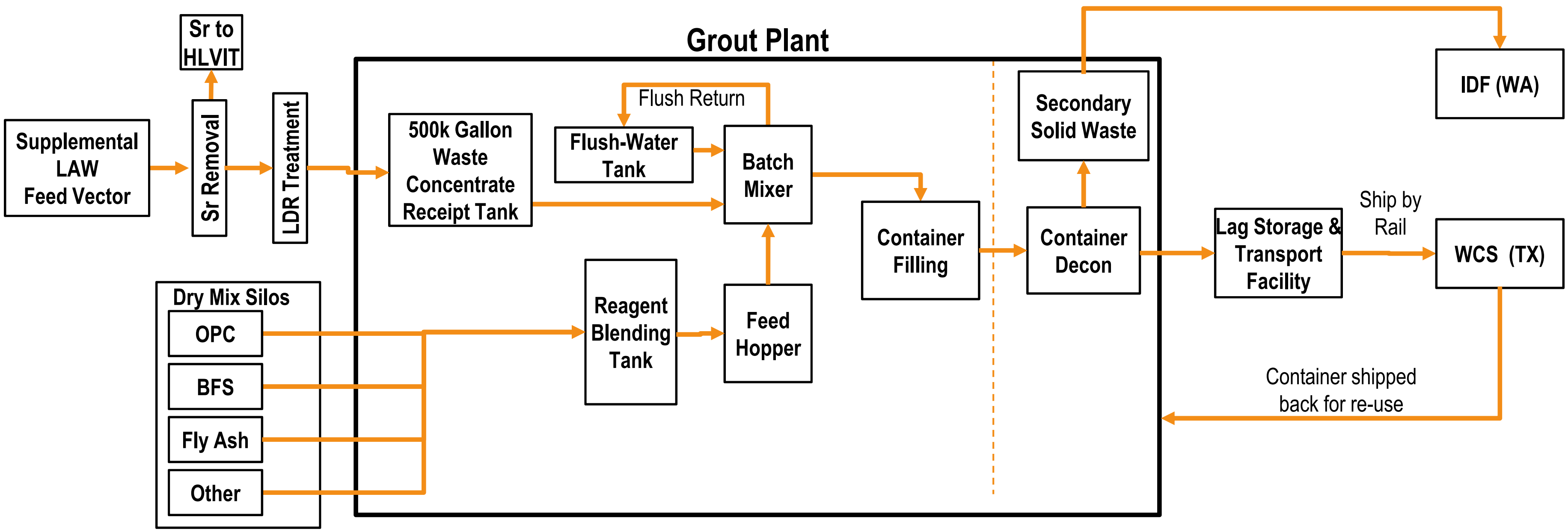
Grout Case I Opportunity—Disposal of Grouted SLAW in Large Disposal Units at IDF



Use of Large Disposal Units (LDUs)

- Requires relocation of grout plant near IDF
- Grout-slurry is pumped into LDUs at/near IDF

Grout Case II Opportunity—Disposal of Grouted Class A SLAW at WCS (TX)



Pretreatment Removal of Sr to Lower Disposal Costs

- Removal of Sr to ensure waste is class A, which lowers disposal costs at WCS
- Sr is sent to the high level vitrification facility
- TRL for Sr removal is medium (4–6)

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

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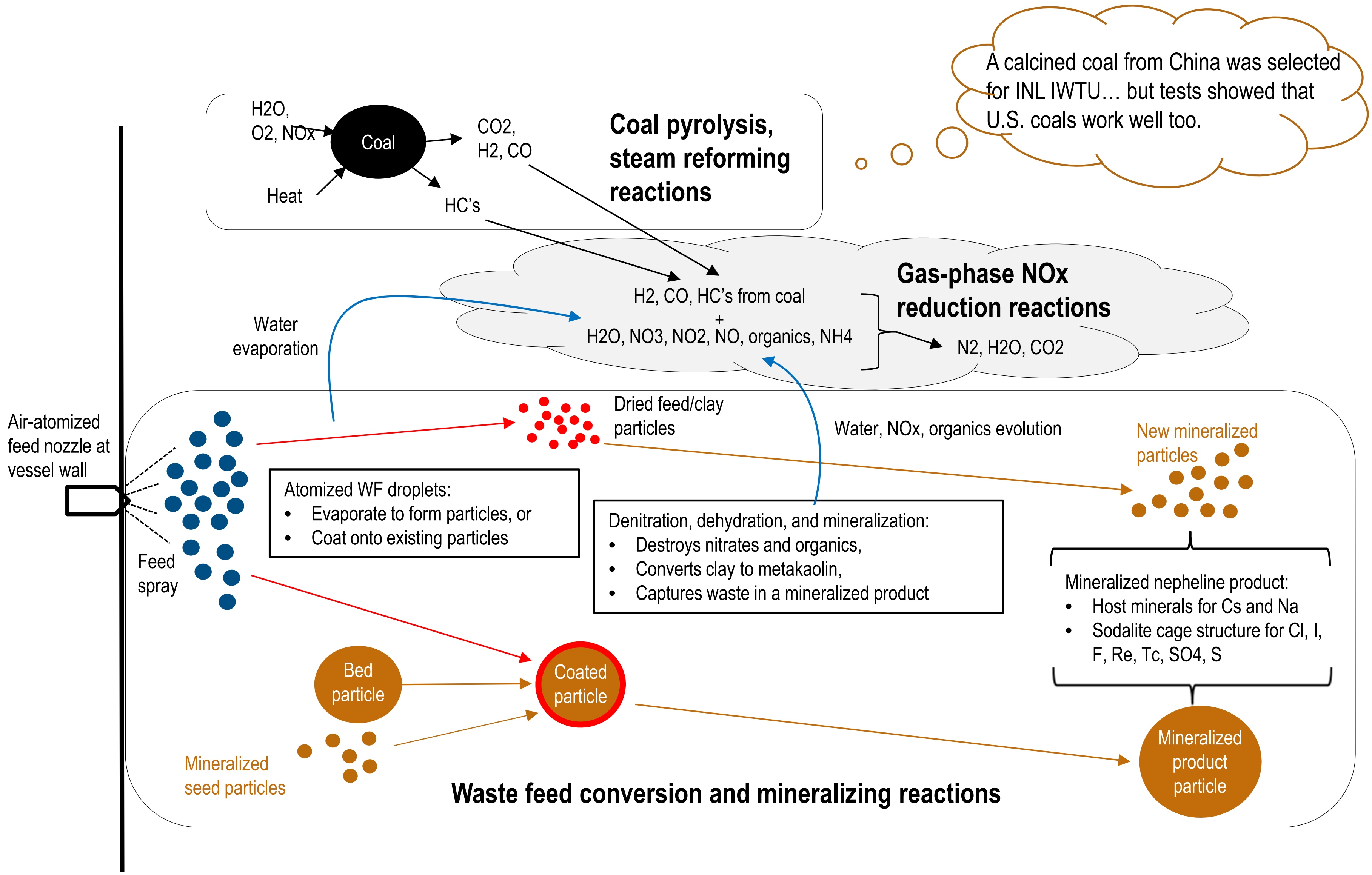
NAS Committee Meeting #4
November 29 and 30, 2018
Richland, WA

Pre-Decisional

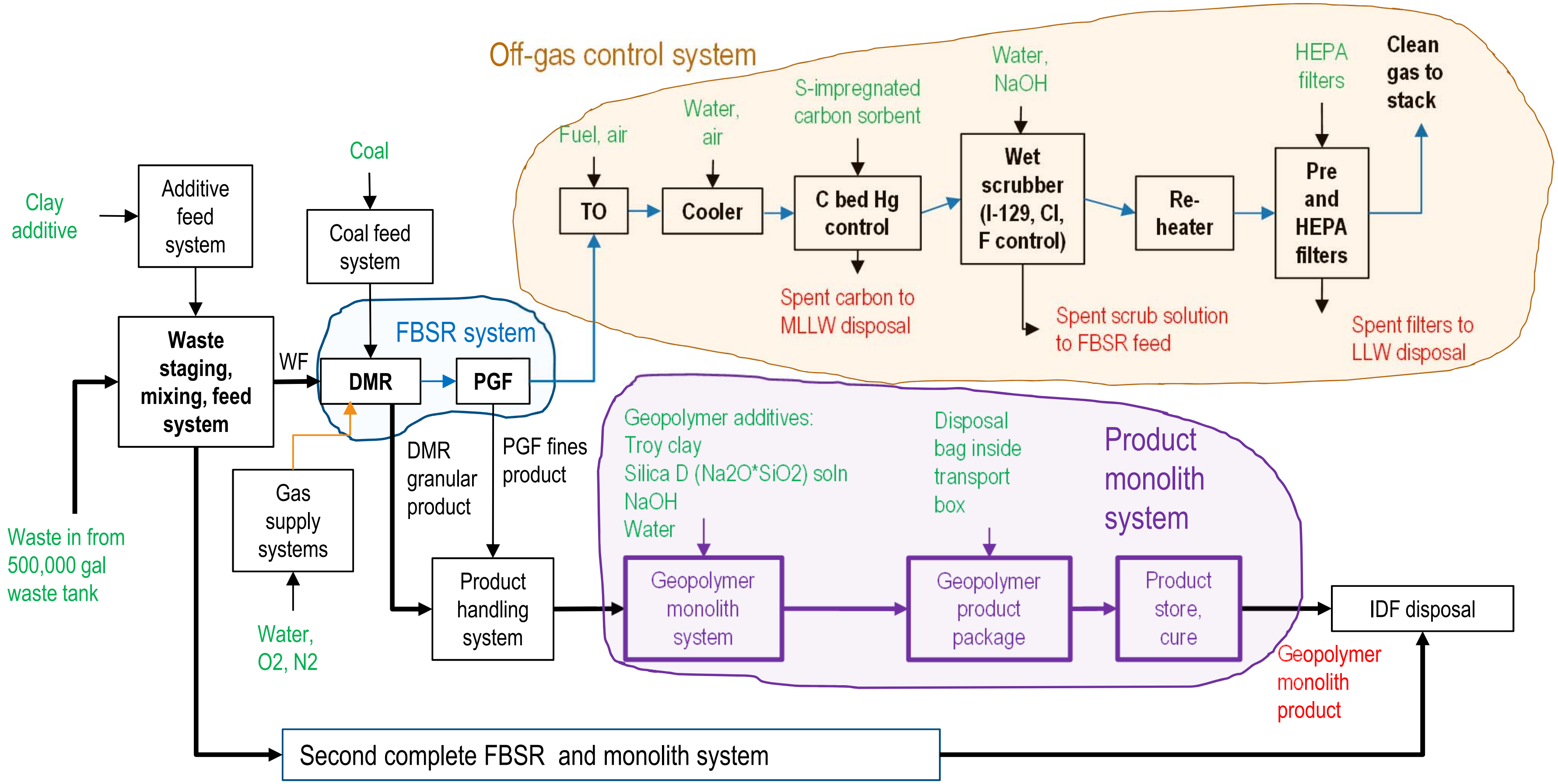
Topics

- **Steam reforming technology**
- **Case 1 Mineralizing FBSR: solid monolith product to IDF**
- **Case 2 Mineralizing FBSR: granular product to WCS**
- **Process safety**
- **Confidence that FBSR will work - Technology Readiness Level**
  - o Steam reforming for Hanford SLAW similarities and differences with INL IWTU
- **Cost and schedule**
- **Regulatory compliance**
  - o Ability to produce a durable, leach-resistant waste form
  - o Mass balance; primary and secondary wastes, radionuclide partitioning
- **Major risks and obstacles**
  - o Risk mitigations
- **Benefits**
- **Areas recommended for further study**

Steam reforming evaporates water, destroys nitrates, organics, and ammonium species, and converts the waste feed to a durable aluminosilicate mineralized product



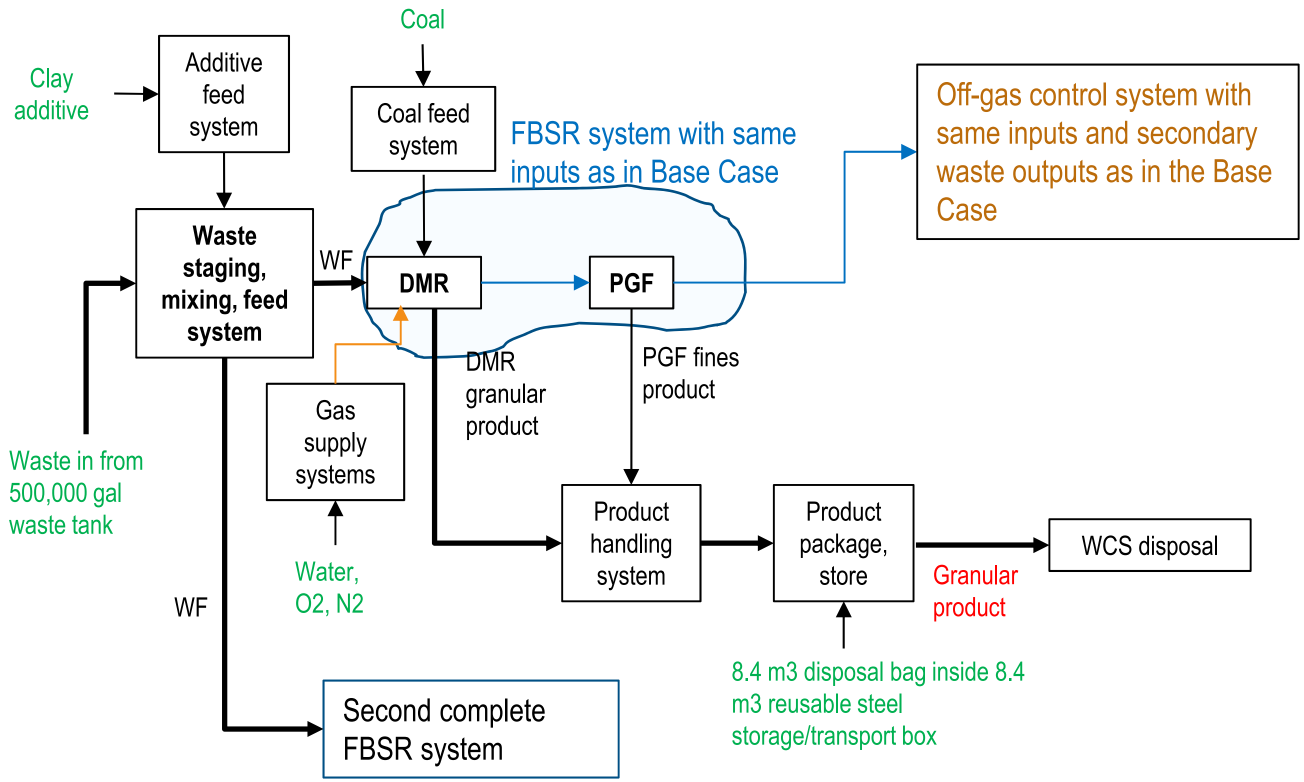
Case 1 Mineralizing FBSR: Two DMR systems; solid monolith product to IDF



- Destroys nitrates, organics, and NH4 in feed; produces durable mineralized waste form
- Two identical FBSR systems to maximize available capacity in first ~3 yrs
- Shared waste staging, mixing, feed system
- Eliminates dust, provides more compression strength compared to granular product
- Secondary wastes (spent HEPAs, equipment, filters, PPE, etc.) grouted for IDF, same as for vitrification

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

Case 2 Mineralizing FBSR: Two DMR systems; solid granular product to WCS



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

Process Safety

- **As a thermochemical process, steam reforming has various risks**
  - Worker exposures
  - Noncompliant air emissions
- **These risks are mitigated by methods established and proven in nuclear and other industries**
  - Engineered controls are preferred
  - Administrative controls
  - Personal protective equipment (PPE)

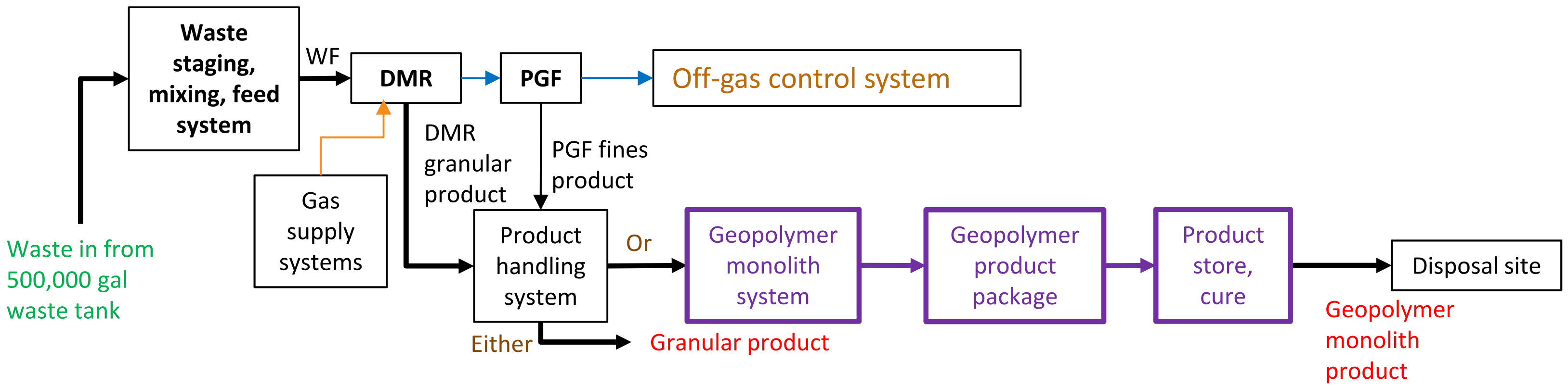
Worker exposure risks and mitigations

Risks	Mitigations in addition to procedures and PPE
Heat	Insulation, process containment
Chemicals	Process containment
Radiation, radioactive contamination	Process containment
Ergonomic	Engineering, tools

Air emissions compliance

Emissions	Mitigations in addition to containment & operating limits
Radionuclides	Multiple redundant filters and scrubbing, HEPAs
NOx and Hazardous/toxic organics	Steam reforming chemistry, kinetics, mass & heat transfer
Hazardous/toxic particulate, metals	Multiple redundant filters and scrubbing, HEPAs
Hazardous/toxic acid gases	Multiple dry and wet scrubbing

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



Estimated Technology Readiness Level, assumptions

- Feed systems TRL Hi

(Not unique to FBSR, common commercial equipment)

- DMR TRL Med
- Product system TRL Med
- (Unique to FBSR, requires special equipment)

- Monolith system TRL Med

(Not unique to FBSR, common commercial equipment)

- Off-gas system TRL Hi
- Wet scrubber TRL Med

(Not unique to FBSR, common commercial equipment)

- Product cure, store, transport TRL Med-Hi

(Not unique to FBSR, common commercial equipment)

- Integrated FBSR system TRL is Medium because of its dependence on multiple integrated subsystems

(TRL 1-3 = Low; 4-6 = Med; 7-9 = Hi)

Steam reforming for Hanford SLAW similarities and differences with INL IWTU

- **INL IWTU: First-of-a-kind full-scale facility; the Erwin Resin*Solutions* Facility has more significant differences**
  - Still in startup operations; some modifications have been needed
  - Tests in 2018 successfully demonstrated the most recent modifications
  - SLAW mineralizing steam reforming would also be first-of-a-kind due to dissimilarities and until IWTU becomes operational

IWTU Feature	Hanford SLAW	Comments
Waste feed system	Conceptually identical	Technically mature liquid feed, handling systems in nuclear and other industries; difference between acidic SBW and caustic SLAW not significant
---	Clay additive system	Pilot-scale tested, mature; needs design & demo in this application
Coal, gas feed sys.	Conceptually identical	Technically mature; needs demo for SLAW treatment
DMR feed nozzles	Conceptually identical	Need to design/demo/optimize for SLAW-clay slurry feed
DMR, 2.5 gpm	Conceptually identical, 4.4 gpm	Need to design/demo/optimize for higher feedrate, mineralized product
Product system	Conceptually identical	Need to design/demo/optimize mineralized product
---	Product monolith system	Analogous to a grouting system
Process Gas Filter	Conceptually identical	Need to design/demo/optimize mineralized product
Fluidized bed ox.	Open chamber thermal ox.	Technically mature open chamber TO proven in many industries
Hg control	Conceptually identical	Technically mature; needs demo for SLAW treatment
---	Wet scrubber	Technically mature; needs demo for SLAW treatment
HEPAs	HEPAs	Technically mature in nuclear industries and IWTU
Hot cells	---	Low enough radionuclides to avoid hot cells

Preliminary cost and schedule estimate: FBSR

Case 1 - IDF

Tech Dev	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replace	D&D	Total Program Cost
$480M – $1,100M	$1,000M – $2,600M	$1,900M – $4,400M	$1M – $2.6M	$3,300M – $4,900M	N/A	$300M – $690M	$TBD	$8,500M – $15,000M

Case 2 - WCS

Tech Dev	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replace	D&D	Total Program Cost
$480M – $1,100M	$1,000M – $2,600M	$1,900M – $6,900M	N/A	$2,500M – $3,800M	$1,900M – $2,800M	$300M – $690M	$TBD	$9,500M – $19,000M

Schedule Estimate: 10-15 years to hot startup

- Lowest cost thermal treatment option to meet BDAT for organics, and destroy nitrates.
- T&D costs are due to maturing the technology readiness to TRL>7.
- OPEX / Life Cycle cost are also impacted by maturity
- Transport and disposal costs are significant but not a dominant portion of total cost
- Cost and schedule estimates are informed by INL IWTU design, demo, and startup; because it is the most similar full-scale process.

Regulatory Compliance — Steam Reforming

- High likelihood to meet DOE technical performance criteria for onsite disposal (IDF) (e.g., DOE 435.1)
- Permitting of mineralized product at IDF has not been done: neither primary or secondary solid waste forms
- Steam reformer waste forms are compliant with offsite transport and with disposal at WCS (TX)

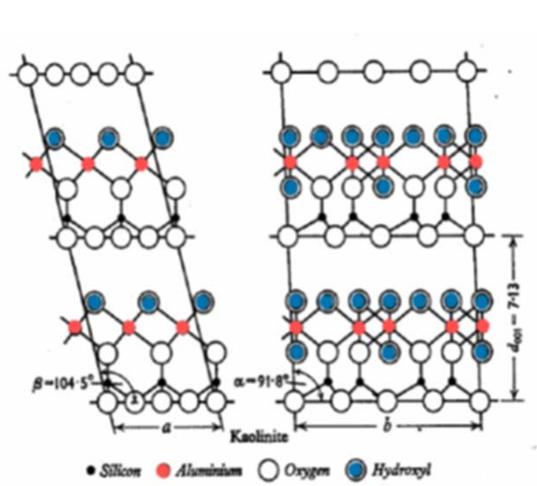
Chemistry of a mineral waste form from steam reforming

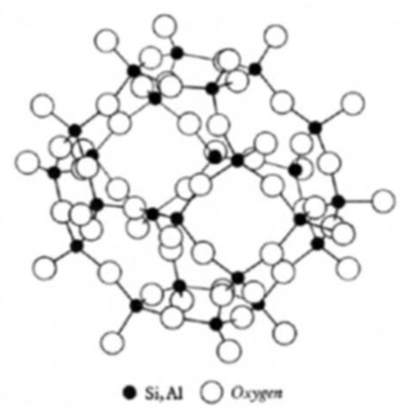
Kaolin clay [$Al_2Si_2O_5(OH)_4$] dehydrates, converts to reactive meta-Kaolin, which incorporates waste feed elements into feldspathoid structures to become stable again. This also produces sodalite and nosean "cages" that also incorporate some waste feed elements.

Kaolin Crystal

Meta-Kaolin Amorphous

Feldspathoid Crystal





Resultant Nepheline – Kalsilite structures that can contain radionuclides:	
$Na_xAl_ySi_zO_4$	Group 1, 2, and certain other elements
$CsAlSiO_4$	
$RbAlSiO_4$	
$(Ca_{0.5},Sr_{0.5})AlSiO_4$	
$(Sr,Ba)Al_2O_4$	
$(Na,Ca_{0.5})YSiO_4$	
$(Na,K)LaSiO_4$	
$(Na,K,Ca_{0.5})NdSiO_4$	

Anions that can be incorporated into cages:

Anion	Mineral Name	Oxidation State
F^-	F-sodalite	-1
Cl-	Cl-sodalite	-1
ClO_4^-	Cl-sodalite	-1
SO_4^{2-}	Nosean	+6
TcO_4^-	Tc-sodalite	+7
ReO_4^-	Re-sodalite	+7
I^-	I-sodalite	-1
Br^-	Br-sodalite	-1

Durability of the steam reformer mineralized waste form

- **"…The steam reformed waste form would not be equal to that of the WTP glass…" was among the conclusions in the 2012 Hanford tank closure and waste management environmental impact statement (TC and WM EIS, DOE 2012)**
- **More steam reforming waste form performance data was generated between 2012-2015, that was not available for the 2012 TC and WM EIS**
  - 20 new publications from a multi-year, multi-laboratory SRNL, ORNL, PNNL, and WRPS study performed by many waste form performance experts following the guidance of NRC 2011 "Waste Forms Technology and Performance, Final Report"
  - Summarized with ~200 other references in a multi-lab, ~21-author report (Jantzen 2015)
  - Tests were performed per NRC 2011 recommendations:
    - ASTM C1285 Product Consistency Test (PCT) (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 (SPFT) on product of Rassat 67 tank blend LAW (Rassat 2002).
    - Pressure Unsaturated Flow-through (PUF) test on product of Rassat 67 tank blend LAW.
    - X-ray Absorption Spectroscopy (XAS)
- **These more recent data show that the waste form can likely meet DOE technical performance criteria for disposal in IDF**

SR waste form tests characterize the waste form, provide release mechanisms, measure release rates

- **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 TcO_2 or $Tc_2S(S_3)_2$; equally low solubility during durability testing (bench-scale rad tests). TcO_2 is the same oxide species present in HLW waste glasses formed under slightly reducing flowsheets like the Defense Waste Processing Facility (DWPF).

- **PCT:**
  - <2 g/m2 leachable for granular product and monoliths (per geometric surface area, same as vitreous WFs)
  - <2 orders of magnitude lower than 2 g/m2 if BET surface area is used for granular product
  - 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/(m^2d)**
  - 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

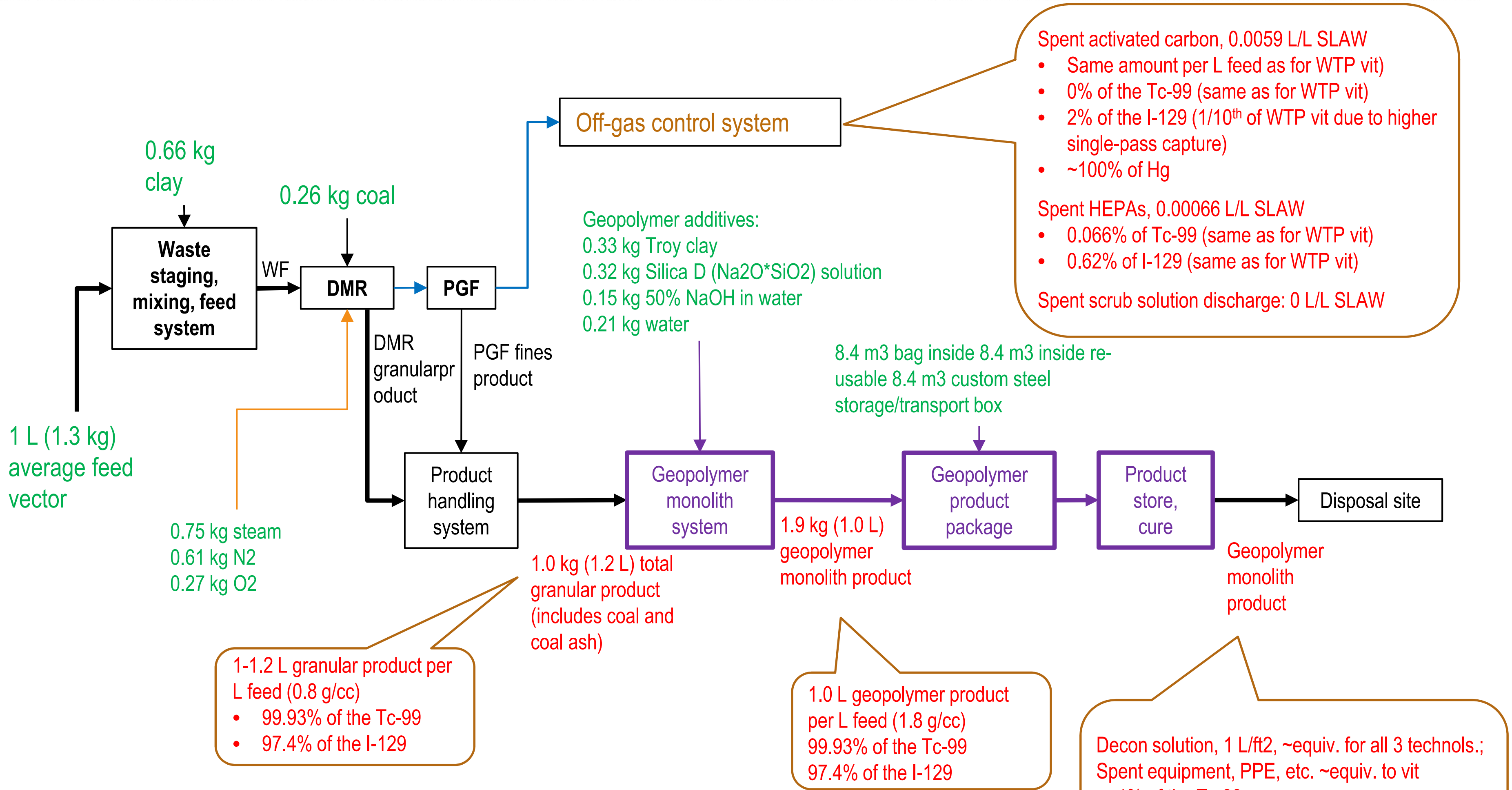
SR waste form tests characterize the waste form, provide release mechanisms, and measure release rates

- **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**
  - o PUF tests 1-year long were performed on the Rassat LAW FBSR granular products made Pilot and BSR
    - 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 from the predominant nepheline phase and release rates for iodine and Re suggests that the I and Re were captured in sodalite cages
  - o The 2.5-year-long PUF test results for 2004 SAIC-STAR pilot scale FBSR products were similar
    - Elemental release rates and 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 their release from the same phase or from different phases with similar stability
    - Geochemical calculations using PHREEQ-C on 200 day PUF data suggests the steadystate S and Re solubility was within order of magnitude of solubility of phase pure nosean and Re-sodalite, respectively

SR monolith waste form tests were also done successfully

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

FBSR mass balance; Product volumes, Tc-99 and I-129 management



References:

- **FBSR mass balances for average SLAW feed vector (February 15, 2018 and October 13, 2018)**
- **SRNL-ORNL-PNNL-WRPS down-select (Jantzen 2015) and 2014 Waste Management paper.**
- **Tc-I Inventories.xlsx, from 2017 IDF PA for LAW**
- **FBSR product canister surface contamination analyses (2017)**

Major overall risks/obstacles — steam reforming

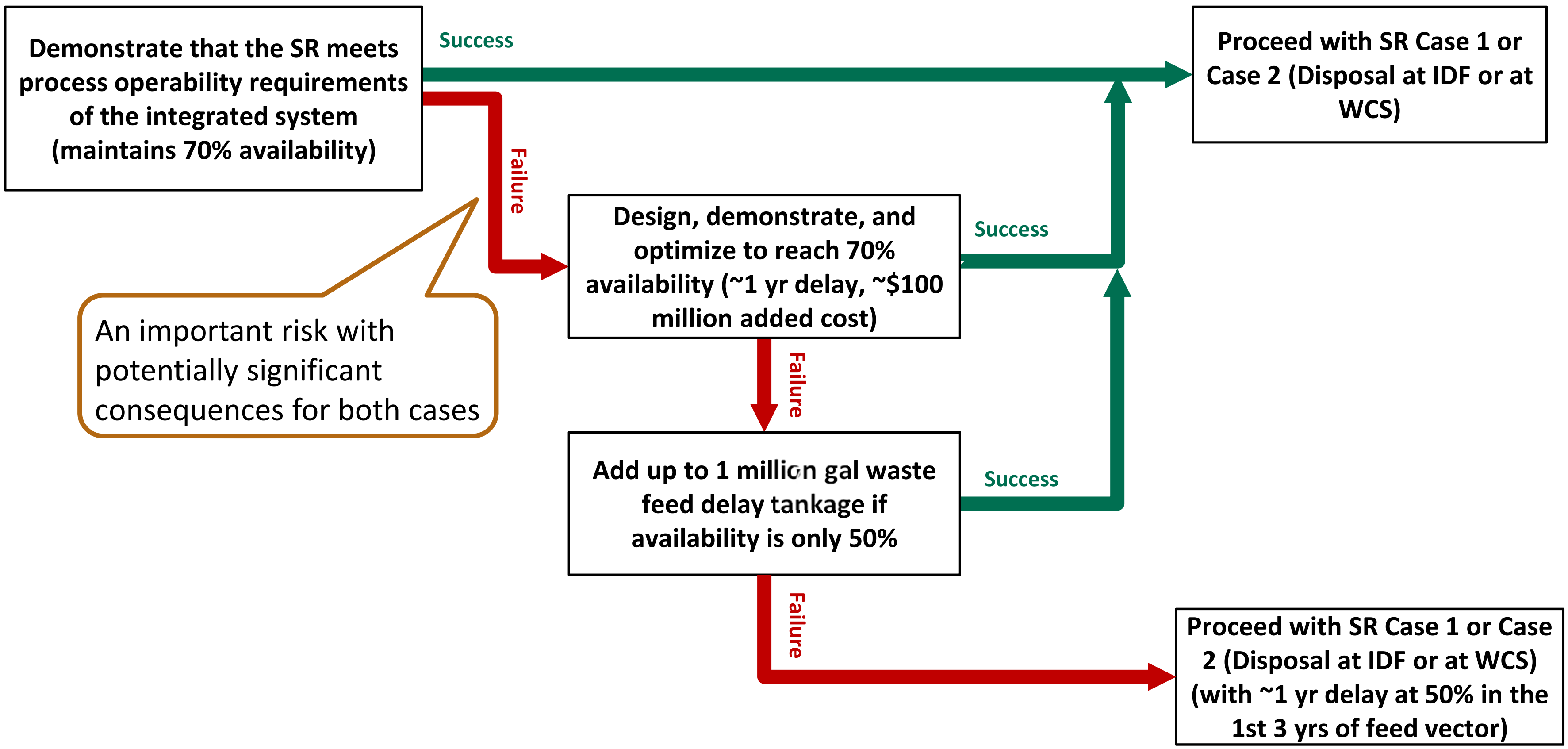
Technical

- Need to mature the overall process from Medium to High for this application
  - Maturation plan needs to include pilot and demonstration-scale testing, modeling, and waste form performance demonstration
- Need to better demonstrate waste form performance to enable stakeholders to consider if the mineralized product is acceptable

Programmatic

- Current lack of regulator acceptance for onsite disposal (IDF)
- Requires significant concurrent line-item and operational funding (>$1.5B) (applies to all options considered)

Steam Reforming process operability risk and mitigations – both Case 1 and 2



Other steam reforming risks and mitigations

Risks	Mitigations
1. Case 1, IDF: During demonstration testing, waste form fails to meet IDF performance requirements	i. Modify additives and stoichiometries. ii. Proceed with Case 2 (Disposal at WCS)
2. Case 1, IDF: Partitioning of Tc99 and I129 to HEPA filters and spent carbon is higher than can meet IDF acceptance requirements	i. Off-gas scrubber reconfiguration ii. Improve Tc/I retention in grouted spent carbon and filter waste forms iii. Proceed with Case 1 but send spent HEPAs and carbon to offsite disposal iv. Proceed with Case 2 - WCS
3. Case 2, WCS: Texas blocks WCS from accepting Hanford wastes	i. Negotiate with WA, TX, or alternate to secure viable disposal options (e.g., HIC to IDF)
4. Case 2: Political opposition to transportation halts rail shipping.	i. Change route, shift to road/truck shipping, or alternate to secure other disposal options

Benefits — steam reforming

- **Tolerant of feed vector variations and to integrated system process upsets that change the feed vector flowrate or compositions**
  - o Can ease system integration complexity
  - o Can be started up, shut down, and operated with reduced feedrate
- **Thermal process meets BDAT requirements similar to vitrification**
  - o Destroys hazardous organics
  - o Destroys nitrates and NOx
  - o Destroys ammonium compounds
- **Waste form benefits:**
  - o According to recent waste tests, can produce a durable waste form
  - o Does not appreciably increase waste volume during treatment
  - o Does not produce any liquid secondary wastes (besides equipment decon, etc.)

Potential Opportunities for Steam Reforming

- **Reduce "flywheel" concentrations of volatile & semivolatile elements (Cl, Cr, F, I, S, Tc) by recycling scrub solutions less to WTP vitrification and more to SLAW steam reforming with higher single pass control %**

Element	Cl	Cr	F	I	S	Tc
Single pass control efficiency, %	90%	99.99%	85%	89%	90%	83%

- **Multiple steam reformer systems could be either co-located (as in Cases 1 and 2) or located in different tank farm locations**
- **Liquid secondary wastes destined for grouting could be steam reformed to replace the grouted waste form with a ~2-100x lower-volume, durable mineralized waste form**
- **If integrated system upsets occur that cause unplanned feed vector changes, steam reforming can be started up, shut down temporarily, or operated with reduced feedrate**

Areas recommended for further study to fill in data gaps or improve Hanford SLAW treatment options

- Perform IDF PA for non-glass waste forms
- Develop consensus on how to assess performance of non-glass waste forms
- Update conclusions from 2012 TC and WM EIS to account for new steam reforming waste form performance data
- Perform a trade study on separating more Sr-90, Tc-99, and I-129 from the LAW; and for treating ammonium and organics
- Consider in future System Plans more LAW delay tankage to better time-average the total SLAW feed vector flowrate and composition (a mitigation for <70% process availability)
- Include shipping some or certain wastes or waste forms to commercial sites for treatment and/or disposal as an option in future System Plans
- Evaluate and test off-gas system process improvements to reduce liquid secondary waste generation from vitrification
- Improve technical maturity of alternatives to vitrification and disposal in IDF – provide options for shortening tank remediation schedule and reducing costs

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NDAA 3134 Supplemental Low Activity Waste FFRDC Team Study Overview– Integrated Disposal Facility and Waste Form Performance Evaluation

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NAS Committee Meeting #4
November 29 and 30, 2018
Richland, WA

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Pre-Decisional

Sec. 3134 “Analysis”

- **“(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.”

Hanford Integrated Disposal Facility (IDF)

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

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

- **Design of Disposal Cells**
  - o Multi-barrier design including RCRA-compliant liner and leachate collection system

Hanford IDF

- **Licensing**
  - DOE-self regulates LLW disposal
  - Final DOE Authorization and Waste Acceptance Criteria not issued
  - Department of Ecology has issued a dangerous waste permit for the RCRA cell for ILAW (glass), and for technology-demonstration quantities of a Bulk Vitrification waste form
- **Capacities**
  - Approximately 165,000 m^3 of total LLW and mixed LLW capacity in “first expansion” composed of two cells
  - Capacity of six cells possible

IDF

Waste Form Performance for On-Site Disposal (IDF)

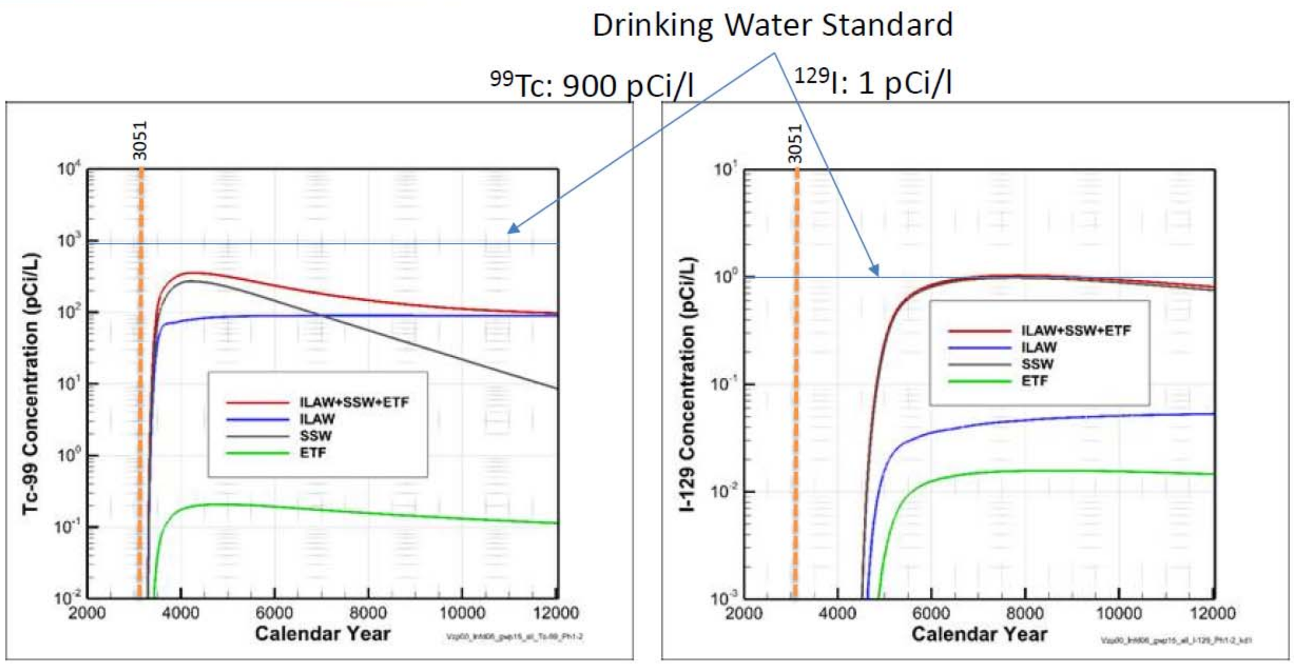
- **IDF RCRA Permit and WAC**
  - WAC are defined in the current IDF Permit
    - *(Hanford Dangerous Waste Permit Rev. 8C, WA7890008967, IDF Operating Unit Group 11)*
  - IDF is currently limited to ILAW from WTP ILAW glass canisters and 50 Bulk Vit test boxes
    - *Permit specifies process to propose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

- **2017 IDF Performance Assessment** *(Ref. Pat Lee Overview Presentation to NAS, 2/28/18)*
  - Performance measured against DOE Order 435.1 performance objectives
    - *For example, 1,000-year time frame, 100-m buffer zone, air & groundwater pathways, inadvertent intruder scenario*
    - *Includes EPA, State, or local groundwater protection standards*
  - ILAW Glass waste form, and cement-based waste forms for solid secondary wastes
  - Performance meets DOE performance objectives during time of compliance

2017 IDF Performance Assessment *(Ref. Pat Lee Overview Presentation to NAS, 2/28/18)*

- **Groundwater concentrations of Tc and I are driven from solid secondary waste (SSW)**

Tc & I Concentration >1,000 Years



Groundwater concentrations

Tc-99 driven by SSW initially, then ILAW glass when SSW inventory in IDF is depleted. ILAW source is about 10×below drinking water standard

I-129 driven by SSW at all times. ILAW source is about 18× below drinking water standard

11

IDF Disposal Performance Evaluation for SLAW Treatment – Analysis Approach

- **Study is employing a waste form performance evaluation approach to directly compare alternative SLAW processing options**
  - Model Tc-99 and I-129 release from primary waste form and any secondary wastes generated for each processing option, as needed.
    - *SLAW Grout and Steam Reforming products and their secondary wastes to be modeled in this study*
    - *ILAW and SLAW Glass and secondary wastes already modeled in IDF PA. Benchmark analysis to be performed for ILAW glass and secondary waste to verify comparability of this study's modeling and that of IDF PA.*
    - *Use IDF PA base conditions (IDF configuration, infiltration, secondary waste form performance parameters)*
  - Waste form-specific radionuclide release mechanisms, rates, and transport to groundwater
  - Bounding assumptions and parameter values are being used, to the extent practical, to assess uncertainty
- **Inventory**
  - Inventory of Tc-99 and I-129 has varied over time based on evolution of the waste tank inventory "Best Basis", waste processing data, flowsheet changes, and modeling assumptions.
  - SLAW study inventory is based on the current integrated flowsheet (System Plan 8, baseline process)
    - *Some differences exist in total inventory of Tc and I and their incorporation into HLW glass, LAW glass, and secondary waste forms between the IDF PA and current integrated flowsheet*

Comparison of IDF PA and Integrated Flowsheet (System Plan 8) Processed Tank Waste Inventories for Tc-99 and I-129

Waste Forms	IDF Performance Assessment		Integrated Flowsheet (System Plan 8, Base Case)	
	Tc-99 (Ci)	I-129 (Ci)	Tc-99 (Ci)	I-129 (Ci)
IHLW Glass[1]	-	-	1,530	0.53
ILAW Glass	26,400	16.5	12,227	15.0
SLAW Glass or Alternative			11,593	10.5
LSW (solidified liquid secondary waste)	0.23	0.064	0.26	.023
SSW (solid secondary waste)	20.0[2]	12.1	ND[3]	ND[3]
Total Tank Inventory – Best Basis	26,500	29.4	25,334	28.7

[1] To be disposed offsite. Not included in IDF PA analysis.
[2] Does not include ~1.2 Ci of non-Tank Waste inventory
[3] Not determined or not available from analysis. Study will use IDF PA split factors to estimate SSW inventories

- **This study uses total Tc and I inventories to ILAW and SLAW glass based on the current integrated flowsheet**
  - *Distribution between primary and secondary waste streams (split factors) from 2017 IDF PA are being applied for comparison purposes.*

Primary LAW + SLAW Waste Form "Systems" for IDF Evaluation

Analysis Case	Primary LAW Waste Forms: LAW	Primary LAW Waste Forms: Secondary Wastes	Supplemental LAW Waste Forms: SLAW	Supplemental LAW Waste Forms: Secondary Wastes
Vitrification Reference Case (2017 IDF PA)	ILAW Glass	LSW - ETF SSW - HEPA filters SSW - GAC absorber	ILAW Glass	LSW - ETF SSW - HEPA filters SSW – GAC absorber
Grout Case 1			Cast Stone	SSW – HEPA filters SSW - GAC absorber
Steam Reforming Case 1			FBSR Mineral - Macroencapsulated	SSW – HEPA filters SSW - GAC absorber

Waste Form Release Mechanism and Performance Parameters Modeled

Primary LAW & SLAW Waste Forms

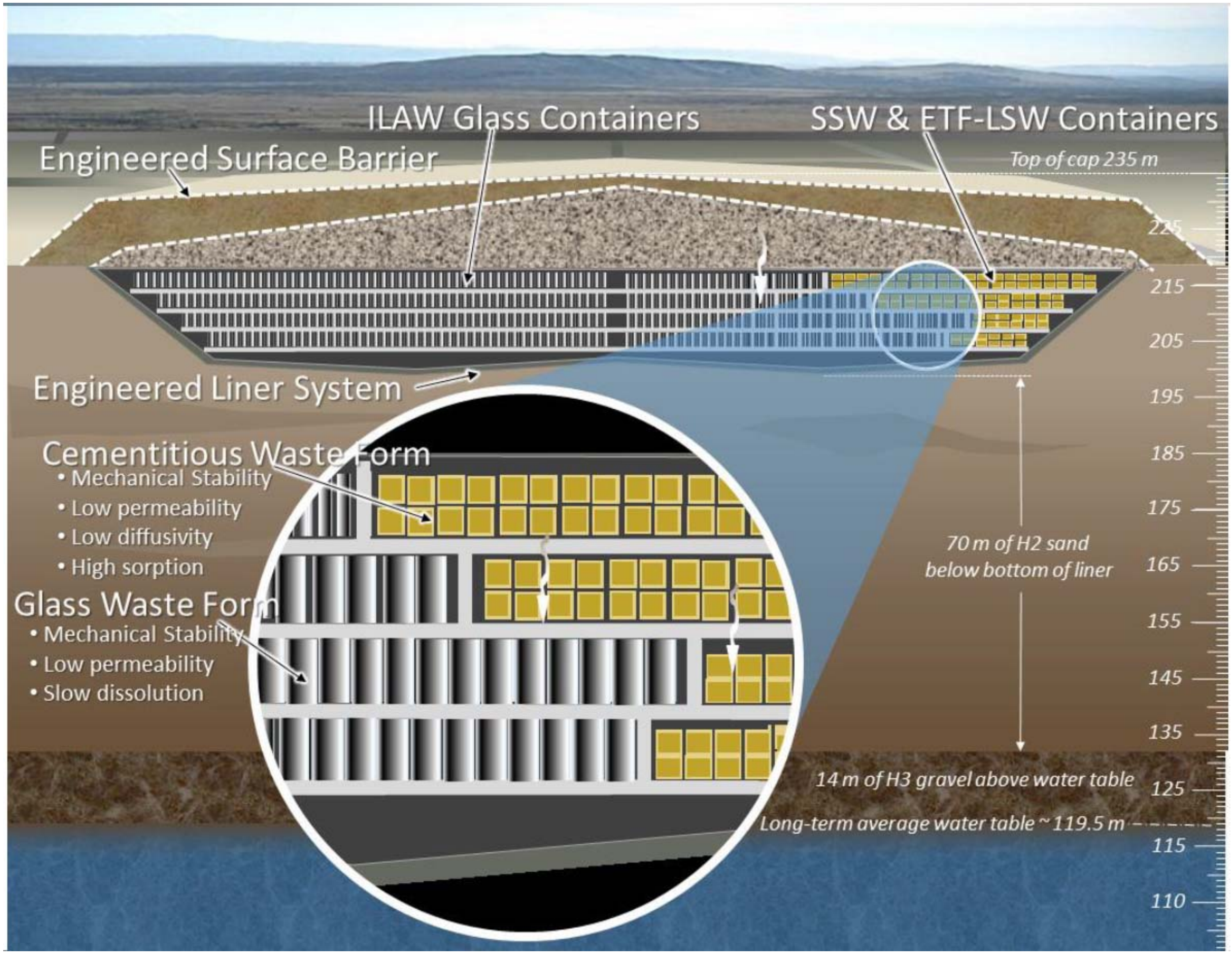
	LAW Glass	LAW Cast Stone (Grout)	LAW Steam Reforming Mineral Product
Mechanism of Release	Glass surface matrix dissolution	Diffusion through interstitial pore water	Mineral (sodalites) dissolution, diffusion (monolith), and chemical oxidation (reduced Tc)
Model	Geochemical: Reactive transport	Physical: Diffusive-advective transport	Geochemical: Reactive transport
Code	eSTOMP	eSTOMP	eSTOMP
Release Rate Parameters	Dissolution rate law expression based on transition state theory. LAWA44 glass rate law parameters (2017 IDF PA benchmark)	Effective diffusion coefficient (D_e), Recommended range of recent test data (oxidizing conditions), + lowest D_e test result	Dissolution rate law expression based on transition state theory. Thermodynamic data for sodalite minerals and rate law parameters from latest testing

Waste Form Release Mechanism and Performance Parameters Modeled

Solidified Secondary Wastes

	Solidified Secondary Wastes		
	LSW	SSW – HEPA	SSW - GAC
Waste	ETF-generated solid residue from liquid waste processing	Spent off-gas HEPA filters. Debris waste.	Spent off-gas carbon absorber (GAC). Non-debris waste.
Waste Form	Solidified (grout)	Macro-encapsulated. Grout surrounding compacted HEPA filters	Solidified (grout)
Mechanism of Release	Diffusion through interstitial pore water of grout matrix and retardation via geochemical interactions with the waste form and disposal environment		
Model	Physical: Diffusive-advective transport		
Code	eSTOMP		
Release Rate Parameters	• Diffusion coefficient (D_e) for diffusion through grout matrix interstitial pore fluids, • Distribution coefficient (K_d) to describe geochemical interactions that retard diffusion out of the waste form and disposal site materials • Rate parameters identical to 2017 IDF PA.		

IDF Characteristics – Engineered System

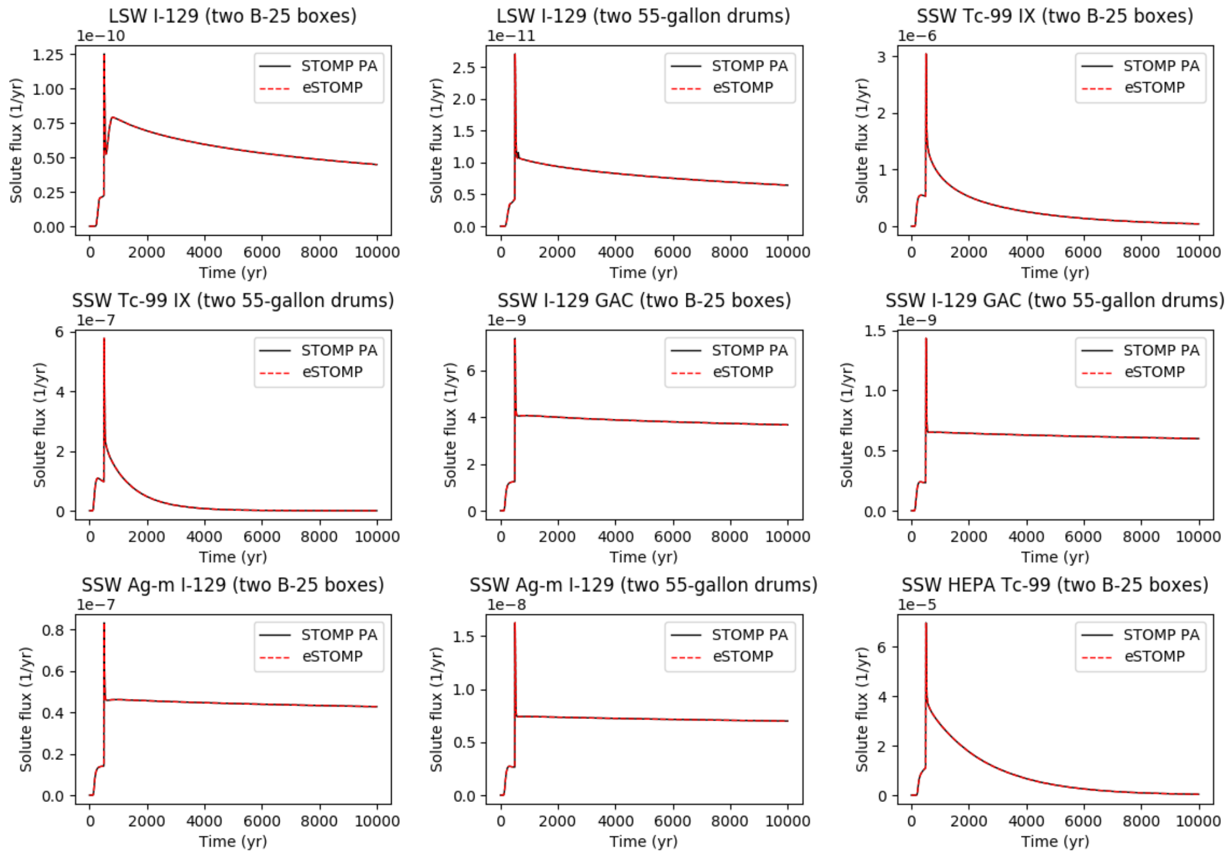


Performance Evaluation in Progress – Approach and Status

- **Use of eSTOMP enables use of 2017 IDF PA input files with increased computational efficiency (processing time)**
  - o Assures use of baseline IDF configuration, infiltration, and relevant parameters
  - o Initial Benchmarking studies confirm model setup and eSTOMP use produces comparable output to 2017 IDF PA
    - *Solid Secondary Waste*
    - *ILAW Glass*
- **Modeling each waste form separately in IDF configuration (e.g., 4 to 8 stacked waste containers) to represent full height of IDF and geochemical interactions occurring as constituents migrate downward**
  - o Quantifying total predicted flux (Ci/Ci disposed/yr) of Tc and I for each waste form (primary and secondary wastes) out of IDF
  - o Combine individual waste form flux projections to represent total flux for each SLAW case analyzed
  - o Post processing analysis of different inventory splits (e.g., Tc, or I to primary or secondary waste forms)

Performance Evaluation in Progress – Approach and Status (continued)

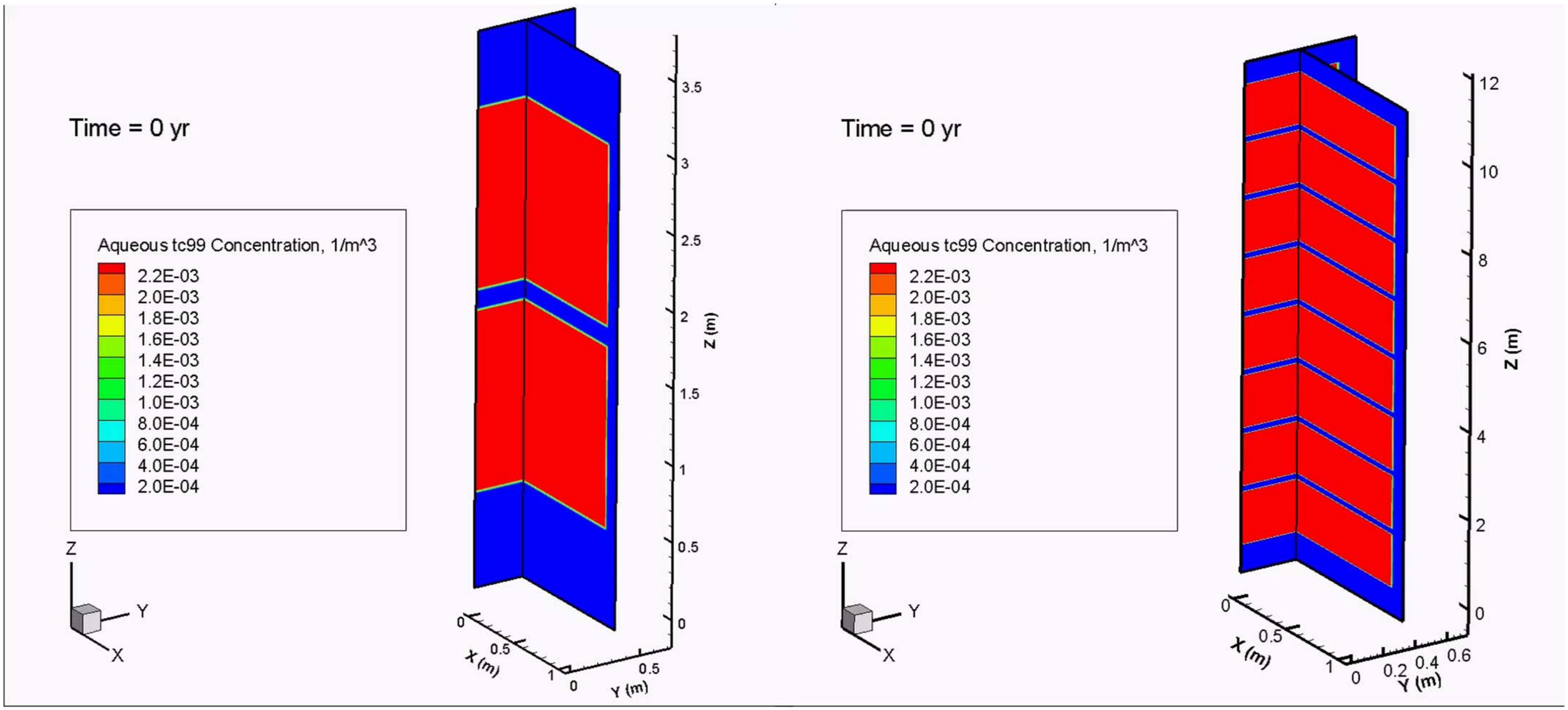
- **Benchmarking studies nearing completion**
  - o Re-executed simulations to ensure STOMP and eSTOMP codes yield the same results
    - ▪ *LSW, SSW and glass*



Solute flux comparisons between STOMP PA model and eSTOMP simulations

Performance Evaluation in Progress – Approach and Status (continued)

- **Simulating full stack of containers within the IDF**
- **SLAW Grout modeling in progress**



2 Containers Represented in IDF PA

8 Containers Represented in NDAA Analysis

Performance Evaluation – Next Steps

- **Complete benchmark analysis for ILAW and SLAW Glass and Solidified Secondary Waste**
  - o Comparison of projected Tc and I flux to those of 2017 IDF PA results
- **Complete Cast Stone and Steam Reforming modeling**
  - o Case 1 modeling with projected SLAW inventory for Tc and I
- **Projection of total system Tc and I flux for each SLAW case, and comparative analysis**
  - o Sensitivity analysis with varying Tc and I splits including additional pretreatment mitigation options
  - o Internal review and re-analysis as needed to address questions, anomalies
- **Finalize documentation and reporting of IDF waste form performance evaluation to support final draft report issuance**

Off-Site Disposal and Transport to Waste Control Specialists

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NAS Committee Meeting #4
November 29 and 30, 2018
Richland, WA

Pre-Decisional

Topics

- **Off-site disposal at Waste Control Specialists (WCS) Facility**
  - o Overview of WCS's Disposal Facility for Federal Wastes
  - o Overview of Wastes Identified for Possible Disposal at WCS
  - o Ability of Wastes to meet WCS's Waste Acceptance Criteria
  - o Costs to Dispose at WCS
  - o Risks/Obstacles
  - o Areas for further analysis

- **Program to Transport Wastes to WCS Facility**
  - o Scope of the Transportation Program
  - o Costs to transport to WCS
  - o Risks/Obstacles
  - o Areas for further analysis

Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
  - Overview of WCS's Disposal Facility for Federal Wastes
  - Overview of Wastes Identified for Possible Disposal at WCS
  - Ability of Wastes to meet WCS's Waste Acceptance Criteria
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Waste Control Specialists

- **Commercial disposal facility** owned and operated by Waste Control Specialists LLC
- **Located in west Texas**
- **Licensed by Texas, an NRC "Agreement State"**
- **Licensed for Class A, B & C LLW and Mixed LLW (MLLW)**
- **Federal Waste Disposal Facility**
  - Licensed specifically for federal waste
  - Licensed Capacity: 737,000 m3 (volume grout is 367,900 m3)
  - *DOE signed Agreement to take ownership of Federal Waste Facility after closure*
- **Site Setting**
  - Characterized & monitored with over 500 core samples and monitoring wells
  - Facilities are underlain by 600 ft (180 m) of nearly impermeable redbed clays
  - *WCS facilities are not over or adjacent to a drinking water aquifer*

o **TRL for Off-Site Disposal - high**


11(e)2 Byproduct Disposal Facility
RCRA Landfill
Federal Waste Disposal Facility
Compact Disposal Facility

Scale of WCS Disposal Facilities

Modular Concrete Containers (MCCs)

- **Class B and C MLLW** – usually disposed in their DOT shipping container, in a MCC
- **Class A MLLW** – not disposed in a MCC

Photo of Rectangular MCCs

Each MCC can hold two 8.4 m3 containers of waste

Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
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Radiological Content of Wastes to be Immobilized

- **Feed Vector provides radiological content and volume of SLAW from WPT-PT and LAWPS, for every month of production (Michael described System Plan 8 and Feed Vector)**
- **Based on analysis of Feed Vector, average of 1.85 curies** *per cubic meter of feed*
- **Immobilization increases volume and decreases specific activity**
- **Three nuclides responsible 96% all activity**
  - Strontium-90 81%
  - Samarium-151 12%
  - Technetium-99 3%

Average Radiological Profile of Supplemental LAW (WTP-PT + LAWPS)

Nuclide	Ci/m3		Nuclide	Ci/m3		Nuclide	Ci/m3
Ru-106	6.40E-14		Th-229	7.80E-08		Pu-242	1.60E-07
Cd-113m	5.30E-04		Pa-231	2.40E-06		Am-243	3.60E-06
Sb-125	2.10E-06		Th-232	1.90E-07		Cm-243	1.40E-06
Sn-126	6.20E-04		U-232	7.00E-07		Cm-244	2.00E-05
I-129	5.40E-05		U-233	7.50E-05		H-3	3.10E-04
Cs-134	2.90E-11		U-234	2.60E-05		Ni-59	5.40E-04
Cs-137	1.00E-02		U-235	1.10E-06		Co-60	1.50E-05
Ba-137m	0.0+0		U-236	7.00E-07		Ni-63	3.50E-02
C-14	1.70E-03		Np-237	2.00E-05		Se-79	1.00E-03
Sm-151	2.30E-01		Pu-238	1.10E-04		Sr-90	1.50E+0
Eu-152	1.10E-05		U-238	2.50E-05		Y-90	0.00E+0
Eu-154	1.40E-04		Pu-239	2.80E-03		Zr-93	1.90E-03
Eu-155	1.40E-05		Pu-240	5.80E-04		Nb-93m	1.90E-03
Ra-226	6.00E-09		Am-241	7.20E-03		Tc-99	5.40E-02
Ac-227	1.50E-06		Pu-241	9.60E-04			
Ra-228	2.30E-07		Cm-242	2.40E-05		**Total**	**1.85**

Immobilized Wastes Identified for Disposal *and Off-Site Transport*

- **Primary Waste Forms**
  - **Grouted Waste Form**
    - Volume change from treatment: 1.8 (increases volume & decreases specific activities)
    - Density of final WF: 1770 kg/m3 (110 lb/ft3)
    - **Average volume: 1092 m3 / month for 337 months**
  - **Steam Reformed Waste Form – Granular Mineral**
    - Volume change from treatment: 1.2 (increases volume & decreases specific activities)
    - Density of final WF: 800 kg/m3 (50 lb/ft3)
    - **Average volume: 728 m3 / month for 337 months**

- **Secondary Wastes**
  - Solid Secondary Wastes – operational wastes (e.g., HEPA filters, PPE, etc.)
  - Pretreatment Wastes – waste containing specific nuclides (e.g. 2E2: Tc-99 & I-129)
  - Liquid secondary wastes – solidified liquid effluents

Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
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  - Ability of Wastes to meet WCS's Waste Acceptance Criteria
  - Costs to Dispose at WCS
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  - Areas for further analysis

- Program to Transport Wastes to WCS Facility
  - Scope of the Transportation Program
  - Costs to transport to WCS
  - Risks/Obstacles

Waste Acceptance Criteria

- **[as used here] Waste Acceptance Criteria (WAC) are the criteria the waste must meet to be acceptable for disposal**

- **Examples of WAC for WCS:**
  - Wastes must meet Land Disposal Restrictions of RCRA
  - Free liquids must be < 1% by volume
  - Containers must be > 90% full

- **Focus on radiological WAC for WCS – provided in 2 tables**

- **Two Tables divide wastes into 3 Classes – Class A, Class B, Class C**

Radiological WAC for Long-Lived Nuclides (Table 1)

Radionuclide	Class A Limit		Class B Limit		Class C Limit	
C-14	0.8	Ci/m³	1	Ci/m³	8	Ci/m³
C-14 in Activated Metals	8	Ci/m³	1	Ci/m³	80	Ci/m³
Ni-59 in Activated Metals	22	Ci/m³	1	Ci/m³	220	Ci/m³
Nb-94 in Activated Metals	0.02	Ci/m³	1	Ci/m³	0.2	Ci/m³
Tc-99	0.3	Ci/m³	1	Ci/m³	3	Ci/m³
I-129	0.008	Ci/m³	1	Ci/m³	0.08	Ci/m³
Alpha-emitting transuranic radionuclides with half-lives greater than five (5) years	10	nCi/g	1	nCi/g	100	nCi/g
Pu-241	350	nCi/g	1	nCi/g	3,500	nCi/g
Cm-242	2,000	nCi/g	1	nCi/g	20,000	nCi/g
Ra-226[2]	10	nCi/g	1	nCi/g	100	nCi/g

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

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

- **Each limit is the full limit**
- **If multiple long-lived nuclides – use sum of fractions**

Observation: Disposal Limits Tc-99 & I-129 Not Limited by Groundwater Pathway

Radionuclide	Class A Limit		Class B Limit		Class C Limit	
C-14	0.8	Ci/m³	1	Ci/m³	8	Ci/m³
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There are no limits established for these radionuclides in Class B wastes

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

- Disposal limits Tc-99 & I-129 identical to NRC's generic disposal limits to protect inadvertent intruder found in 10 CFR 61.55
- If a significant groundwater pathway to member of public – limits for Tc-99 & I-129 might be smaller

Observation: Disposal of Tc-99 and I-129 from Hanford is Not Issue at WCS

Radionuclide	Class A Limit		Class B Limit		Class C Limit	
C-14	0.8	Ci/m³	1	Ci/m³	8	Ci/m³
C-14 in Activated Metals	8	Ci/m³	1	Ci/m³	80	Ci/m³
Ni-59 in Activated Metals	22	Ci/m³	1	Ci/m³	220	Ci/m³
Nb-94 in Activated Metals	0.02	Ci/m³	1	Ci/m³	0.2	Ci/m³
Tc-99	0.3	Ci/m³	1	Ci/m³	3	Ci/m³
I-129	0.008	Ci/m³	1	Ci/m³	0.08	Ci/m³
Alpha-emitting transuranic radionuclides with half-lives greater than five (5) years	10	nCi/g	1	nCi/g	100	nCi/g
Pu-241	350	nCi/g	1	nCi/g	3,500	nCi/g
Cm-242	2,000	nCi/g	1	nCi/g	20,000	nCi/g
Ra-226[2]	10	nCi/g	1	nCi/g	100	nCi/g

There are no limits established for these radionuclides in Class B wastes
[2] This isotope is not listed in the classification tables in 10 CFR Part 61 but is required by the state of Texas to be included in classification determination

- **WAC for Tc-99 is 3 Ci/m3 and average SLAW 0.05 Ci/m3, before immobilization**
- **WAC for I-129 is 0.08Ci/m3 and average SLAW 0.0005 Ci/m3, before immobilization**

Radiological Waste Acceptance 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/m³	[3]	Ci/m³	[3]	Ci/m³
H-3	40	Ci/m³	[3]	Ci/m³	[3]	Ci/m³
Co-60	700	Ci/m³	[3]	Ci/m³	[3]	Ci/m³
Ni-63	3.5	Ci/m³	70	Ci/m³	700	Ci/m³
Ni-63 in Activated Metals	35	Ci/m³	700	Ci/m³	7,000	Ci/m³
Sr-90	0.04	Ci/m³	150	Ci/m³	7,000	Ci/m³
Cs-137	1	Ci/m³	44	Ci/m³	4,600	Ci/m³

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

- **Each limit is the full limit**
- **If multiple nuclides – use sum of fractions**

If long & short-lived nuclides: classify based on long-lived (Table 1), unless higher classification from short-lived (Table 2)

Observation: Sr-90 Concentrations Exceed Class A Limits

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

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

- **Note: Sr-90 limit is 0.04 Ci/m3 for Class A, and average 1.5 Ci/m3**

Classification of Wastes for Disposal at WCS

- **EXCEL Spreadsheet used to determine waste classification: Feed Vector data each month + waste form characteristics compared to WCS's radiological WAC**

Classification of Waste Forms to be Disposed at WCS (measured as number of months of output from WTP-PT and LAWPS)				
Variant	**Class A**	**Class B**	**Class C**	**GTCC**
Grout Case II with LDR pretreat (2G2))	0	408	33	0
Steam Reformed Granular (3B)	0	302	130	9

Classification of Wastes for Disposal at WCS

- **Localized mixing to prevent generation of greater-than-class-C (GTCC)**

Classification of Waste Forms to be Disposed at WCS (measured as number of months of output from WTP-PT and LAWPS)				
Variant	**Class A**	**Class B**	**Class C**	**GTCC**
Grout Case II with LDR pretreat (2G2)	0	408	33	0
Steam Reformed Granular (3B)	0	302	139	0

Key Takeaway - All waste forms acceptable for disposal at WCS

Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
  - Overview of WCS's Disposal Facility for Federal Wastes
  - Overview of Wastes Identified for Possible Disposal at WCS
  - Ability of Wastes to meet WCS's Waste Acceptance Criteria
  - Costs to Dispose at WCS
  - Risks/Obstacles
  - Areas for further analysis

- Program to Transport Wastes to WCS Facility
  - Scope of the Transportation Program
  - Costs to transport to WCS
  - Risks/Obstacles
  - Areas for further analysis

Disposal Fees (no other costs)

- **For regular monthly deliveries & defined quantities, WCS did not object to 25% discount from current pricing, for this study:**
  - $1370 / m3 for Class A MLLW and
  - $5220 / m3 for the Class B and C MLLW

Classification of Waste Forms to be Disposed at WCS (measured as number of months of output from WTP-PT and LAWPS)					**Disposal Fees**
Variant	**Class A**	**Class B**	**Class C**	**GTCC**	
Grout Case II with LDR pretreat (2G2)	0	408	33	0	**$1.9 B**
Steam Reformed Granular (3B)	0	302	139	0	**$1.3 B**

Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
  - Overview of WCS's Disposal Facility for Federal Wastes
  - Overview of Wastes Identified for Possible Disposal at WCS
  - Ability of Wastes to meet WCS's Waste Acceptance Criteria
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- Program to Transport Wastes to WCS Facility
  - Scope of the Transportation Program
  - Costs to transport to WCS
  - Risks/Obstacles
  - Areas for further analysis

Assessment of Programmatic Risks

- This Team undertook quantitative assessment of risks based on elicitation of technology leads and other subject matter experts
- Tom and Steve will make a presentation on this risk assessment
- One programmatic risk was identified for disposal at WCS

Programmatic Risk for Disposal at WCS

- *Initiating scenario:* **Due to changing political considerations, Texas regulator blocks WCS from accepting Hanford wastes**
- *Probability of Scenario*: **Low**
- *Unmitigated Consequences*: **Very high costs, Very high schedule**
- *Mitigation Strategy*: **Negotiate with TX, WA, others to secure viable alternative**
- *Mitigation Probability of Success*: **Medium**
- *Mitigation Consequences*: **Medium cost and Low schedule**

Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
  - Overview of WCS's Disposal Facility for Federal Wastes
  - Overview of Wastes Identified for Possible Disposal at WCS
  - Ability of SLAWs to meet WCS's Waste Acceptance Criteria
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- Program to Transport Wastes to WCS Facility
  - Scope of the Transportation Program
  - Costs to transport to WCS
  - Risks/Obstacles
  - Areas for further analysis

Pre-Treatment to Remove Sr-90 and Reduce Disposal Costs

- **Recall that Sr-90 causes wastes to be Class B & C**
- **Analyzed effect of removing 99% of Sr-90 from grout**

Classification of Waste Forms to be Disposed at WCS (measured as number of months of output from WTP-PT and LAWPS)					**Disposal Fee**
Variant	**Class A**	**Class B**	**Class C**	**GTCC**	
Grout Case II with LDR pretreat (2G2)	0	408	33	0	**$1.9 B**
Grout Case II with LDR pretreat & 99% Sr-90 removed (2F)	406	2	33	0	**~$0.7 B**

- **Removal Sr-90: save > $1 B in disposal fees**
- **Areas for further analysis:**
  - **Research pre-treatment technologies & cost remove 99% of Sr-90 (Bob overview)**
  - **If viable – reassess disposal at WCS**
  - **If viable – assess transportation & cost savings for disposal at Clive facility in Utah**

Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
  - Overview of WCS's Disposal Facility for Federal Wastes
  - Overview of Wastes Identified for Possible Disposal at WCS
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  - Costs to transport to WCS
  - Risks/Obstacles
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Bottom Line Up Front - Transporting SLAW from Richland to WCS

Off-Site Shipping Program Summary			
Waste Form	**Container**	**Containers / gondola railcar**	**Average Railcars / month**
Grout & grout minus Sr-90 (2G2 & 2F)	8.4 m3 soft side IP-2 container in steel overpack	5	26
Steam Reformed Granular Mineral Product (3B)	8.4 m3 soft side IP-2 container in steel overpack	12	8
Secondary Solid Wastes and Pretreatment Wastes (Tc-99, I-129) Liquid Secondary Wastes	2.5 m3 "B-25 box"	18	TBD TBD TBD

- **On average: 8 or 26 gondola railcar per month for 337 months**
- **For reference: there are roughly 240,000 gondola railcars in North America**

Regulations for Shipping and Shipping Containers

- **NRC's 10 CFR 71 governs "Packaging and Transportation of Radioactive Material"**
  - **Defines packaging criteria for safe transport of radioactive material**
  - **Grout can be shipped as Low-Specific Activity (LSA-III) material**
  - **Steam Reformed Granular shipped as LSA-II material**
  - **LSA II & LSA-III materials must be shipped in containers that meet DOT Industrial Package 2 (IP-2) criteria (in 49 CFR 73.465 (c) & (d))**

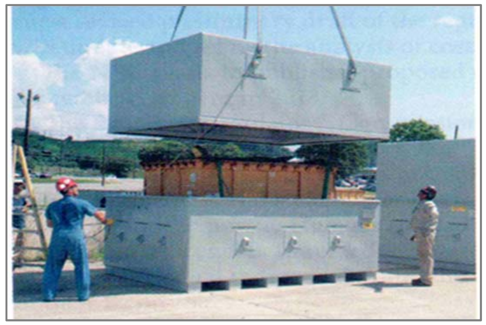
Shipping Containers

- 8.4 m3 soft side containers meeting DOT IP-2 criteria
- Containers placed in reusable steel overpacks - facilitate forming, handling and public confidence (boxes not needed to meet DOT IP-2 criteria)
- All wastes shipped on gondola railcars
- DOE own the gondolas
- TRL: High – DOE routinely ships radioactively contaminated soils for disposal by rail

Key Takeaway – All waste forms can be shipped to WCS

Off-Site Shipping Program

Example Soft Side Container (photo from PACTEC)

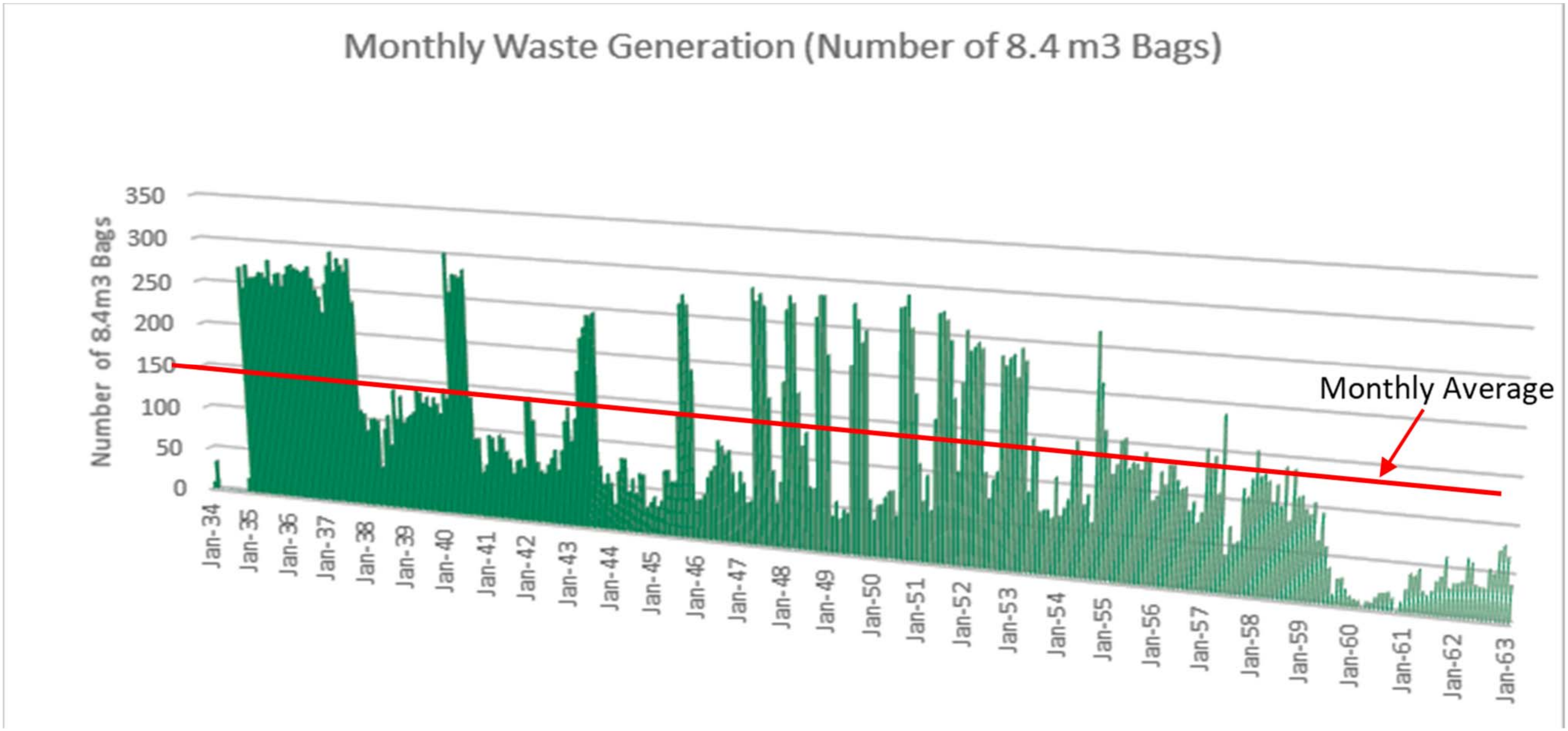


Example of Reusable Steel Overpack (photo from CTI)

Example of Gondola Railcar (photo from MRC)

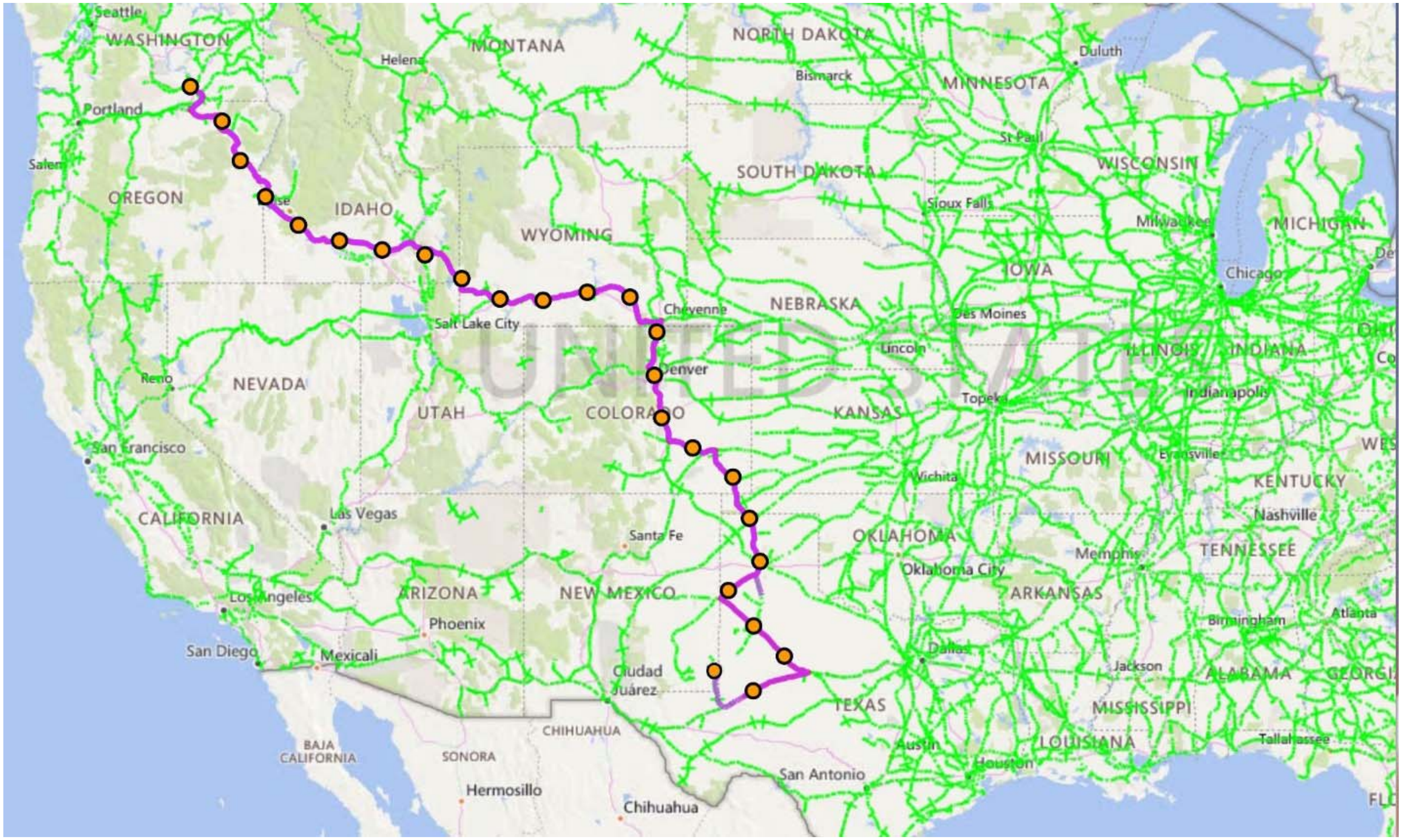
Lag Storage Facility Needed to Even-out Volumes for Shipping Program

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



Possible Rail Routing

- ~ 2,200 miles each way by rail



Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
  - Overview of WCS's Disposal Facility for Federal Wastes
  - Overview of Wastes Identified for Possible Disposal at WCS
  - Ability of SLAWs to meet WCS's Waste Acceptance Criteria
  - Costs to Dispose at WCS
  - Risks/Obstacles
  - Areas for further analysis

- Program to Transport Wastes to WCS Facility
  - Scope of the Transportation Program
  - Costs to transport to WCS
  - Risks/Obstacles
  - Areas for further analysis

Railroad Shipping Costs (no other shipping costs)

- **Railroad shipping rates are proprietary**
- **DOE / EM's Office of Packaging and Transportation**
  - o **Placed many contracts for shipping radioactive waste by rail**
  - o **Recommended $12,500 per loaded gondola ($3,000 return empty)**

Off-Site Shipping Program Summary			**Total Cost** 337 months
Waste Form	**Container**	**Railcars / month**	
Grout & grout minus Sr-90 (2G2 & 2F)	8.4 m3 soft side in steel box	26	**$0.136 B**
Steam Reformed Granular Mineral Product (3B)	8.4 m3 soft side in steel box	8	**$0.042 B**

Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
  - o Overview of WCS's Disposal Facility for Federal Wastes
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  - o Scope of the Transportation Program
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  - o Areas for further analysis

Assessment of Technical Risks

Environmental Impact Statement for major transportation program might analyze:

1. **Non-radiological impacts on Local & National Traffic**
2. **Non-radiological Impacts of Transportation Accidents**
3. **Radiological Impacts of Routine Transportation**
4. **Radiological Impacts of Transportation Accidents**

This study not an EIS.

Technical Risks – Assessed Traffic Fatalities Associated With Rail Traffic

- **Reviewed U.S. statistics for rail traffic fatalities**
  - Average: 741 million train-miles per year (2006 through 2016)
  - Average: 760 fatalities per year (2006-2016)
  - Average: 1.0 fatality per million Train-miles (2006 through 2016)

- **This transportation program:**
  - 1 train per month to WCS and return
  - 53,000 train miles per year
  - Statistically: 0.053 fatalities per year

- **In context:** Statistical 0.053 fatalities per year is very small compared to average of 760 fatalities per year.

- **Could reduce to 0.026 fatalities per year by shipping every 2 months**

Programmatic Risk for Shipping to WCS

- *Initiating scenario:* **Political opposition, in major city on rail route, following rail accident, causes DOE to temporally stop shipping**
- *Probability*: **Low**
- *Unmitigated Consequences*: **Very high costs, Very high schedule**

- *Mitigation Strategy*: **Change rail route or shift to truck**
- *Mitigation Probability of Success:* **Very High**
- *Mitigation Consequences*: **Low cost and low schedule**

Topics

- Disposal Off-Site at Waste Control Specialists (WCS) Facility
  - Overview of WCS's Disposal Facility for Federal Wastes
  - Overview of Wastes Identified for Possible Disposal at WCS
  - Ability of SLAWs to meet WCS's Waste Acceptance Criteria
  - Costs to Dispose at WCS
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- Program to Transport Wastes to WCS Facility
  - Scope of the Transportation Program
  - Costs to transport to WCS
  - Risks/Obstacles
  - Areas for further analysis

Waste- and Route-Specific Analysis of Transportation Impacts

Detailed, <u>waste- and route-specific analysis</u> of transportation impacts:

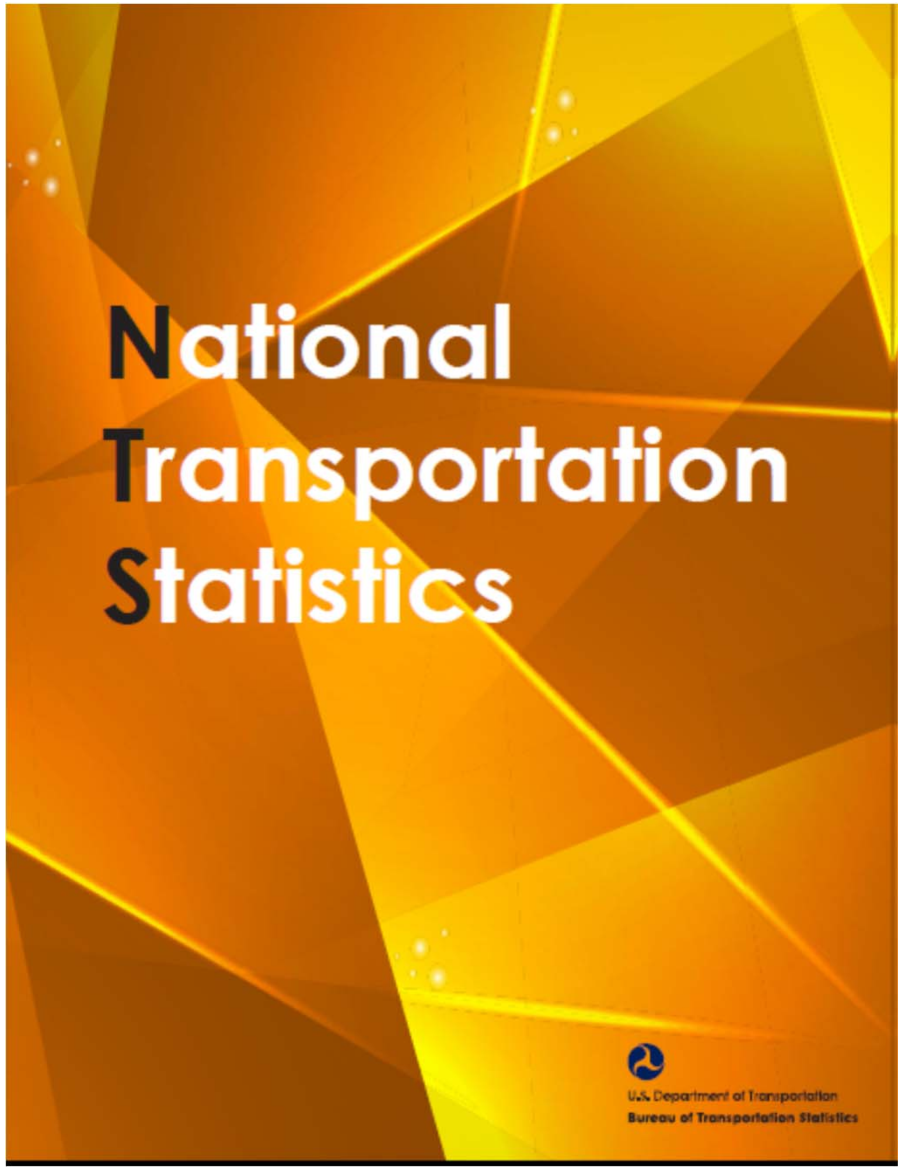
1. **Impacts on Local and National Traffic from Routine Transportation** (air quality, noise, wear-and-tear)

2. **Non-radiological Impacts of Transportation Accidents** (statistical number accidents and fatalities)

3. **Radiological Impacts of Routine Transportation** (dose to maximally exposed individual and dose to the population along the route)

4. **Radiological Impacts of Transportation Accidents (s**tatistical doses from a hypothetical accident.

Thank You



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NDAA 3134 Supplemental Low Activity Waste Risk Analysis of Technology Options

Steve Unwin and Tom Brouns
Energy & Environment Directorate
Pacific Northwest National Laboratory

NAS Committee Meeting #4
November 29 and 30, 2018
Richland, WA

Pre-Decisional

Outline

- **Basis for risk methods selection**
  - Why this risk methodology was chosen
- **Methods description**
  - Methodology structure and implementation
- **Results of assessment**
  - Comparison of technology options
  - Risk drivers

Risk Methodology Options

- **A spectrum of risk methods exists**
  - From: Full quantitative study, system modeling to component level, formal elicitations
  - To: A qualitative study, inputs researched by analysts
- **Guiding factors in selection**
  - Objectives of assessment
  - Level of system definition and operational detail available
  - Robustness of bases for quantification
  - Availability of subject matter expertise
  - Project resources (time/budget) available

Common structure of all risk models: The triplet

Scenario: what can go wrong?

Probability: how likely is it to happen?

Consequences: what's the impact?

Methodology Selected

- **Method selected**
  - Conforms to "triplet" risk structure
  - Semi-quantitative
  - Based on SME elicitation
  - Analogous to several standard methods
    - *Hazard and Operability Study*
    - *Failure Modes, Effects and Criticality Analysis*
    - *Preliminary Hazard Analysis*
    - *What-If? Studies*

- **Scenario focus**
  - Events involving deviations from R&D, design or operational intent

- **Consequence/risk metrics**
  - Extent of delay in completion of tank waste treatment mission
  - Incremental costs (excluding delay costs) in achieving mission
    - *R&D, redesign and deployment costs*

Methodology Outline

- **Elicitation of technology leads and other SMEs**
- **Use of risk worksheet**
  - To ensure formal risk structure of elicited information
  - Basis for documentation
- **Identification of**
  - Causal events that could give rise to deviations from design/operational intent
  - Means of mitigating such events
  - Descriptions of cost/schedule impacts when
    - *Mitigation succeeds*
    - *Mitigation fails*
- **Approximate quantitative assessments to support risk characterization**
  - Probability of causal event
  - Probability that mitigation succeeds
  - Cost/schedule impacts for both mitigated and unmitigated cases

$$R = P_c \cdot [P_m \cdot C_m + (1-P_m) \cdot C_u]$$

R = Risk

Pc = Cause probability

Pm = Mitigation probability

Cm = Mitigated consequence (cost or schedule)

Cu = Unmitigated consequence (cost or schedule)

Risk Worksheet Column Headers

Column Header	Definition
Option/Variant ID	S-LAW option ID to which scenario applies
Option/Variant Name	S-LAW option description
Scenario ID	A scenario designation for reference
Cause	Event that initiates the scenario
Cause Prob	The probability rating associated with occurrence of the cause
Mitigation	Once the cause has occurred, actions that would be taken to mitigate its impact
Mitigation Prob	The probability rating associated with implementing the mitigation and its subsequent success
Unmitigated Consequences	Description of the consequences that would occur if the mitigation fails
Unmitigated Consequences: Cost	The cost impact rating of the unmitigated scenario
Unmitigated Consequences: Schedule	The schedule impact rating of the unmitigated scenario
Mitigated Consequences	Description of the residual consequences that would occur if mitigation is successful
Mitigated Consequences: Cost	The cost impact rating of the mitigated scenario
Mitigated Consequences: Schedule	The schedule impact rating of the mitigated scenario
Risk - Cost	Internally calculated central estimate of cost risk in $B
Risk - Schedule	Internally calculated central estimate of delay risk in years
Comments	Notes clarifying or justifying the scenario

Quantification Ratings

Scenario Probability/Consequence/Mitigation Ratings					
Rating	Category	Cause Probability	Cost Consequences	Schedule Consequences	Mitigation Probability
VH	very high	95 - 100%	> 5 $B	> 10 years	95 - 100%
H	high	40 - 95%	3 - 5 $B	7 - 10 years	40 - 95%
M	medium	25 - 40%	1 - 3 $B	3 - 7 years	25 - 40%
L	low	1 - 25%	0.1 - 1 $B	1 - 3 years	1 - 25%
VL	very low	<1%	< 0.1 $B	< 1 year	<1%

Consensus approach

A Worksheet Extract

Grout	S-LAW Grout Case I and Grout Case 2
Review Date: 10/16/2018	

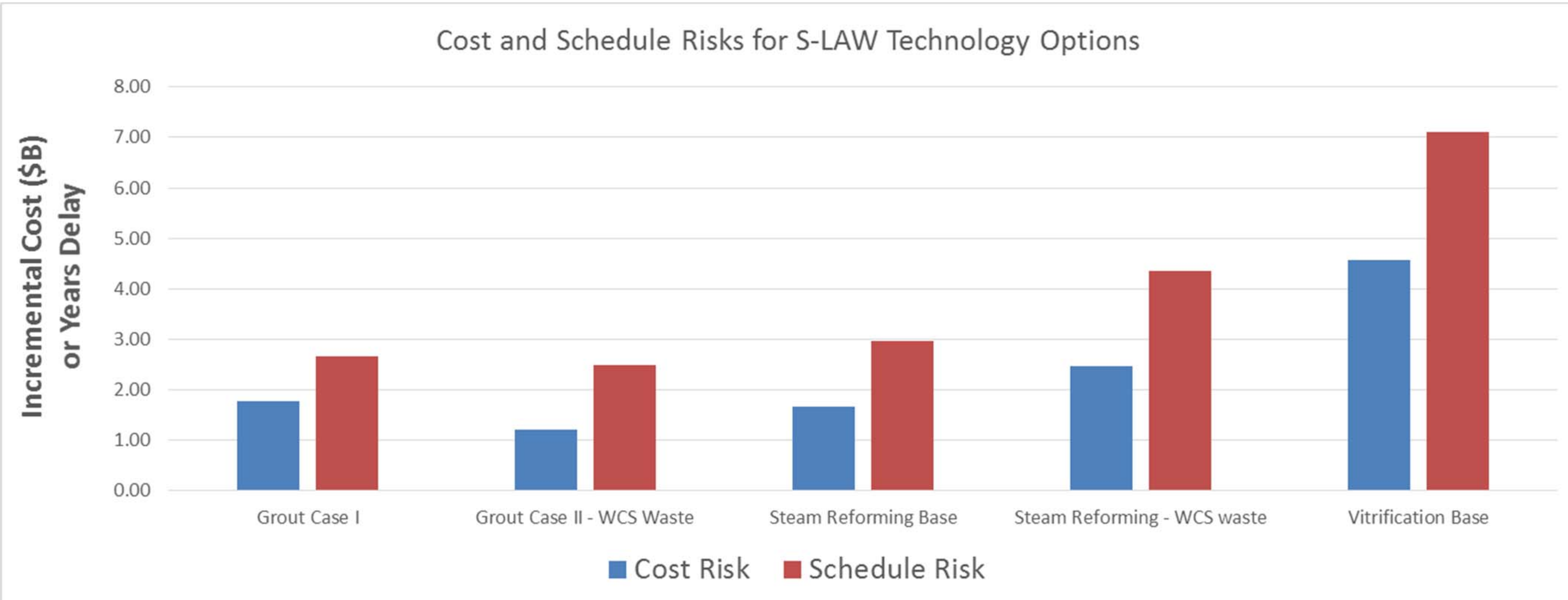
Option/Variant ID	Option/Variant Name	Scenario ID	Cause	Cause Prob	Mitigation	Mitigation Prob	Unmitigated Consequences	Unmitigated Consequences Cost	Unmitigated Consequences Schedule	Mitigated Consequences	Mitigated Consequences Cost	Mitigated Consequences Schedule	Risk Calc Cost Risk ($B)	Risk Calc Schedule Risk (Yrs)	Comments
2G2	Grout Case II (2G2)	REG 1	Due to changing political considerations, Texas regulator blocks WCS from accepting Hanford wastes	L	Negotiations with WA, TX, or alternate to secure viable disposal options	M	Cost and delays associated with pursuit of alternative non-grout technology - extended operation of LAW and HLW Vit	VH	VH	Cost and delay associated with negotiations and possible added facility/process mods	M	L	0.70	1.23	Mitigation may include special cells, separating Sr90 to allow for Class A to Utah. Unmitigated consequence - if during design/development, could go to Vit baseline. If at startup or after, could consider longer operation of existing facilities vs. second vit facility. Cause is assumed to occur at/after startup of grout facility. Inherent assumption that grout started, that if TX/UT won't take it, can negotiate small volume treated so far goes to IDF with understanding remaining waste goes to LAW VIT Mitigated consequence assumes negotiation for disposal
2G2	Grout Case II (2G2)	TRP 8	Political opposition, in major city, on rail route following a rail accident. Result may be that DOE temporarily abandon rail shipping. Occurs after shipping has started.	L	Change/renegotiate route, or shift to road/truck shipping, or alternate to secure viable disposal options	VH	Cost and delays associated with pursuit of alternative non-grout technology - extended operation of LAW and HLW Vit	VH	VH	Cost and delay associated with implementing mitigation	L	L	0.09	0.30	Cause - Assumes an accident occurs and triggers outcry. Is road/truck shipping (mitigation) subject to similar risk as rail? - many more options (routes) by truck, and not significantly more expensive. Transportation costs are not appreciable relative to disposal costs. First priority negotiate, then truck, and finally alternate disposal site where Sr90 would need to be removed. Mitigation consequences assume most conservative (alt. disposal). Same unmitigated case as Reg. 1
2G2	Grout Case II	PT 5b	During operation it is determined that for a range of tank compositions non thermal oxidative methods do not result in sufficient LDR organic destruction	M	Divert problematic waste streams to LAW VIT - able to swap other waste to balance SLAW and LAW VIT - no impact on schedule.	H	Diverts to LAW VIT, but more waste causes delay in schedule, inability to balance SLAW and LAW VIT	M	M	Cost of vitrifying fraction of LAW stream that was planned to go to grout	VL	VL	0.22	0.55	Unmitigated, Assuming a fraction of tanks have elevat3d organics that require diversion, possibly 1-3 years of operation and up to $3B in costs.
All	Grout Cases I and II	GRT 1	Key grout reagents become unavailable in the future	VH	Stockpile reagents and/or qualify alternative grout reagents	VH	Cost and delays associated with pursuit of alternative non-grout technology - extended operation of LAW and HLW Vit	VH	VH	Reagent stockpile and identification & qualification of alternate reagents	VL	VL	0.20	0.41	Applies to all grout cases. Given timeframe of processing, fly ash supply will become limited over time with H to VH probability. Will build this into grout options as part of the development process to assess and qualify reagents.

Example of Event Tree for Multiple Mitigation Options

Model adjustments to reflect instances
where there are multiple mitigation options

CAUSE	MITIGATION 1	MITIGATION 2	MITIGATION 3	Scenario Description	Scenario Probability	Cost Consequence	Schedule Consequence
Grout Case 2D - Failure to Meet O 435.1	Additional R&D - Improve Grout	Go to Option 2E1 - TC/I Separations	Go to Option 2G2 - Waste to WCS				
Probability PC: H	Success Probability PM1: VH	Success Probability PM2: H	Success Probability PM3: H				
	Success			First Mitigation Option Succeeds	PC . PM1	VL	VL
	Failure	Success		Second Mitigation Option Succeeds	PC. (1-PM1). PM2	L	VL
		Failure	Success	Third Mitigation Option Succeeds	PC. (1-PM1) . (1-PM2) . PM3	M	L
			Failure	Pursue Non-Grout Technology	PC. (1-PM1) . (1-PM2) . (1-PM3)	VH	VH

Preliminary Results



Risk Drivers

Individual scenarios for which cost risk > $1B or delay risk > 1 year

Option	Scenario	Cost Risk ($B)	Schedule Risk (Years)
Grout Case I	Grout formulation- performance unable to meet Tc/I ECY performance expectations/State permitting requirements - given DOE requirements are met	1.32	1.61
Grout Case II	Due to changing political considerations, Texas regulator blocks WCS from accepting Hanford wastes	0.70	1.23
Steam Reforming Base Case	Demonstration testing results in less than 70% availability (design basis) for facility	1.13	2.01
Steam Reforming to WCS	Demonstration testing results in less than 70% availability (design basis) for facility	1.13	2.01
	Due to changing political considerations, Texas regulator blocks WCS from accepting Hanford wastes	0.70	1.23
Vit Baseline 1	WTP LAW throughput (70% TOE) not achieved in actual operations	2.75	3.43
	WTP LAW Startup results in facility mods that must also be implemented in SLAW VIT	0.67	1.63
	Melter idling during actual operations of SLAW significantly decreases waste loading (S and halides) and increases LSW volume and Tc99 levels	0.69	1.35

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NDAA – Hanford Supplemental LAW Evaluation

Estimate and Schedule Summary

William Ramsey & Frank Sinclair
SRNL Environmental Stewardship & Nuclear Materials Management Directorates

NAS Committee Meeting #4
November 29 and 30, 2018
Richland, WA

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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**
  1. Vitrification
  2. Fluidized Bed Steam Reforming
  3. Grouting

- **Two disposal sites**
  1. Hanford WA, Integrated Disposal Facility (IDF)
  2. Offsite Commercial Facility (WCS)

Overview

- **Cost estimating follows the process technology and pre-treatment flowsheets as well as the transportation/disposal cost (for offsite) disposal, where applicable.**

- **Work performed indicative of Estimate Class 5: Concept Screening**
  - AACE International Recommended Practice 18R-97 key guidance

- **Not all variants will be estimated. Key focus points include:**
  - Technology complexity, history, and maturity.
  - The projected range within a given technology (between variant).

- **Final disposal location is a significant factor for Grout and FBSR.**

- **Transportation/disposal logistics and cost are treated as individual field to better reflect the impacts and provide comparison.**
  - Detailed description (in conjunction with Cochran et al.) in final report.

Status

Iterative process with multiple technology variants and transportation disposal options.

Key Points:

- Significant variation between different technologies
  - Consistent between estimating effort and SME ranking process
  - Risk analysis workshop under review
- Analogs selected for each base technology
- Technology type appears significantly more impactful than sub-variants
- Transportation and <u>off-site disposal</u> included
  - Largest impact to Grout and FBSR options
  - Disposal is significant cost for either technology with respect to life-cycle
  - Cost estimate includes recent quotes
- Support from SMEs in detailing transportation, regulations, and disposal cost noted and appreciated.

Methodology

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

Class 5 estimates developed from SME flowsheets with at least 2 iterations per SME team plus May (variant comparison) and October (risk) FFRDC group meetings.

1. Identification / Utilization of Analog Facility for Primary Process

Vitrification	*WTP-LAW w/ EMF (Hanford)*
	Vit Case 1: 2X capacity of existing LAW w/ enhanced off-gas
	Vit Case 2: 2 double capacity melters with enhanced off-gas
Grout	*Saltstone (SRS)*
	Grout Case 1: PT w/ disposal at IDF, packaged form, additional load-out / logistics
	Grout Case 2: PT w/ disposal at WCS, packaged form, load-out through to TX
FBSR	*IWTU (Idaho)*
	FBSR Case 1: 2 IWTU process lines - grouted monolithic waste form
	FBSR Case 2: Same scale as Case 1, but with mineral product to offsite disposal

Methodology, continued

Class 5 estimate as per characteristics (Classification Matrix for the Process Industries) and DOE Capital Facility guidance and history.

End Usage:	**Concept Screening, Evaluation of Alternatives, Resource and Long-Range Capital Planning**
Methodology:	**Capacity Factored, Judgement, Analogy**
Purpose:	**Identification of key cost factors**

- **Analogs for each technology exist – at varying levels of construction and operations.**
  - WTP >> Saltstone > IWTU with respect to degree of compatibility basis
- **Class 5 estimates are consistent with downselects versus direct comparisons,**
  - Example, DWPF estimates for cold crucible versus joule heated refractory lined melter.
- **Technology development requirements and scaling not consistent with Class 4 or Class 3 (which are more appropriate for budget planning and authorization).**
- **Transport and offsite disposal much better than ROM, more akin to Class 2.**
- **Intent was to evaluate flowsheet coherence and primary cost components.**

Disposal Fees (no other costs)

- **For regular monthly deliveries & defined quantities, WCS did not object to 25% discount from current pricing, for this study:**
  - o $1370/m3 for Class A MLLW and
  - o $5220/m3 for the Class B and C MLLW

Classification of Waste Forms to be Disposed at WCS (measured as number of months of output from WTP PT and LAW PS)					**Disposal Fees**
Variant	**Class A**	**Class B**	**Class C**	**GTCC**	
Grout Case II with LDR pretreat (2G2)	0	408	33	0	**$1.9 B**
Steam Reformed Granular (3B)	0	302	139	0	**$1.3 B**

Disposal cost estimate significantly better than Class 5, however, Quantity (FBSR), timeliness, & package/handling details exist

Railroad Shipping Costs (no other costs)

- **Railroad shipping rates are proprietary**
- **DOE / EM's Office of Packaging and Transportation**
  - Placed many contracts for shipping radioactive waste by rail
  - Recommended $12,500 per loaded gondola ($3,000 return empty)

Off-Site Shipping Program Summary			**Total Cost** 337 months
Waste Form	**Container**	**Railcars / month**	
Grout & grout minus Sr-90 (2G2 & 2F)	8.4 m3 soft side in steel box	26	**$0.136 B**
Steam Reformed Granular Mineral Product (3B)	8.4 m3 soft side in steel box	8	**$0.042 B**

Cost detail better than Class 5. Key points – gondola car availability nor transport pricing impact results.

Methodology, continued

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

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

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

Methodology, continued

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

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

Transportation	For grout / FBSR products (preferred method – rail)
Disposal	Commercial facility pricing based on volume and radiological input
D&D	TBD – will be estimated as function of TPC (on order of 5%)
G&A	overhead and general services

Notes:

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

Estimate Range
by
Technology and Variant Case

Preliminary Cost Estimate: FBSR

FBSR Case 1

Technology Development	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replacement	D&D	Total Program Cost
$480M – $1,100M	$1,000M – $2,600M	$1,900M – $4,390M	$1M – $2.6M	$3,276M – $4,914M	N/A	$300M – $690M	$TBD	$8,493M – $15,232M

FBSR Case 2

Technology Development	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replacement	D&D	Total Program Cost
$480M – $1,100M	$1,000M – $2,600M	$1,900M – $6,880M	N/A	$2,520M – $3,780M	$1,850M – $2,775M	$300M – $690M	$TBD	$9,471M – $19,246M

Notes:

- T&D cost impacted by waste characteristics, maturity, type of testing
- OPEX / Life Cycle cost impacted by maturity
- Transport and disposal significant but not dominant portion of cost

Preliminary Cost Estimate: Grout

Grout Case 1

Technology Development	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replacement	D&D	Total Program Cost
$90M – $210M	N/A	$500M – $1,150M	$1M – $2.6M	$1,120M – $1,680M	N/A	$250M – $1,160M	$TBD	$2,000M – $5,000M

Grout Case 2

Technology Development	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replacement	D&D	Total Program Cost
$120M – $280M	N/A	$650M – $1,464M	$1M – $2.6M	$1,120M – $1,680M	$2,775M – $4,163M	$320M – $1,508M	$TBD	$5,000M – $10,000M

Notes:

- T&D cost impacted by waste characteristics, maturity, type of testing
- OPEX / Life Cycle cost impacted by maturity
- Transport and disposal significant but not dominant portion of cost
  - o Estimates being updated to reflect most recent estimates

Preliminary Cost Estimate: Vitrification

Vit Case 1

Technology Development	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replacement	D&D	Total Program Cost
$340M – $1,020M	$1,000M – $2,600M	$6,800M – $15,600M	$1M – $2.6M	$10,080M – $15,120M	N/A	$1400M – $2100M	$TBD	$21,300M – $40,000M

Vit Case 2

Technology Development	Pilot Plant TPC & OPEX	Total Project Cost (TPC)	IDF Expansion	OPEX/Life Cycle Cost	Shipment WCS	Major Equipment Replacement	D&D	Total Program Cost
$680M – $1,560M	$1,000M – $2,600M	$6,800M – $15,600M	$1M – $2.6M	$8,540M – $12,810M	N/A	$770M – $1160M	$TBD	$19,300M – $37,000M

Notes:

- Significant overlap exists between HLW/PT capital projects and SLAW Vit
  - o Specific concern is multiple projects @ current funding cap (6-10 years)
  - o Alternative is schedule slip for SLAW Vitrification (as per current WTP PT/HLW)
- OPEX / Life Cycle and TPC cost based on DFLAW actuals and estimates
  - o Closest analog of three technologies
- Major equipment replacement examples – melters, bubblers
  - o Systematic replacement built into existing program

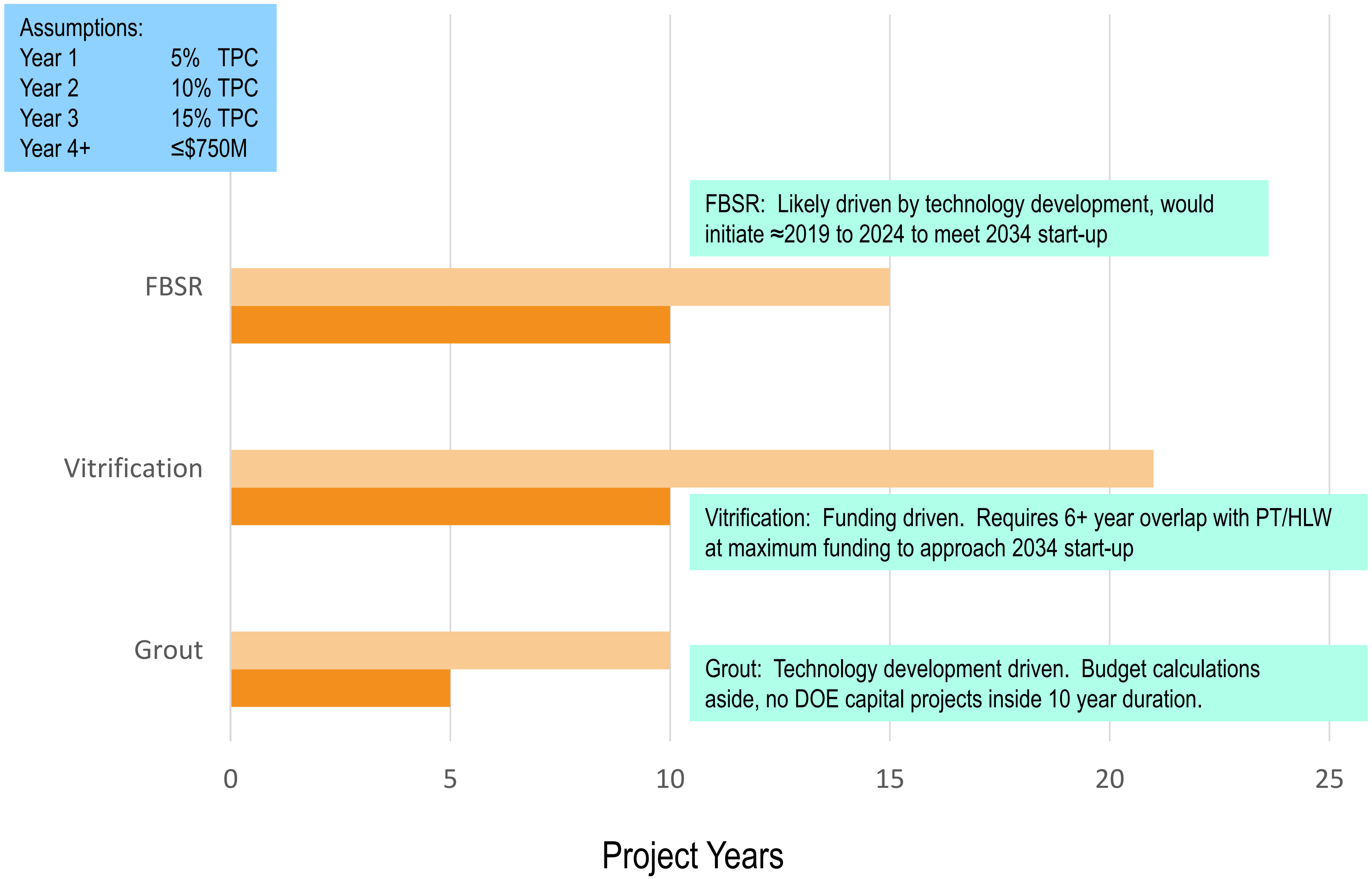
Cost Range Comparisons

	Technology Development $(M)	Total Project Cost, TPC $(M)	OPEX / Life Cycle Cost $(M)	Total Program Cost $(M)
Vitrification	340-1560	6800-15,600	8500-15,100	19,000-40,000
FBSR	480-1100	1900-6900	2500-4900	8500-19000
Grout	90-280	500-2180	1100-1700	2100-10000

Notes:

- Analog based values consistent with aggregate SME rankings
- Values shown reflect high – low range within individual technologies
- Significant differential in DFLAW operations estimate vs IWTU or Saltstone
- T&D cost impacted by duration, type of testing
- Offsite disposal costs significant for variants, not between technologies

Timelines for Technology



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Wrap-Up and Next Steps

Bill Bates
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Deputy Associate Laboratory Director
SRNL Nuclear Materials Management Programs Directorate

NAS Committee Meeting #4
November 29 and 30, 2018
Richland, WA

Summary and Next Steps

- **Comparative Analysis**

NDAA PARAMETERS	VITRIFICATION	GROUT	STEAM REFORMING
COST	$19B-$40B	$2B-$10B	$8.5B-19B
SCHEDULE	10-21 Years	5-10 Years	10-15 Years
BENEFITS	• Current baseline • Most technically mature for SLAW feed • Thermal LDR organic/nitrate destruction • Lowest primary waste volume	• Lowest temperature process (less offgas, stop/start flexibility, safety) • Least complex process • Utilizes vast international experience • Lowest secondary waste volume	• Lowest cost thermal LDR organic/ nitrate destruction • Medium primary & secondary waste volume
REGULATORY COMPLIANCE	• Primary wasteform compliant for onsite disposal (IDF) • Secondary grout wasteform & onsite disposal (IDF) pending	• High likelihood to meet DOE Technical Performance Criteria for onsite disposal (IDF) • Secondary solid wasteform & onsite disposal (IDF) pending	• High likelihood to meet DOE Technical Performance Criteria for onsite disposal (IDF) • Secondary solid wasteform & onsite disposal (IDF) pending
	All wasteforms are compliant with offsite transport and disposal (WCS).		
RISKS/ OBSTACLES (Technical)	• Most dependent on integrated facility performance (DFLAW, WTP, TF) ○ Most complex ○ Highest throughput risk ○ Most impacted by feed rate variability • Highest secondary waste volume (liquid and solid)	• May require System Plan feed adjustments or pretreatment to address organic peaks • Highest primary waste volume • Additional validation/demonstration of wasteform performance needed	• Lowest technical maturity • Latest waste form performance tests show promise, but more needed for regulator/stakeholder acceptance
RISKS/ OBSTACLES (Programmatic)		• Potential lack of stakeholder/ regulator acceptance for onsite disposal (IDF)	• Potential lack of regulator/stakeholder acceptance for onsite disposal (IDF)
	All technologies require significant concurrent Line Item and operations funding (> $1.5B/yr).		

- **Report Drafted and Maturing**
  - Refining to Address NAS Review Report #2 Input
  - Submit Final Draft Report to NAS on 12/21/2018
- **Next Steps**
  - Collect Meeting #4 Feedback
  - Await NAS Report #3
  - Finalize and issue FFRDC final report