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Federally Funded Research and Development Center (FFRDC) Team Report Overview – Supplemental Treatment of Low-Activity Waste at Hanford

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2021 NDAA-3125 Meeting #4

January 31-February 1, 2023

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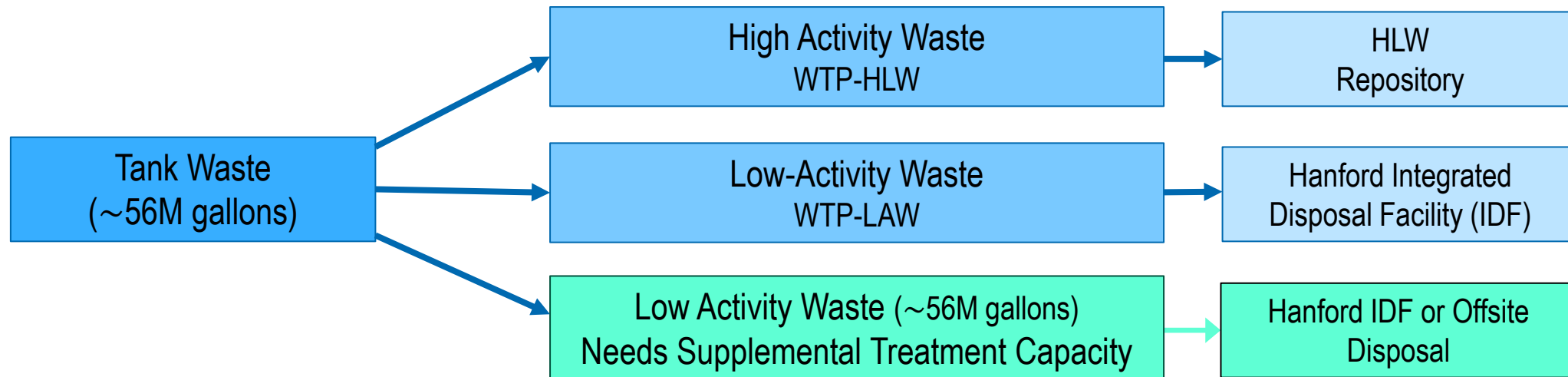
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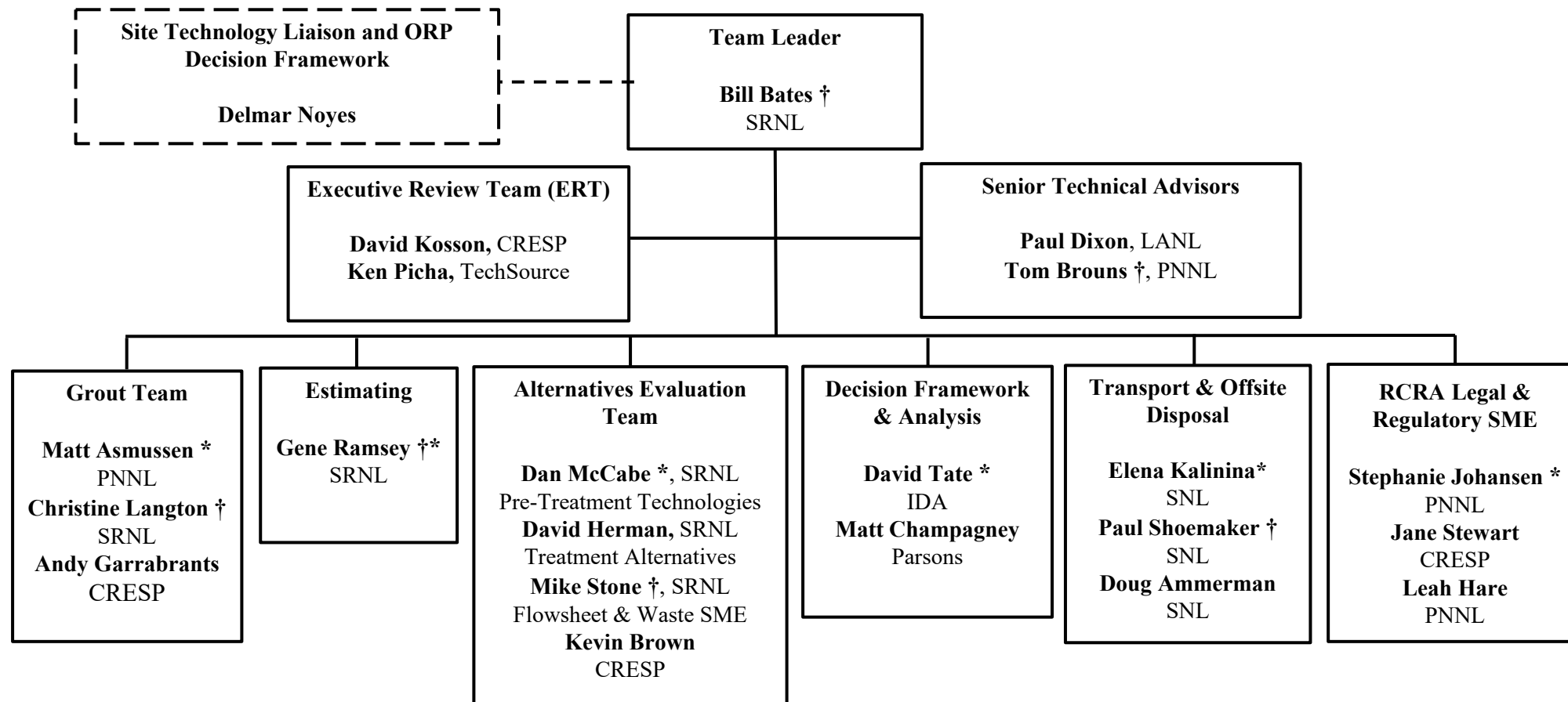
FFRDC Team Scope

- **2021 National Defense Authorization Act (NDAA) Section 3125**
 - Continued Analysis of Approaches for Supplemental Treatment of Low-Activity (LAW) Waste at Hanford Nuclear Reservation
- **Supplemental LAW Treatment Capacity Needed to Meet Mission Schedule Objectives**



- **WTP LAW Does Not Have Capacity to Treat all LAW Without Impacting the HLW Processing Mission Duration**

FFRDC Team Structure



†Member of 2017 NDAA-3134 FFRDC Team

*Assessment Area Lead

Order of Presentations & NAS Recommendation Discussions

- **Bill Bates (SRNL)** — FFRDC Team Report — Introduction & Overview (F)
- **Michael Stone (SRNL)** — Process and Feed Vector Overview (A, H)
- **Dan McCabe (SRNL)** — Alternative Descriptions (K)
- **David Tate (IDA)** — Decision Framework Development (B)
- **William Ramsey (SRNL)** — Risk Reduction, Cost, & Schedule (B, C, G)
- **Matt Asmussen (PNNL)** — Grout Technology Advances & Uncertainties
- **Kevin Brown (CRESP)** — Fluidized Bed Steam Reforming Enhancements
- **Elena Kalinina (SNL)** — Off-Site Disposal and Transportation Description (E, H, I)
- **Stephanie Johansen (PNNL)** — On-Site Disposal Description
- **Dan McCabe (SRNL)** — Summary of Selected Alternative Criteria Assessments (D, E, J)
- **Matt Champagney (Parsons)** — Assessment Summary and Results (L)
- **David Tate (IDA)** — Recommendation Development (M)
- **Bill Bates (SRNL)** — Wrap Up — Summary and Conclusions

FFRDC Analysis per NDAA Section 3125

- “... shall be designed, to the greatest extent possible, to *provide decisionmakers with the ability to make a direct comparison between approaches for the supplemental treatment of low-activity waste at the Hanford Nuclear Reservation based on criteria that are relevant to decision making and most clearly differentiate between approaches.*”
- **Technologies**
 - Vitrification — Glass Waste Form
 - Fluidized Bed Steam Reforming (FBSR) — Granular Waste Form (may be further encapsulated)
 - Grout — Cementitious Waste Form
- **Timing**
 - Intent to Finish LAW Treatment Concurrent with WTP-HLW Vitrification Facility Mission

FFRDC Analysis Approach

- **Developed Detailed Analysis Criteria**
- **Assessed 15 Alternatives Against all Criteria**
- **Selected Four (4) Alternatives for Comparative Analysis**
 - Vitrification, FBSR, and two Grout Alternatives
- **Developed Recommendation and Supporting Conclusions**

NAS Committee Review #2 Report

- **Recommendations Were Very Helpful In Completion of the Analysis**
- **The FFRDC Team also Reviewed Chapter 3 and other Observations**
- **Presenters will Expand on How Recommendations were Addressed**
 - Other Improvements & Clarifications
 - Changes Related to Observations

FFRDC Response to NAS Recommendations

NAS Recommendation (summarized):	FFRDC Approach/Response	Applicable Section(s)
A: Include a discussion of the tank integrity program with references to describe the strategy that is adopted and the status to provide perspective for decision makers.	- Added References & Discussion of Hanford structural integrity programs - FFRDC scope does not assess or predict structural failures	1.3.2
B: The affordability concept should be removed from the "likelihood of successful mission completion" criterion and not assume any funding limit for this purpose. The FFRDC should then compare unconstrained lifecycle cost profiles with sensitivity analyses about what funding levels would be required.	- Changed to "benchmark annual funding" - Expanded discussion of insensitivity to unconstrained funding - Retained annual funding needs in Criterion 3 (Likelihood of Successful Completion) - FFRDC does not view annual funding needed as duplicative with LC Cost (Criterion 4)	Executive Summary, 3.2, 4.1, 5.0, and 6.1, Appendix I.A., I.C., II.D., II.F.
C: i. Make defensible assumptions related to cost (e.g., capital cost, interest rates, escalation, operating cost, time to construct), calculate the cost profile for the duration of the mission, and then perform sensitivity studies on this analysis. C: ii. Provide graphs depicting the amount of SLAW processed and the amount remaining each year in terms of waste volume and radioactivity, and the annual projected budget requirements for each alternative to achieve a comparable rate of SLAW processing.	- Costs, rates, timing, & mission impacts clarified in Appendices - Table moved from Appendix to Main Body of report showing quantities and curies removed and dollars spent vs. time for selected alternatives (Risk Reduction)	Appendix II. F. Section 3.4 (Table 3.4-1) and Appendix II.F.

FFRDC Recommendations, cont.

NAS Recommendation (summarized):	FFRDC Approach/Response	Applicable Section(s)
D: Include a discussion of issues associated with obtaining regulatory approval for the various options. Specifically, it would be helpful to focus on the significant adverse consequences of grouted SLAW not being acceptable for disposal at IDF or other out-of-state disposal sites.	- Expanded discussion of dual paths for offsite disposal - Expanded discussion of risks and likely options if offsite options are unavailable	Section 6.2
E: Expand consideration of the consequences of potential impediments impacting the safe and expeditious SLAW management, such as grouted SLAW not being accepted for transportation, disposal at IDF, or other out-of-state disposal sites. The FFRDC should incorporate insights from public comments obtained to date in the final report, as well as the experiences of other sites that have transported radioactive waste to distant treatment or disposal locations	- Expanded discussion of transportation requirements - Expanded discussion of Offsite Facility Requirements - Discussed Dual Pathway Risk Mitigation	Sections 6.1 and 6.2 Appendix I.D., II, G., and II.H (H.13)
F: Acknowledge as a sub-criterion under key criterion 6 (community/public acceptance), consideration of the location and amount of land to which tribal members are likely to have access among the four alternatives that were evaluated.	- Added Tribal Treaty Aspects and reference to DOE Order 144.1 - Did not revise Criterion 6 because treaty rights aspects involve government to government interactions.	Executive Summary Sections 2.0 and 6.2
G: Give more discussion of the consequences for cost, time to completion, and likelihood of completion of the delayed start date of the vitrification treatment.	Tables from Appendix moved into the Main Body	Section 3.4 Appendix II.F.
H: Address the implications of using monthly averages of pre-treated liquid SLAW compositions when dose limits are on a tanker-by-tanker basis	- Expanded discussion of monthly feed vector - Performed LSA Package Dose Modeling	Section 1.3.1.1. Appendix II.H. (H.10)

FFRDC Recommendations, cont.

NAS Recommendation (summarized):	FFRDC Approach/Response	Applicable Section(s)
I: The FFRDC needs to resolve this possible dose rate inconsistency: i. Describe how tanker dose rates were calculated and provide some summary results, especially for the dose rate at 3 meters and ii. Reconcile the inconsistency between using shielding to meet the dose rate limit at 3 meters with the statement that such an approach is prohibited to underpin the conclusion that liquid SLAW will be LSA waste (USNRC, 2021).	Documented Package Dose Rate modeling & results	Appendix II.H. (H.5.3) Appendix II.H. (H.5.3)
J: The FFRDC report should elaborate the potential negative consequences of the unavailability of off-site disposal by (1) discussing the possibility that permission to dispose of grouted SLAW at WCS and/or Clive might never occur or someday be withdrawn; (2) discussing what is known about public acceptance regarding potential grouted SLAW disposal in Texas and Utah; and (3) providing more information surrounding the orphaned waste issue including specifics on how the issue might develop and what the consequences/coping measures might be.	- Discussed “orphaned” waste consequences and logical approaches if offsite options become unavailable - Reinforced that most Supplemental LAW meets Class A enabling two offsite options - Did not discuss Public Acceptance at offsite locations (consistent with approach to criterion 6)	Section 6.2 Appendix I.D (D.3.7)
K: The differences between on-site and off-site grouting treatment should be separately analyzed in the same level of detail as on- and off-site disposal. The grout alternatives should identify potential variations on the on-site and off-site alternatives, such as tank-side treatment or pretreatment, to provide DOE with the ability to make a financial “business case” with a range of budgetary possibilities for on- and off-site alternatives, including additional upfront DOE funding. This is also captured by a public comment from Hastings (see Appendix C) regarding possible technologies to increase the speed with which tank waste is retrieved.	Recognized potential for modular onsite grout plants and added discussion	Section 3.3.4

FFRDC Recommendations, cont.

NAS Recommendation (summarized):	FFRDC Approach/Response	Applicable Section(s)
L: Comparisons should be quantified, and as such, charts and graphs that lack a quantified basis should be eliminated (see Finding 4). This recommendation is particularly directed at the presentations in Section 4.0 Comparative Analyses.	Modified & replaced qualitative graphics	Section 4.3
M: If the FFRDC is to offer a recommendation, it needs to be fully transparent concerning the methods used to reach the recommendation and the analysis that supports the recommendation. In particular: i. The report should explain the process that led to the recommendation, who participated, and explicitly acknowledge the value judgments made in implementing the process. ii. The report should describe how the key criteria of regulatory and public acceptance were considered. If regulatory and public acceptance factors were not considered, except as significant uncertainties, by the FFRDC in developing its recommendation this should be made explicit	- Expanded description of how Recommendation was derived & who participated - Explained that the recommendation is based on assessments not sensitive to Regulatory & Public Acceptance criteria	Section 6.2 Section 4.1, 4.3, and Appendix I.A (A.2)

Recommendation F

- NAS Recommendation Language and FFRDC Approach

NAS Recommendation (summarized):	Applicable Section(s)
F: The FFRDC should acknowledge as a sub-criterion under key criterion #6 (community/public acceptance), consideration of the location and amount of land to which tribal members are likely to have access among the four alternatives that were evaluated and include this in the discussion of community/public acceptance (see Section 2.1.2.6).	Executive Summary Main Body §2.0 Main Body §6.2 Appendix D §D.3.7

Recommendation F Related Text Changes

- **Text Changes**

- Section 2 (Regulatory) – added paragraph regarding Tribal Nations' treaty rights
- Section 6.2 (Recommendations)
 - *Added paragraph on Tribal Treaty Aspects*
 - *Clarified that if the FFRDC recommendation is accepted, tribal treaty aspects will need to be addressed using established formal processes.*

- **Government-to-Government interactions are addressed pursuant to DOE O 144.1, *Department of Energy American Indian Tribal Government Interactions and Policy*.**

Comparative Analysis of Four Selected Alternatives

Vitrification 1: Disposal onsite at Hanford	FBSR 1A: Solid monolith product disposal onsite at Hanford	Grout 4B: Off-site grouting/disposal	Grout 6: Phased Approach Off-site grouting/disposal, then on-site grouting/disposal
Criterion 1: Long-term effectiveness (environmental and safety risk after disposal)			
Highly effective for primary waste; moderately effective for secondary waste. Medium confidence in the assessment.	Effective. Medium confidence in the assessment, due to technology immaturity.	Highly effective. High confidence in the assessment.	Highly effective. Good to high confidence in the assessment.
Criterion 2: Implementation schedule and risk (environmental and safety risks prior to mission completion, including risks driven by waste tank storage duration)			
High risk due to significant cost-based startup delays and operations limits. Moderate technical implementation risk. Construction finishes and treatment starts in 2047, mission does not complete without significant additional annual budget.	High risk due to construction time required and technical execution risk. Construction finishes and treatment starts in 2039; mission completes 2070.	Low risk due to earliest potential start of treatment in 2027, minimal construction, low-temperature process, likely capacity, and modest transportation and operations costs. Limited facilities (e.g., evaporator and load-out station) needed; mission completes 2066.	Very low risk due to earliest potential start of treatment in 2027, flexible timing of conversion to on-site low-temperature process, and inexpensive operations. Grout plant construction finishes 2039; mission completes 2066.
Criterion 3: Likelihood of successful mission completion (including technical, engineering, and resource-related risks)			
Very low probability of successful completion due to resource intensity.	Low probability of successful completion due to technical risk.	Very high likelihood of successful completion.	High likelihood of successful completion.
Criterion 4: Lifecycle cost (discounted lifecycle costs)			
\$7.6B construction; \$5.1B operations (total operations costs exceed benchmark budget by \$1.2B)	\$3.4B construction; \$2.2B operations	\$0.4B construction; \$3.4B operations	\$1.4B construction; \$2.7B operations

Recommendation

- ***DOE should expeditiously secure and implement multiple pathways for off-site grout solidification/immobilization and disposal of LAW in parallel with the DFLAW vitrification process.***
 - **Rapid Risk Reduction** – DST Space, Accelerate Waste Retrievals, Waste Stabilized
 - **Environmental Protection** – Reduce On-Site Disposal Inventory, Offsite Disposal with No Credible Pathway to Potable Water
 - **Flexibility** – Can Route LAW Treatment and Disposal Selectively
 - **Mitigates Risk** – Having Multiple Licensed Off-Site Treatment and Disposal Facilities with Selection Based on Sampling
 - **Time to Enable Transition(s)** – If On-Site Treatment and/or Disposal are Pursued, Benefits from Operating Experience
 - **Reduction or Elimination of Need for Future Capabilities**
 - **Minimized Financial Demands** – Closest to Current Funding Levels
 - **High Likelihood of Successful Implementation and Mission Completion**



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Process and Feed Vector Overview

Michael Stone

SRNL Environmental and Legacy Management
Alternatives Evaluation Team Member

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Recommendations/Significant Changes

NAS Recommendation (summarized):	FFRDC Approach/Response	Applicable Section(s)
A: Include a discussion of the tank integrity program with references to describe the strategy that is adopted and the status to provide perspective for decision makers.	• Added References & Discussion of Hanford structural integrity programs • FFRDC scope does not assess or predict structural failures	Main Body §1.3.2
H: Address the implications of using monthly averages of pre-treated liquid SLAW compositions when dose limits are on a tanker-by-tanker basis	• Expanded discussion of monthly feed vector • Performed LSA Package Dose Modeling	Main Body § 1.3.1.1. Appendix II.H. (H.10)

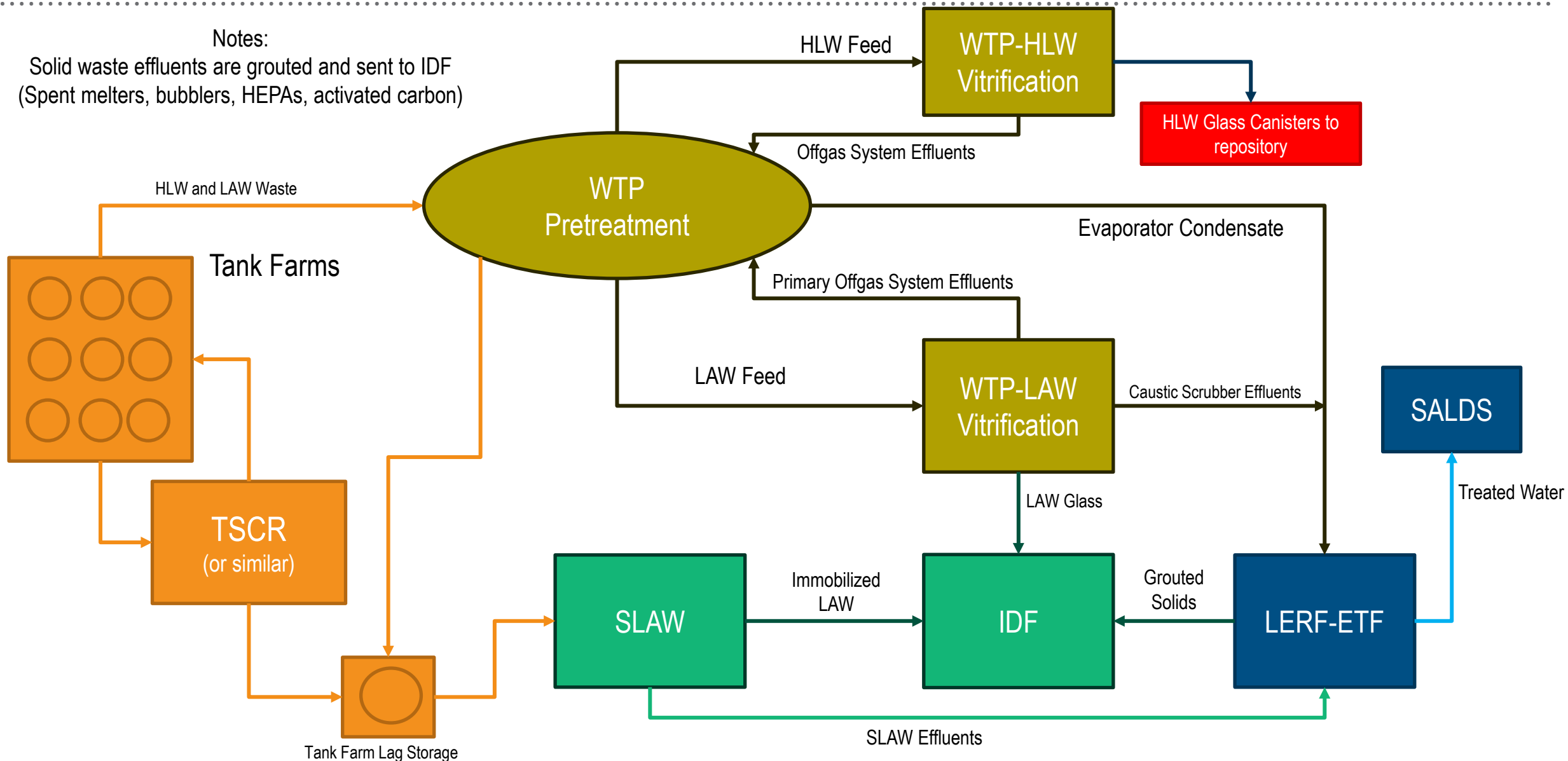


Updates to Feed Vector Section (Recommendation H)

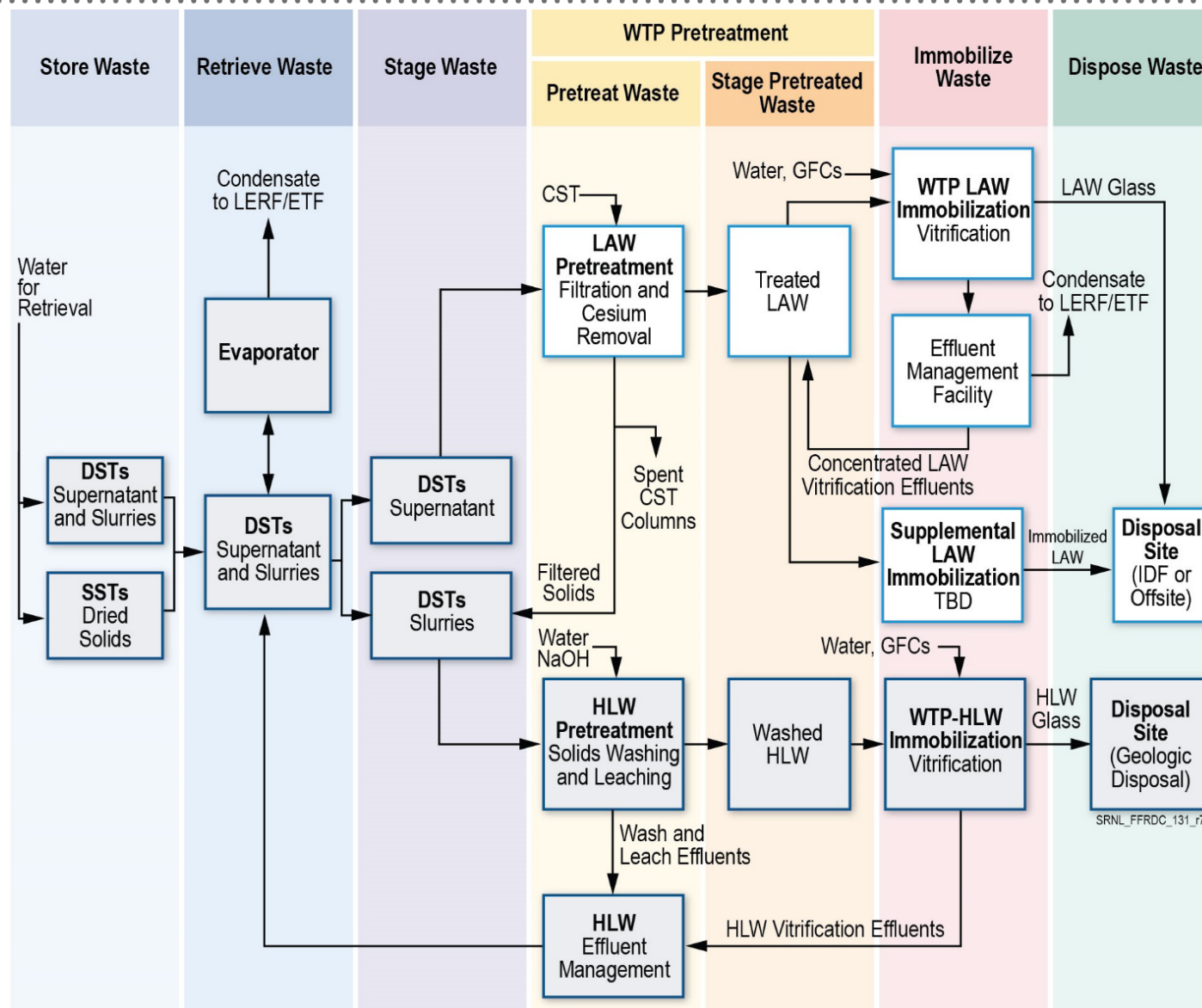
- **Time interval – Is monthly Data Sufficient? Feed Campaigns for a DFLAW Flowsheet Last ~ Six Months Therefore the Time Interval of One Month is Appropriate.**
 - *Discussion added to Appendix II.B.*
- **Discussion Added to Address the Reasons for the Additional Model Runs for Vitrification and Grout Options (Section 1.3.1.1 and Appendix II.B)**
 - SP9, 1B feed vector used for initial evaluations
 - Additional model runs were performed to evaluate impact of constrained funding for grout and vitrification options
 - *Simply moving start dates for SLAW while retaining the same feed vector would not be an accurate representation*
 - Earlier start possible for grout options
 - Later start required to complete capital project for vitrification
 - *FBSR completion under constrained funding was close to the SP9 1B date, therefore a new run was not performed*
 - The additional model runs were used for cost and schedule evaluations

- **Section 1.3.2 Updated to Include Additional References and Update Information Based on Latest Revisions**
- **A Comment was made Whether the Impacts of Tank Failures were Accurately Described.**
 - DOE presented additional information on impacts of DST failures on Jan 11, 2023
 - Report is consistent with the information provided by DOE

Overall Tank Waste Treatment Flowsheet – Full WTP Operation

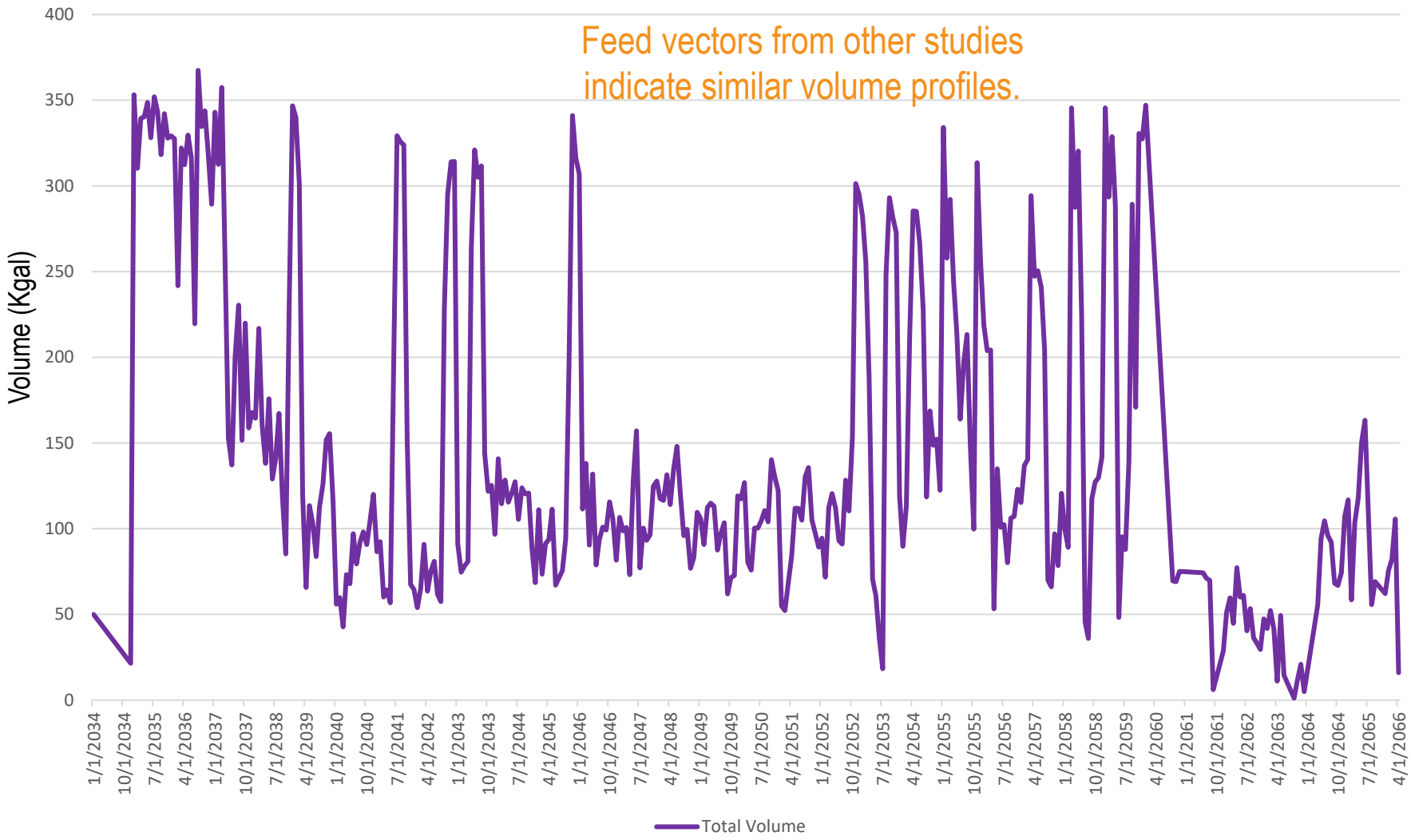


Overall Process Diagram – Direct Feed Flowsheets



SLAW Treatment Capacity

SP9 1A Monthly Volumes



Overall waste volume determines needed capacity for grout facility

System Plan 8

Max: 370,000 gal/month
Ave: 160,000 gal/month
Min: 7,200 gal/month
Total: 54,000,000 gallons
Turndown: 50:1

System Plan 9 1A

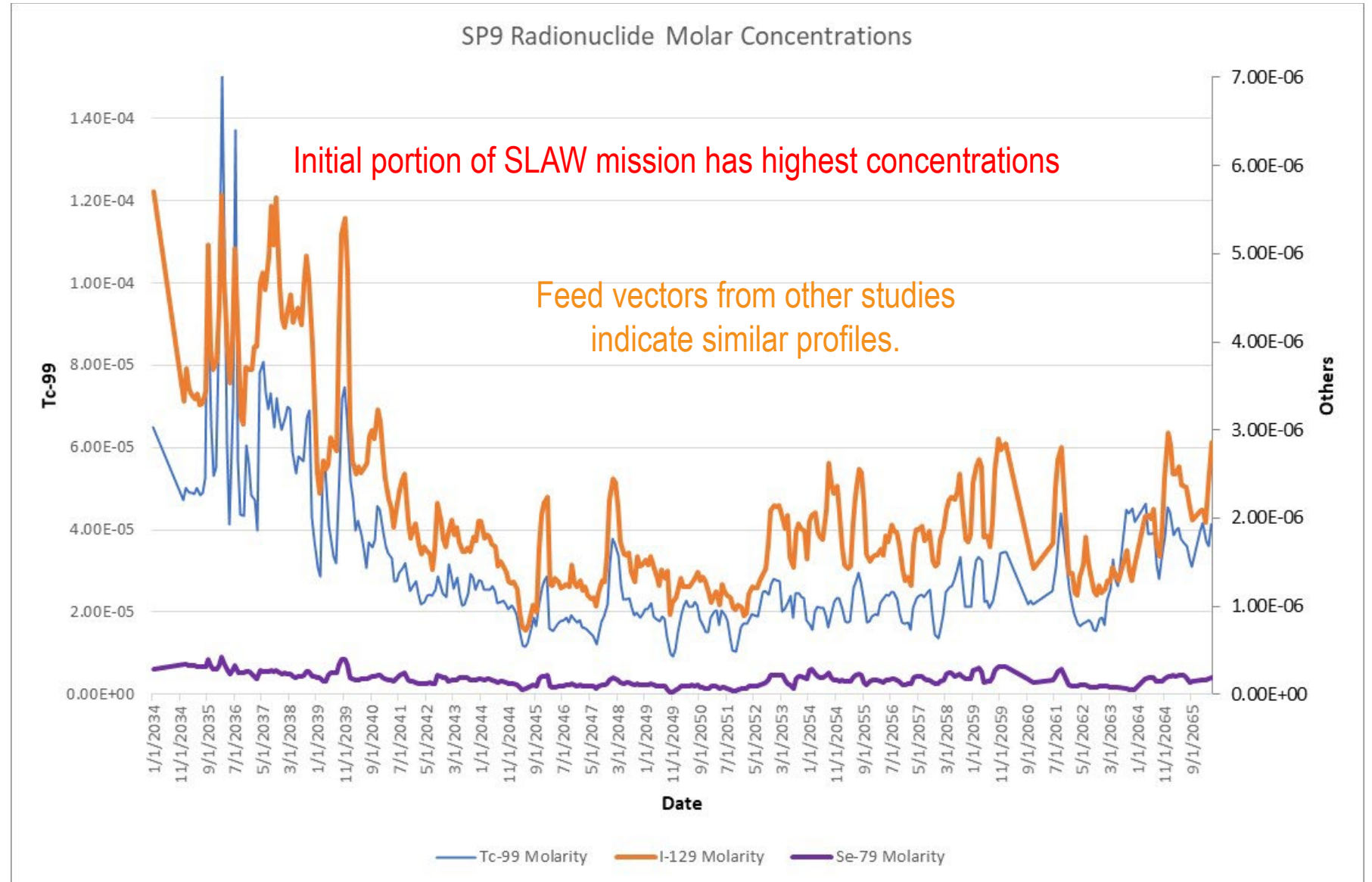
Max: 367,000 gal/month
Ave: 145,000 gal/month
Min: 1,100 gal/month
Total: 52,000,000 gallons
Turndown: 300:1

System Plan 9 1B

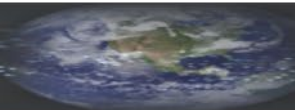
Max: 264,000 gal/month
Ave: 114,000 gal/month
Min: 700 gal/month
Total: 56,000,000 gallons
Turndown: 370:1

Radionuclides of Concern in SLAW

- The IDF Performance Assessment identified Tc-99 and I-129 as the constituents that were most likely to challenge groundwater protection performance standards
- Se-79 also included on chart based on comments received on 2017 evaluation of SLAW



Backup



SLAW Treatment Capacity

- Waste sodium determines needed capacity for vitrification process
- One melter can treat 40 to 80 MT of sodium/day depending on waste loading and operating efficiency

System Plan 8

Max: 296 MT/month

Ave: 138 MT/month

Min: 8 MT/month

Total: 47,000 MT

System Plan 9 1A

Max: 271 MT/month

Ave: 113 MT/month

Min: 1 MT/month

Total: 40,000 MT

System Plan 9 1B

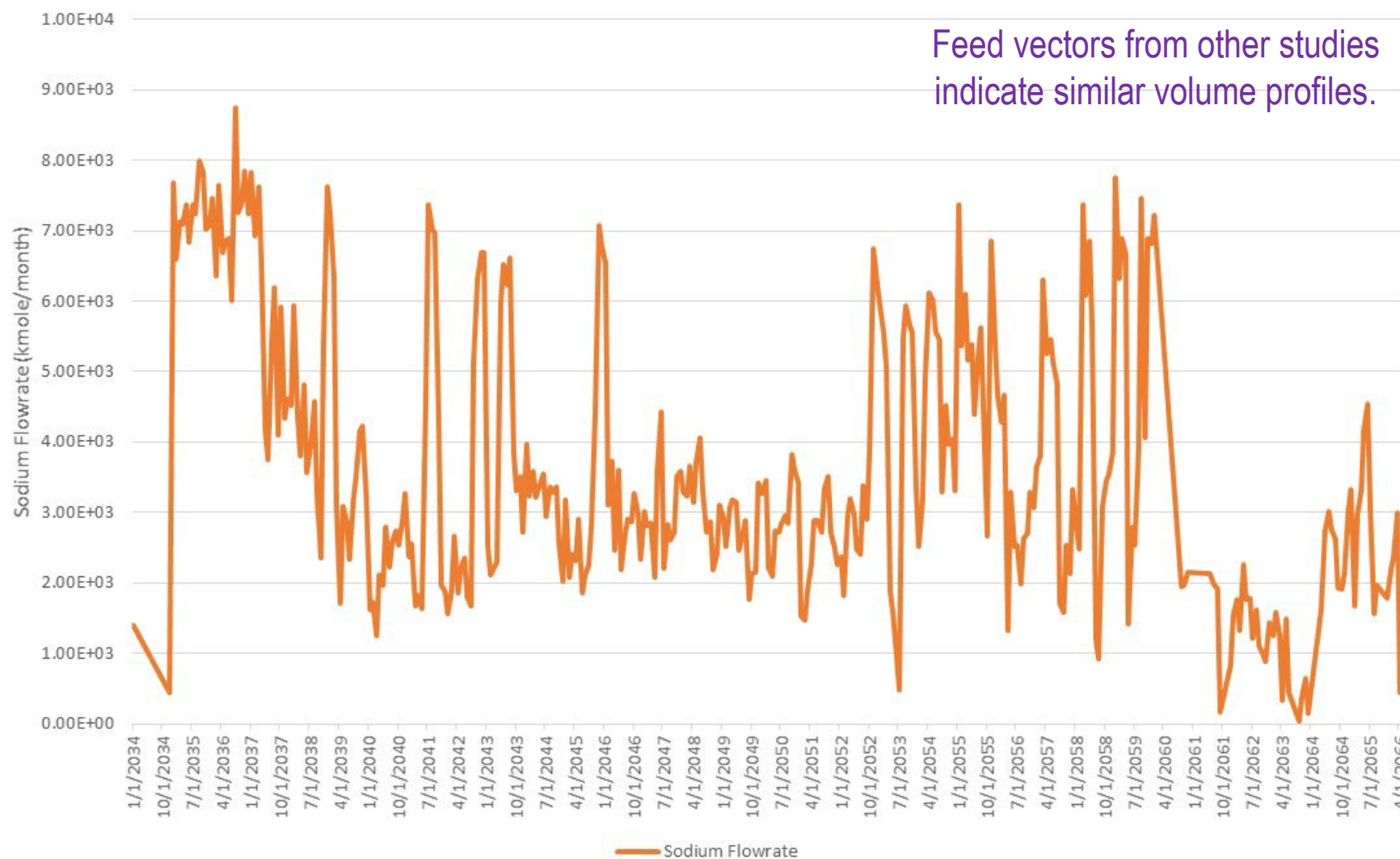
Max: 195 MT/month

Ave: 87 MT/month

Min: 1 MT/month

Total: 43,000 MT

SP9 Sodium Flowrate



What is Supplemental LAW?

- **Treatment Facility for Treated Supernate from Hanford Tank Waste**
 - Treats LAW when feed rate exceeds the capacity of the WTP-LAW facility
 - *Prevents slowing down HLW treatment due to lack of capacity for LAW treatment*
 - Complete treatment facility (no returns to any sending facility)
 - *Includes any additional pretreatment needed for Supplemental LAW process*
 - LDR Organics
 - Tc-99
 - I-129
 - *Includes processing liquid secondary waste to allow recycle and/or treatment at the Hanford Liquid Effluent Retention Facility / Effluent Treatment Facility (LERF-ETF)*
- **Purely a Conceptual System at the Moment**
 - Many aspects are still TBD
 - *Immobilized waste form*
 - *Capacity*
 - *Location*

WTP-LAW: Two LAW melters

Design Capacity: 15 MT (glass)/day each

Footprint – 330 ft x 240 ft x 90 ft

Concrete – 28,500 cubic yards

Structural Steel – 6,200 tons

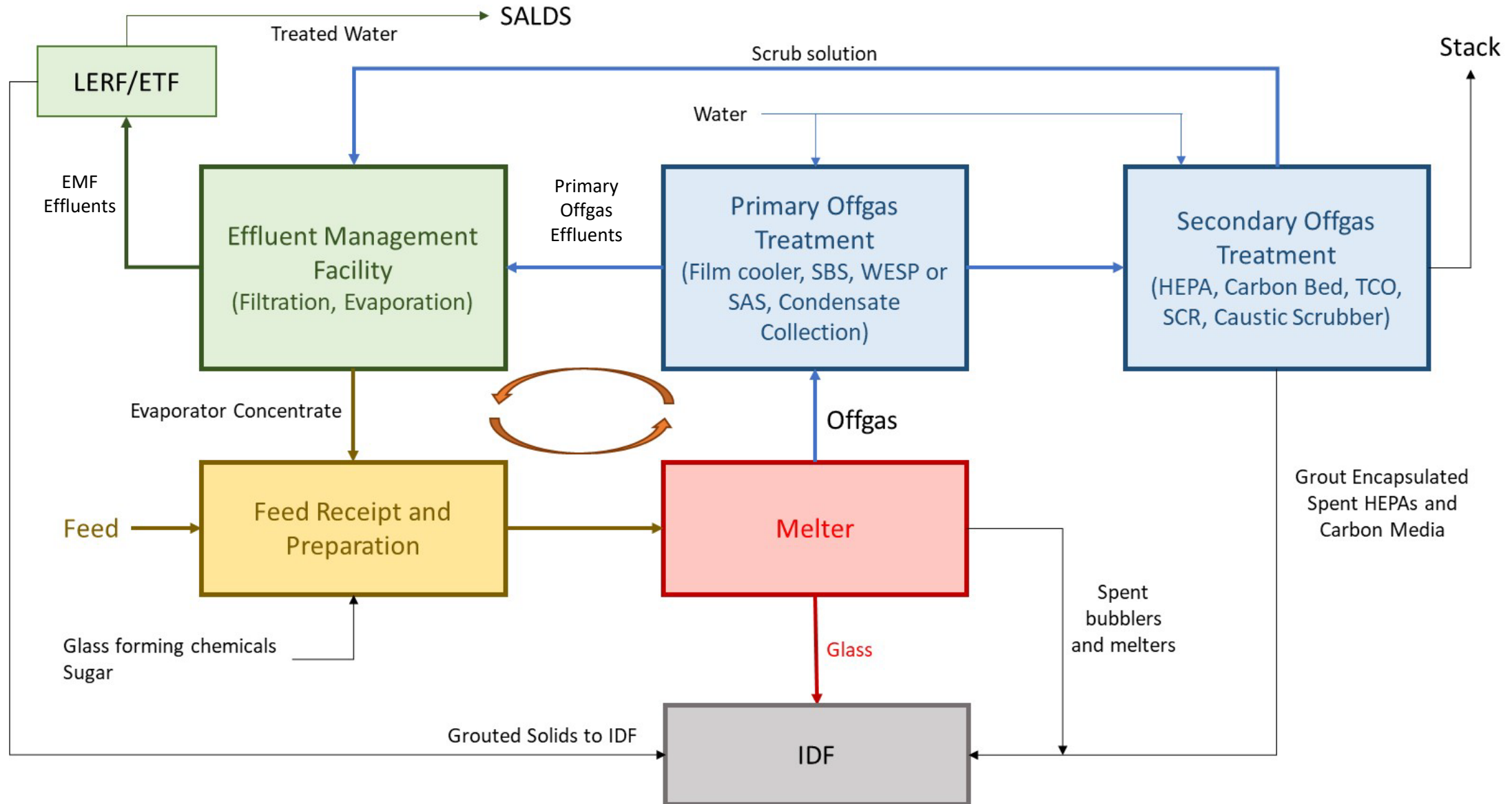
Craft hours to build: 2,337,000



Flowsheet Overview: Significant Changes from 2017 NDAA Evaluation of SLAW

- **Process Based on System Plan 9 (assumes vitrification)**
 - Previous study used System Plan 8
- **AP Tank Farm Tank used to Stage and Deliver LAW and SLAW feed**
- **Total Operating Efficiency (TOE)**
 - System Plan 8 and 9 assume 70%
 - Some recent studies of the WTP flowsheet have assumed 50% or 40%
 - *Based on TOE of comparable facilities*
 - Defense Waste Processing Facility, West Valley Demonstration Project, others
 - *Increases number of melters needed for SLAW for vitrification option*
 - Four assumed in System Plan 8 and 9
 - **Seven SLAW melters required at 40%**
- **ETF**
 - Capacity of LERF-ETF exceeded by SLAW effluents
 - **New LERF-ETF required**
 - Existing LERF-ETF assumed adequate in previous study
- **I-129 in Glass**
 - Increased uncertainty of iodine capture in glass
 - *Estimates of glass capture range from <20% to 96%*
 - *Single pass capture is expected to be low*
 - *The high uncertainty results in differences in the assumed I-129 capture in the primary offgas system*
 - Condensate from the primary offgas system is evaporated and recycled to the melter feed
 - The caustic scrubber in secondary offgas treatment system is expected to capture most of the iodine not captured in glass
 - *Some I-129 capture could occur in other unit operations*
 - *Uncertainty in iodine capture in secondary offgas system also has high uncertainty*
 - *The baseline assumes the material is transferred directly to LERF/ETF for treatment*
 - ETF can treat the I-129, but inventory limits for I-129 could be exceeded in ETF
 - I-129 will be sent to IDF in grouted solids from the ETF
 - Operation of WTP-LAW will reduce the uncertainty for a SLAW vitrification process
 - Potential mitigation measures to address
 - Recycle the caustic scrubber effluents to the SLAW feed with the primary offgas condensate
 - *Sodium in the scrubber effluent would reduce the amount of waste sodium in glass*
 - Evaluate ferrous oxalate as a glass forming chemical to increase I-129 capture in glass
 - Evaluate changes needed to allow the LERF-ETF process to treat the I-129 in the caustic scrubber effluents

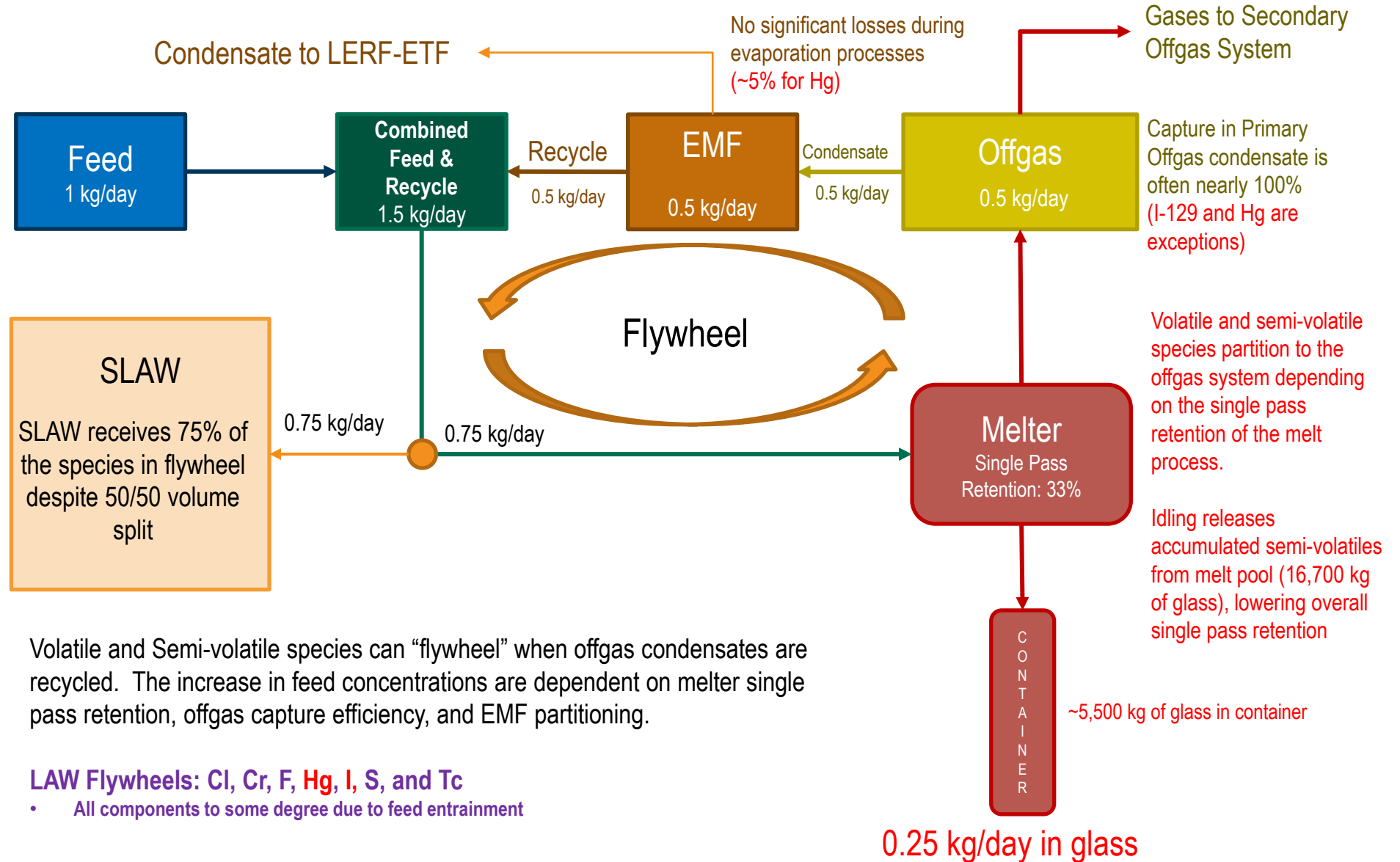
Vitrification Flow Diagram



Semi-volatile Flywheel in Combined WTP-LAW/SLAW Operations

Graphic illustrates the path through the process for 1 kg of a semi-volatile component, such as Tc, in the feed.

WTP-LAW flywheel is intentional to force Tc-99 into glass



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

- All components to some degree due to feed entrainment



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Alternative Descriptions

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Presentation Outline

- **Introduction**
- **Review Assumed Pretreatment**
 - Radionuclide removal
 - Organic removal/destruction
- **Review Selected Alternatives**
 - Vitrification 1
 - FBSR 1A
 - Grout 4B
 - Grout 6
- **Discuss Specific NAS Recommendations**
- **Discuss Additional Changes**

NAS Recommendation (summarized):	Applicable Section(s)	
K: Differences between on-site and off-site grouting treatment should be separately analyzed in detail; identify alternatives such as tank-side treatment....including budgets	Main Body	§ 3.3.4 describes alternatives
	Appendix II.C	§ C.9 vs. C.13 (G1B vs. 4B)
	Appendix II.C	§ C.12 (Grout 3 A/B)
	Main Body	§ 4.3
	Appendix F	

“Building Blocks” of Alternatives

- **Storage** of pretreated waste either
 - in existing Double Shell Tanks (DSTs) or
 - process feed tanks

- **Pretreatment as needed** consisting of one or more of:
 - ^{137}Cs removal (preceded by filtration)
 - ^{99}Tc removal
 - ^{129}I removal
 - Evaporation/Land Disposal Restricted (LDR) organic chemicals destruction or removal

- **Primary treatment and immobilization**
 - On-site vitrification
 - On-site FBSR
 - On-site grouting
 - Off-site grouting

- **Primary disposal**
 - On-site at Integrated Disposal Facility (IDF)
 - On-site in new disposal Grout Disposal Unit (GDU) vault
 - Off-site in state or NRC-licensed MLLW facility
 - (e.g., EnergySolutions [Clive, Utah] and/or
 - Waste Control Specialists [Andrews, Texas])

- **Secondary waste treatment and disposal.**
 - On-site IDF
 - Off-site (only for off-site grout production)

Key Parameters and Assumptions

- **Defining Parameters**

- Hanford System Plan 9, Scenario 1B used to define feed to Supplemental treatment of LAW
 - *No assumed immobilization baseline*
- Cost not used to screen out alternatives
- Offsite disposal sites considered in this study do not have a pathway to potable water
- Information from Performance Assessments use DOE O 435.1 guidance

- **Key General Assumptions**

- WTP LAW melters operate for entire mission at full capacity
- High Level Waste (HLW) processing begins in 2033
 - *Supplemental LAW must be available within 6 months of HLW start*
- Maximum capacity must treat 360,000 gallons/month
 - *Total volume varies, depending on start date and duration*
- Alternatives include an evaporator to reach optimum Na⁺ concentration
- Enabling assumptions:
 - *Waste Acceptance Criteria (WAC)-compliant grout or Fluidized Bed Steam Reformer (FBSR) waste form can be disposed offsite*
 - *Grout or FBSR waste form can be disposed in IDF once compliance with the PA is demonstrated*
- IDF Parameters and Assumptions are the same as 2017 IDF PA

Key Parameters and Assumptions (cont.)

- **Funding**

- Projected expenditures compared to benchmark budget, but not screened out if exceeded
- Cost escalations are 4% on capital, 2.4% on operating, and 3% discount rate per OMB

Alternative-Specific Assumptions

- **Vitrification**

- 50% Total Operating Efficiency (TOE: percentage of time facility is operating – opposite of downtime)
 - *Consistent with System Plan 9, Scenario 1B assumptions for WTP HLW and LAW vitrification*

- **Fluidized Bed Steam Reforming (FBSR)**

- 50% TOE (same as vitrification)

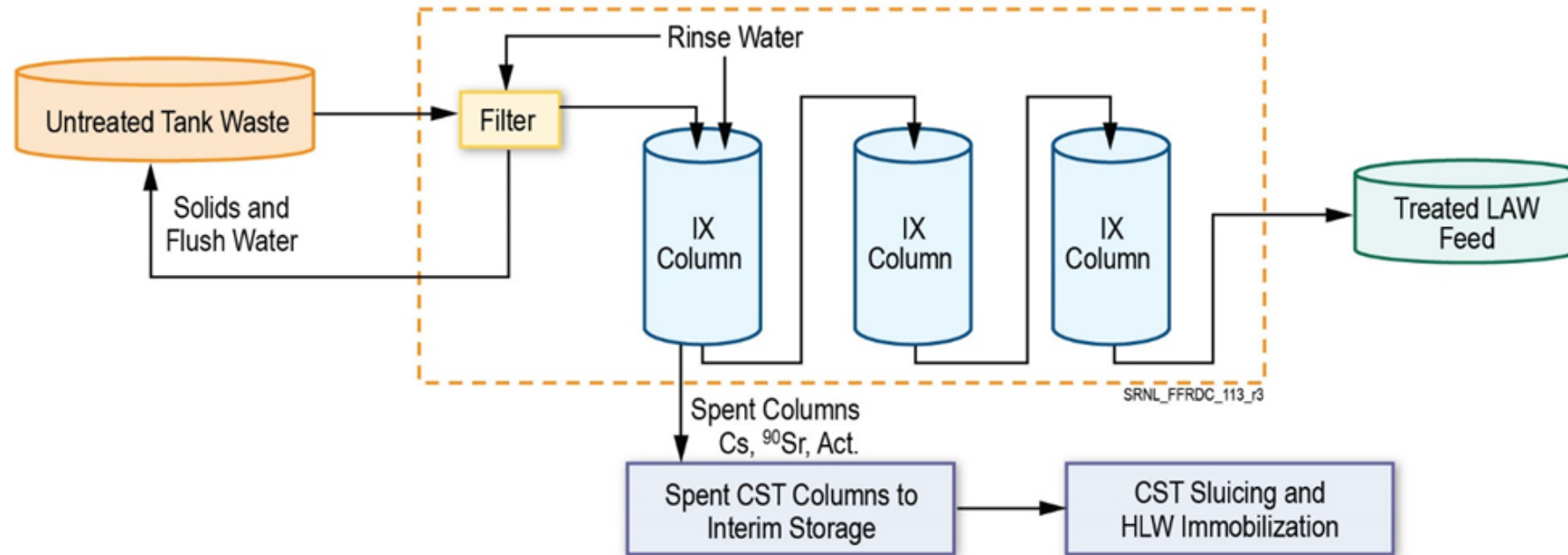
- **Grout**

- If LDR organics require treatment; evaporation and/or treatment will resolve or waste is vitrified
- Getters for ^{129}I are included for grout formulations for onsite IDF disposal, if needed
- ^{129}I and ^{99}Tc removal is not required (but is evaluated in Grout 1C and 2C)
- Grout plant is sized based on days-only operation (TOE < 50%)

Detail and additional assumptions contained in Volume 2, Appendix C of report

Pretreatment

- Pretreatment of LAW Assumed to be Needed to Remove ^{137}Cs equivalent to WTP
LAW Vitrification Facility Criteria ($<3.18\text{E-}5 \text{ Ci/mole Na}^+$)
 - Assume Tank Farm Pretreatment (TFPT) using Crystalline Silicotitanate (CST)
 - also removes $>99\%$ of ^{90}Sr from non-complexant LAW compositions ($\sim 90\%$ $<$ Class A)
 - Does not preclude pretreatment in WTP – but that may impact offsite disposal waste class



Tank Farms Pretreatment Process (TFPT) ~ Tank Side Cesium Removal (TSCR)

Selected Alternatives

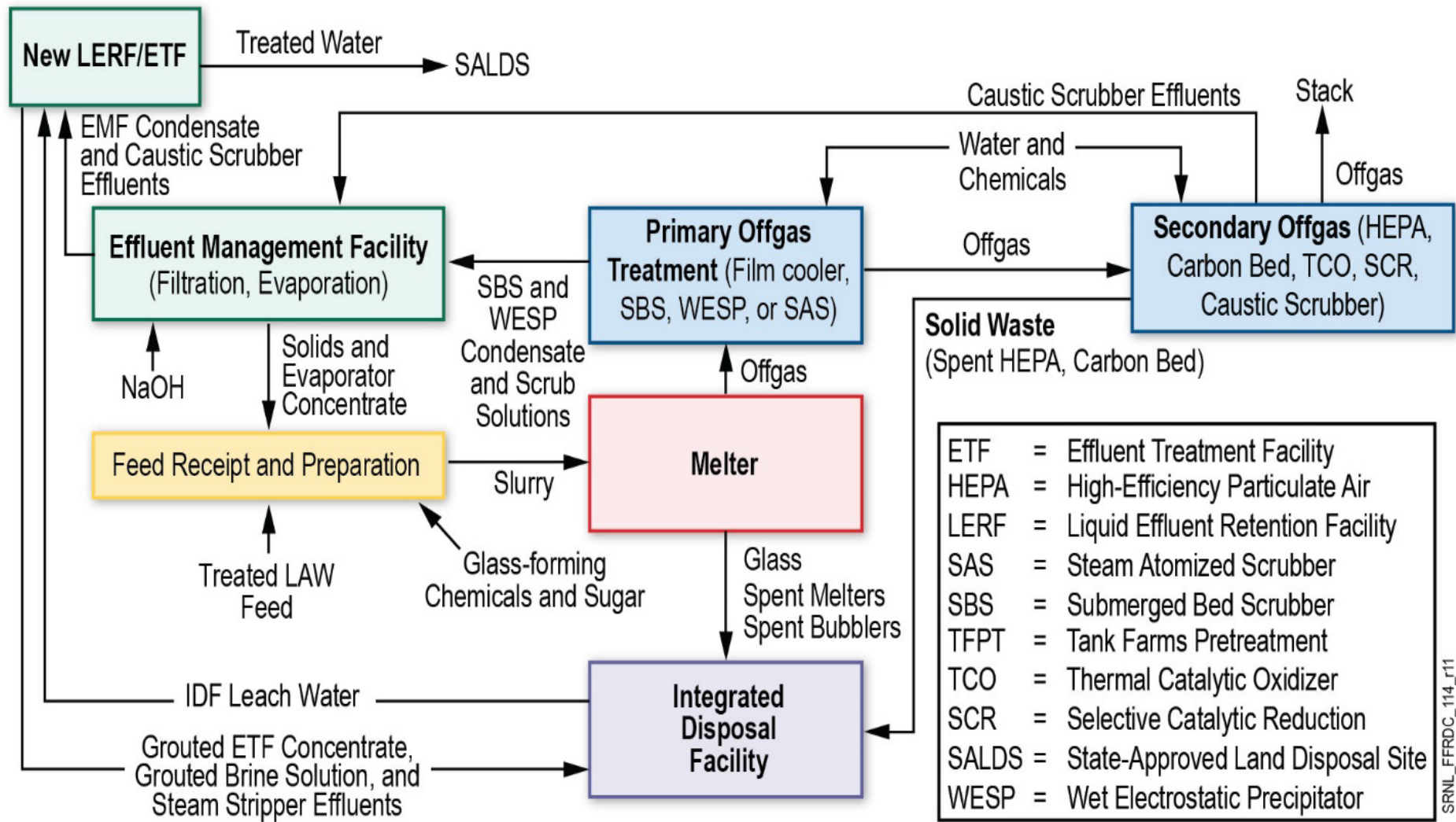
- **Considered 23 Alternatives (Vol. II. Appendix C)**
- **Fully Evaluated 15 Alternatives**
 - *Once the assessments were complete, the FFRDC team selected for detailed comparison the most promising alternatives using each primary technology. With two exceptions*, these were simply the undominated alternatives within that technology group. These four alternatives illustrate the available performance and implementation trade-offs across and within technologies.*
 - *Vitrification 1 - Single Vitrification Plant*
 - *FBSR 1A - Fluidized Bed Steam Reforming – On-site Disposal*
 - *Grout 4B - Off-site Vendor for Grouting – Off-site Disposal*
 - *Grout 6 - Phased Off-site and On-site Grouting in Containers*
- **All Alternatives Assume LAW Vitrification Continues for the Mission Duration**
- **Note that the Feed Vector (Composition and Quantity) Changes, Depending on the Alternative Because the Start-Up Date Varies**

“An alternative is said to be dominated if there is another alternative that scores at least as well on every decision criterion, and better on at least one (Kahneman, and Tversky, 1986).”

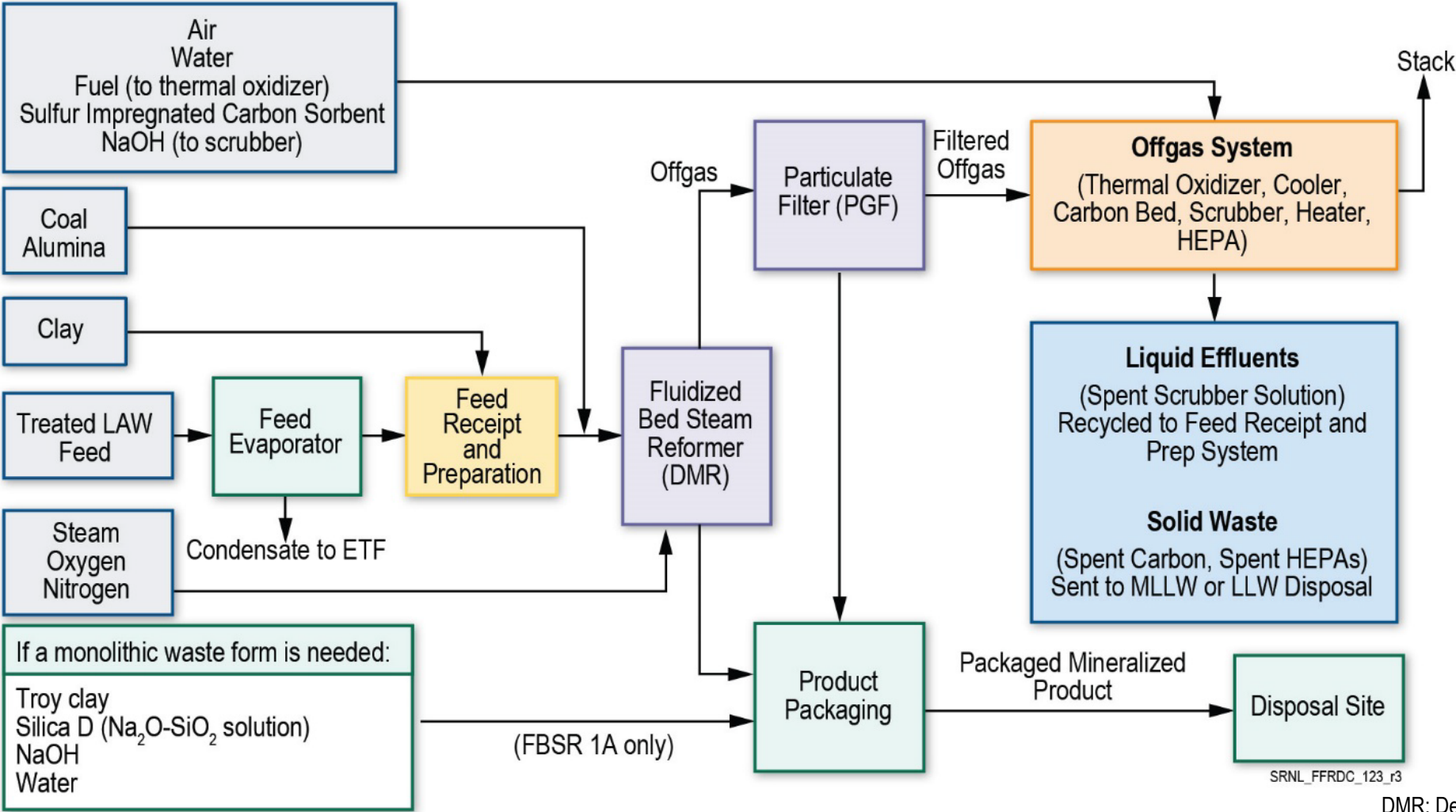
Selected Alternatives - Exceptions

- Footnote added
 - ***Grout 1A had the lowest discounted lifecycle costs among all alternatives but scored significantly lower than other grout alternatives in both long-term performance and implementation schedule; FBSR 1B scored significantly higher than FBSR 1A in long-term performance, driven entirely by the use of off-site disposal. When off-site disposal is available, all of the off-site grouting alternatives dominate FBSR 1B in performance and risk, at much lower lifecycle cost. FBSR 1B is thus not a reasonable candidate for selection, leaving FBSR 1A as the best candidate using FBSR technology.**

Alternative Vitrification 1 Simplified Flowsheet



Alternative FBSR 1A Simplified Flowsheet



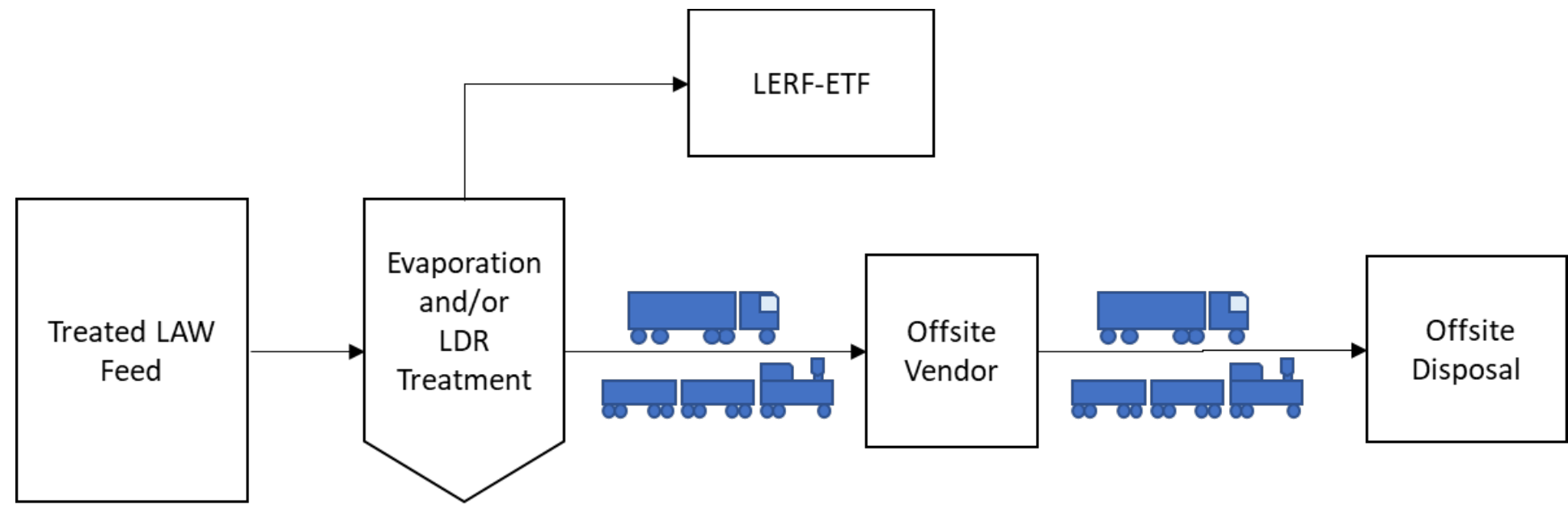
DMR: Denitration and Mineralizing Reformer
MLLW: Mixed Low Level Waste
LLW: Low Level Waste
HEPA: High Efficiency Particulate Air

Land Disposal Restricted (LDR) Organics Removal

- **All Grout Alternatives are Assumed to Handle Tank-Originated Organics, if needed**
 - Evaporation – removes most identified soluble species
 - *Organics destroyed in ETF (as current practice)*
 - Solubility – some organics (esp. PCBs) are lower in solubility than limits
 - Destruction – low maturity but expect infrequently needed
- **Incompatible Wastes Would be Diverted to LAW Melters**
- **Updated Information Discussed in Grout Technology Advances & Uncertainties**

Alternatives Grout 4B – Off-site Vendor – Simplified Flowsheet

.....



Note: all grout options depict “LDR treatment”, although it may not be required for all feeds;
Second transport unnecessary if grouting is performed at disposal site

LERF: Liquid Effluent Retention Facility
ETF: Effluent Treatment Facility

Alternative Grout 6 – Hybrid Phased On-site/Off-site Grout - Concept

Phase 1 2026 – 2028



Phase 2 ~2034



Phase 3 2040

Grout 4B

- On-site pretreatment (200 West Area; then 200 East Area)
- Off-site grout production
- Off-site grout disposal

Maximum flexibility alternative

Grout ~2B

- On-site pretreatment and on-site grout production (200 East Area)
- Off-site grout disposal

Grout ~1A/5A/B

- On-site pretreatment (200 East Area)
- On-site grout production (200 East Area)
- On-site grout disposal in containers in IDF or vaults

NAS Recommendation K

Recommendation K: Separately Analyze On-site and Off-site Grouting Treatment

- **Detailed On-site vs. Off-site Grouting**

- Essentially Grout 1B (on-site production, off-site disposal) versus Grout 4B (off-site production, off-site disposal) (Vol. II. § C.2)
- Detailed taxonomies completed (Vol. II, appendix D)
- Comparison shows difference between shipping liquid vs. grout waste form
 - Expanded discussion of liquid shipments in Vol. I, appendix D Section D.3.7 and Vol. II, Appendix H Section H.13

- **Consider Tank-Side Treatment**

- Comparable to Grout 3A/3B
 - Did not perform full evaluation
- Task objective was to evaluate supplemental treatment of LAW with capacity up to 360,000 gallons/month
 - Much of the LAW for supplemental treatment will be generated during HLW sludge processing in WTP in East area
 - Constructing multiple at-tank pretreatment and treatment units does not meet the objective and adds costs
 - Utilities, TSCR, evaporator, staging, shipping, liquid & solid storage, grout production, etc. along with seismic pads and spill protection
 - Waste transfer facilities needed anyway for sludge
 - Returning filter flushes to SSTs is prohibited
 - Likely viable for augmenting specific tanks/areas but not a comprehensive approach

Alternative Descriptions Changes

- **Minimal Actual Changes to Alternatives**
- **Improved Descriptions to Alternatives and Assumptions (Vol. II, appendix C)**
 - Further details to clarify concepts
 - *Vitrification assumed to need six melters*
 - *Later start using budget benchmark impacts ability to keep HLW on schedule*
 - *Achievable TOE is unconfirmed*
 - *Added description of mission analysis modeling scenarios*
 - *Noted that 2016 glass models were used in TOPSim model runs*
 - *Assumptions and information about ^{90}Sr in complexant vs. non-complexant waste*
 - *Added detail about recent LDR organic reports*
 - *Quantity and disposition of spent CST from TSCR/TFPT*
 - *Added schematic and text to better explain Alternative Grout 6*
 - Explain why some concepts were not pursued



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Development of the Decision Framework

Dr. David Tate

Senior Analyst, Institute for Defense Analyses

FFRDC Team Decision Framework and Analysis Lead

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



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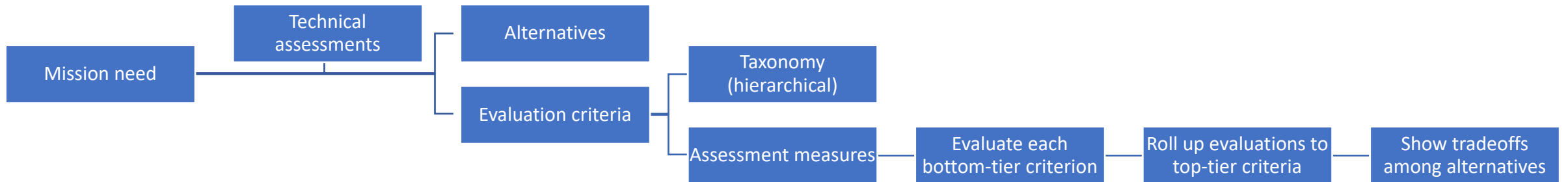
Decision Framework: Presentation Outline

- **Goal of the Decision Framework**
- **Methodology**
- **Taxonomy of Criteria**
- **Rationale for Treatment of Cost and Schedule**
- **Examples of Specific Foundational Criteria**

NAS Recommendation (summarized):	Applicable Section(s)	
B: Do not consider resource shortfall risk in assessing probability of successful completion for each alternative. Treat feasibility of funding profile execution through sensitivity analysis.	Main Body	§ 3.2
	Main Body	§ 4.1
	Main Body	§ 5.0
	Appendix I.D	§ D.3.6
	Appendix II.F	§ F.2.2, Tables F-3, F-4

Decision Framework

- **Overall Goal:** “...to provide decisionmakers with the ability to make a direct comparison between approaches for the supplemental treatment of Low-Activity Waste [...] based on criteria that are relevant to decision-making and most clearly differentiate between approaches.” (FY21 NDAA, Section 3125 (B))
- **Analytical Approach: Hierarchical Taxonomy of Evaluation Criteria**
 - Enumerate criteria with maximum relevance to decision makers
 - Identify key independent criteria that are ends, not means
 - Construct the hierarchy of underlying factors affecting these criteria
 - Establish measures of effectiveness (MOE) for fundamental factors
 - Evaluate each fundamental factor according to its MOE for each alternative
 - Roll up lower-tier evaluations to higher-tier assessments for the entire taxonomy
 - Show explicit top-level criterion tradeoffs among alternatives



Methodology for Taxonomy Development

- **Candidate Criteria were Drawn From:**

- NDAA Statutory Factors from Section 3134 (2017) and Section 3125 (2021) – mandatory to incorporate
- NEPA / RCRA / CERCLA / AEA (DOE 435.1) Decision Factors
- Key technical factors identified in prior report
- DOE and GAO best practices for conduct of Analysis of Alternatives

- **Facilitated Discussions of Which Criteria Are Most Fundamental**

- “Fundamental” means something decision makers care about when comparing alternatives
 - *Examples: long-term immobilization of waste; probability of success; taxpayer burden; near-term risk of harm to people or environment*
- Other criteria are important, but only to the extent that they contribute to fundamental criteria
 - *Examples: destruction of volatile organics; transportation requirements; geology of disposition site; earliest start date for operations*

- **The FFRDC Team Then Iteratively Constructed a Consensus Hierarchy of Contributing Criteria and Factors**

- All members of the team participated
- Many alternative formulations were considered
- Grounded on as much quantitative underpinning as possible

The Resulting Hierarchical Taxonomy of Criteria

- **Is Intended to Capture All Factors of Potential Relevance to Decision Makers in a Way that Makes the High-Level Tradeoffs Between Alternatives as Clear as Possible**
- **Incorporates All Statutory Factors from NDAA Section 3134 (2017) and Section 3125 (2021)**
 - Some explicitly, some implicitly – crosswalk provided in Appendix I.E
- **Includes Both Assessment of Designed Performance and Assessment of Shortfall Risks**
- **Was Patterned on NEPA / RCRA / CERCLA / AEA (DOE 435.1) Decision Factors at the Top Level**
 - Familiar to decision makers; similar to NDAA-specified list of factors to consider
 - Modified to be non-overlapping, supporting meaningful value comparisons and tradeoffs
 - Explicitly cited as information of interest in FY2017 Section 3134 language
- **Permits Direct Tradeoff Comparisons (e.g., Long-term Performance vs. Implementability) of Fundamental Criteria**
- **Supports Analysis of Alternatives (AofA) Approach to Informing Decision-Makers**
 - Consistent with GAO and DOE guidance for Analysis of Alternatives
 - Establishes an objective and consistent assessment framework prior to examination of individual alternatives

Tier 1 and 2 Taxonomy of Criteria to Be Assessed for Each Alternative

1. Long-Term Effectiveness

(environmental and safety risk after disposal)

1. Residual threat to health and environment upon successful completion
2. Long-term risks upon successful completion

Note: Only alternatives assessed as likely to meet applicable performance standards were evaluated.

2. Implementation Schedule and Risk (environmental and safety risks prior to mission completion, including risks driven by waste tank storage duration)

1. Specific risks or benefits related to ongoing tank degradation
2. Risks to humans (other than tank degradation)
3. Risks to the environment (other than tank degradation)
4. Duration

3. Likelihood of Successful Mission Completion

(including technical, engineering, and resource-related risks)

1. Likelihood and consequences of failing to complete due to technical or engineering problems
2. Likelihood and consequences of failing to complete due to resource constraints
3. Likelihood and consequences of failing to complete due to unavailability of key services and materials

Tiers 1 and 2 Taxonomy of Criteria (continued)

- 4. Lifecycle Costs
(discounted present value)**
 - 1. Capital project costs (Design, construction, cold commissioning)
 - 2. Operations costs (onsite and offsite)
 - 3. Shutdown and decommissioning costs
- 5. Securing and Maintaining Necessary Permits/Authorities
(regulatory approval)**
- 6. Community / Public Acceptance
(state / local)**

For Criteria 5 and 6, the FFRDC team concluded that decision-makers should have the benefit of this and other analyses (e.g., by NASEM, GAO) prior to formulating input as part of the decision-making process. Likewise, securing regulatory approval is part of the negotiation process between government agencies, and it would be inappropriate for the FFRDC team to assign likelihood of specific outcomes.

Treatment of Cost- and Schedule-Dependent Criteria (Recommendation B)

- **In Practice, Many Outcomes Are Mutually Interdependent**
 - Cost increases cause schedule delay
 - Schedule delays increase cost
 - Schedule delays increase safety risks
 - Higher costs drive lower probability of successful completion
 - Realized safety risks increase cost and schedule
 - Etc.
- **To Enable Meaningful Comparisons of the Non-Overlapping Top Level Criteria, Indirect Effects Must Be Separately Incorporated for Each Top-Level Factor**
 - The top-level criteria are non-overlapping in their decision influence. They are not *causally* independent.
 - It would not be possible to (for example) account for the fact that more expensive alternatives take longer to build, and thus have higher tank leak risks, as part of Criterion 4, Life Cycle Cost. That would eliminate the ability to accurately compare alternatives on the basis of short-term risks, or to show tradeoffs between short-term risk and other criteria.

Criterion 1: Long-Term Effectiveness

1.1 Residual threat to health and environment upon successful completion

1.1.1 Residual toxicity of wastes

1.1.2 Mobility of primary and secondary wastes to a groundwater source (given intended disposal site(s))

1.1.3 Total volume of primary and secondary waste forms

1.2 Long-term risks upon successful completion

1.2.1 Confidence in estimated residual toxicity

1.2.2 Confidence in immobilization with regard to groundwater

1.2.3 Confidence in total volume of primary and secondary waste forms produced

Criterion 2: Implementation Schedule and Risk

2.1 Specific risks or benefits related to ongoing tank degradation

2.2 Risks to humans (other than tank degradation)

2.2.1 Effort required to ensure worker safety

2.2.2 Transportation risks

2.3 Risks to the environment (other than tank degradation)

2.3.1. Wastewater discharges (intentional)

2.3.2. Atmospheric discharges

2.3.3. Transfer/process tank (on-site) spills

2.3.4. Off-site transportation spills

2.3.5. Secondary waste streams generated

2.3.6. Greenhouse gas emissions during construction and operations

2.4 Duration

2.4.1. Duration to hot startup

2.4.2. Duration to full capacity

2.4.3 Duration of operations

2.4.4 Risk of additional mission delay (including technical / engineering and resource-based)

Criterion 3: Likelihood of Successful Mission Completion

3.1 Likelihood / consequences of failing to complete for technical reasons

- 3.1.1 Technical / engineering risks that could stop the project before completion
- 3.1.2 Robustness to known technical risks
- 3.1.3 Adaptability to the full range of tank waste compositions
- 3.1.4 Potential to incorporate future technology advances

3.2 Likelihood / consequences of failing to complete due to resource constraints

- 3.2.1 Average annual spending vs. benchmark budget (including sensitivity analysis)
- 3.2.2 Projected peak spending vs. benchmark budget (including sensitivity analysis)
- 3.2.3 Schedule flexibility – ability to stop and start operations if needed
- 3.2.4 Expected work accomplished / remaining at most likely failure point
- 3.2.5 Worst case work remaining at failure

3.3 Likelihood / consequences of failing to complete due to unavailability of key services or materials

Criterion 4: Lifecycle Cost (discounted present value)

4.1 Capital project costs (design + construction + cold commissioning)

4.2 Operations costs

4.3 Shutdown and decommissioning costs

For Criterion 4 assessment, anticipated costs for each alternative were categorized, escalated by category, constrained to the benchmark budget (with carryover) for construction, deflated to constant FY2023 dollars, then discounted at 3% annually to get the present value of future costs.

Examples of the Full Hierarchy for Specific Bottom-Tier Criteria

1. Long-term effectiveness

1.1 Residual threat to health and environment upon successful completion

1.1.2 Mobility of primary and secondary wastes to potable water, given disposal site

1.1.2.4 RCRA metals

1.1.2.4.1 Mercury

2. Implementation schedule and risk

2.2 Risks to humans (other than tank degradation)

2.2.2 Transportation risks

3. Likelihood of successful mission completion

3.1 Likelihood and consequences of failing to complete for technical/engineering reasons

3.1.1 Technology and engineering risks that could stop the project before completion

3.1.1.5 Technology maturity (including Test Bed Initiative)

Recap: Top-Tier Criteria to Enable Direct Comparisons

1. Long-Term Effectiveness

(environmental and safety risk after disposal)

2. Implementation Schedule and Risk

(environmental and safety risks prior to completion, including risks driven by waste tank storage duration)

3. Likelihood of Successful Mission Completion

(including technical, engineering, and resource-related risks)

4. Lifecycle Costs

(discounted present value)

5. Securing and Maintaining Necessary Permits/Authorities

(regulatory approval)

6. Community / Public Acceptance (state / local)

Not assessed by the FFRDC team



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Risk-Reduction, Cost, and Schedule

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Technical Advisor

Environmental and Legacy Mgmt., SRNL

Estimating Lead

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



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Evaluation(s) of the Hanford Mission: Scope, Cost, and Schedule

- The Hanford Site clean-up program is a massive and complex undertaking.
- Federally Funded Research and Development Centers (FFRDC) studies per National Defense Authorization Act (NDAA) directives are running in parallel with other types of analyses, such as those by
 - *Government Accounting Office (GAO-17-306 and GAO-22-104365)*
 - *U.S. Department of Energy (DOE) Office of River Protection (ORP) (System Planning)*
 - *U.S. Army Corps of Engineers (USACE) (Waste Treatment and Immobilization Plant [WTP] remaining capital facilities)*
- The various studies plus the *Tank Closure and Waste Management Environmental Impact Statement (DOE/EIS-0391)* provide different views of the mission.
- This presentation will summarize this FFRDC study – specific to low-activity waste (LAW) supplemental treatment – with consideration of implementation as per the above.

Presentation Outline

1. Introduction
2. Mission Construction
 - **Constrained Schedule**
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3. Methodology
4. Modeling Scenarios
 - Development
 - Results
 - **Short-Term Risk Reduction**
 - **Long-Term Risk Reduction**
5. Analysis (Alternatives and Sensitivities)
 - Development
 - Results
6. Summary

NAS Recommendation (summarized):	Applicable Section(s)
B. Remove, “failure to complete due to funding shortfalls,” sub-criterion. Consider impact of GAO report in final report.	Main Body § 3.3 Appendix F § F.2.1
C. Make defensible assumptions related to cost; calculate profile; perform sensitivity studies. Provide graphs depicting amount of SLAW processed and remaining.	Main Body § 1.3.1.2 Appendix F § F.2.3
G. Add discussion of consequences for cost, time, and likelihood of completion of the delayed start of vitrification.	Main Body Table 3.4-1 Appendix F § F.2.3

Technology Selection Planning and Execution are Interrelated Pertaining to Mission Progress

How

- **Process** – Technology selection
- **Funding** – Constrained/unconstrained
- **Schedule** – Implementation (constrained/unconstrained)

Where

- **Treatment** – Onsite (tank farm quadrants) / offsite
- **Disposition** – Onsite (IDF or vault) / offsite

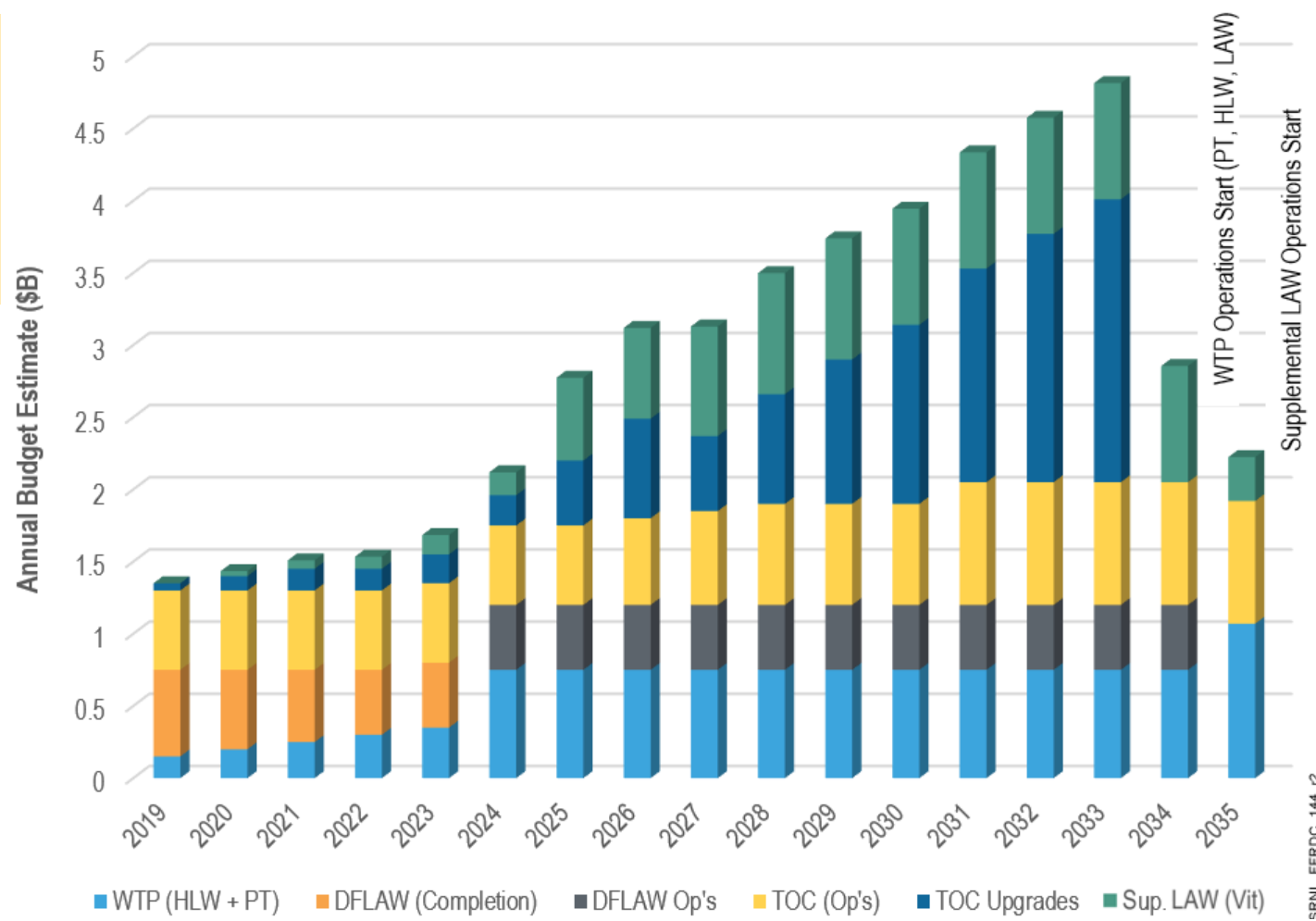


When

- (Pertaining to) **high-level waste (HLW)** - Mission length and efficiency level
- (Pertaining to) **LAW** – Risk reduction rate

Impacts to Budget when Schedule is Constrained

Graphic demonstrates a budget for completing capital facility and tank farms upgrades to meet a series of desired facility start-up dates.



Starting dates include:

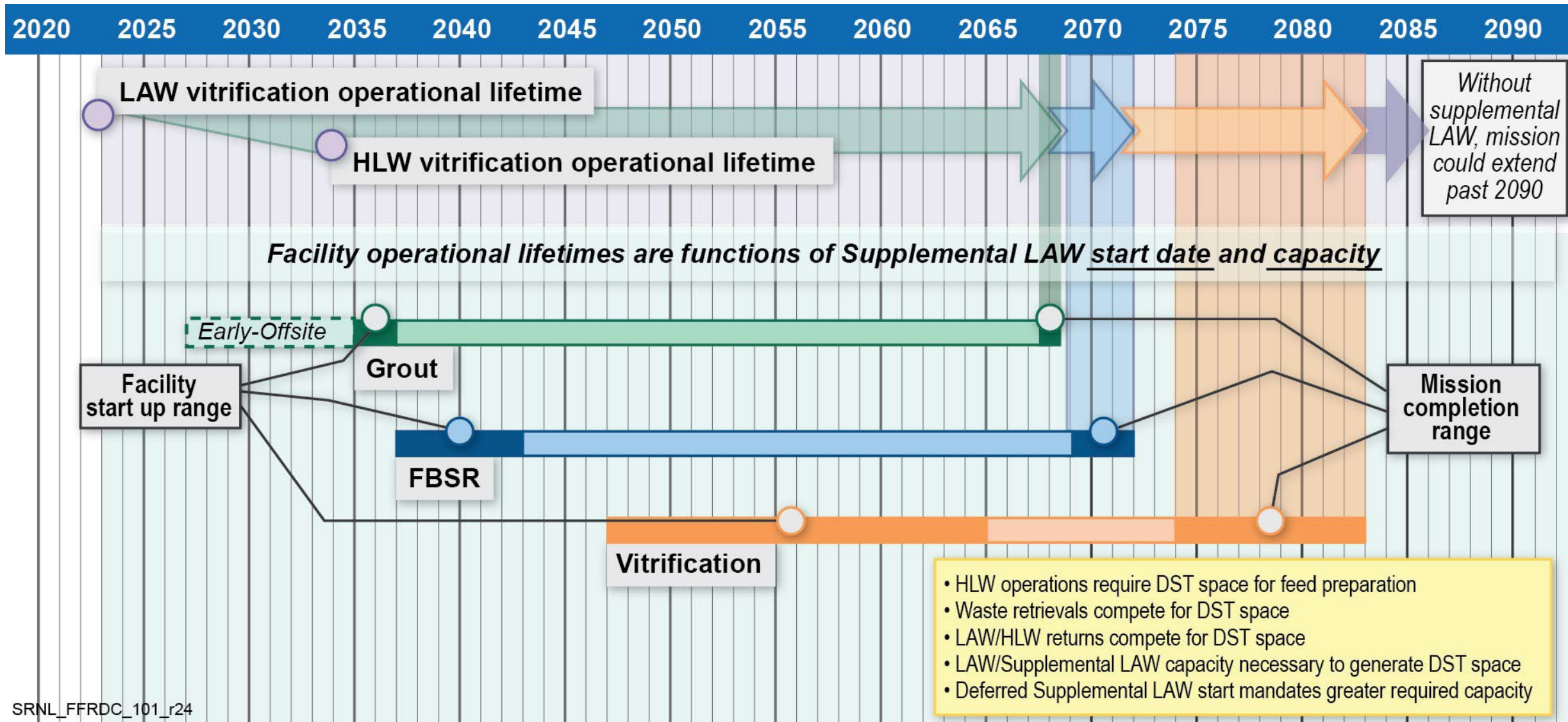
DFLAW* process:	2023
WTP HLW vitrification:	2034
LAW supplemental treatment:	2035

Annual funding of \$2-2.5B not adequate for WTP plus Tank Operations Contract (TOC) upgrades, independent of LAW supplemental treatment (shown as vitrification).

1. USACE and GAO reports indicate facility costs may exceed 2017 projections
2. DFLAW process delay or cost increase will force higher annual budget requirements unless WTP, TOC, and/or LAW supplemental treatment capital projects are extended.

* DFLAW = direct-feed low-activity waste

Projected Integrated Mission Completion Profiles



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For reference, TC&WM EIS projected 2018 through 2093 if no LAW supplemental treatment (EIS Alternative 2B)

Potential for Disparity Between the Alternatives

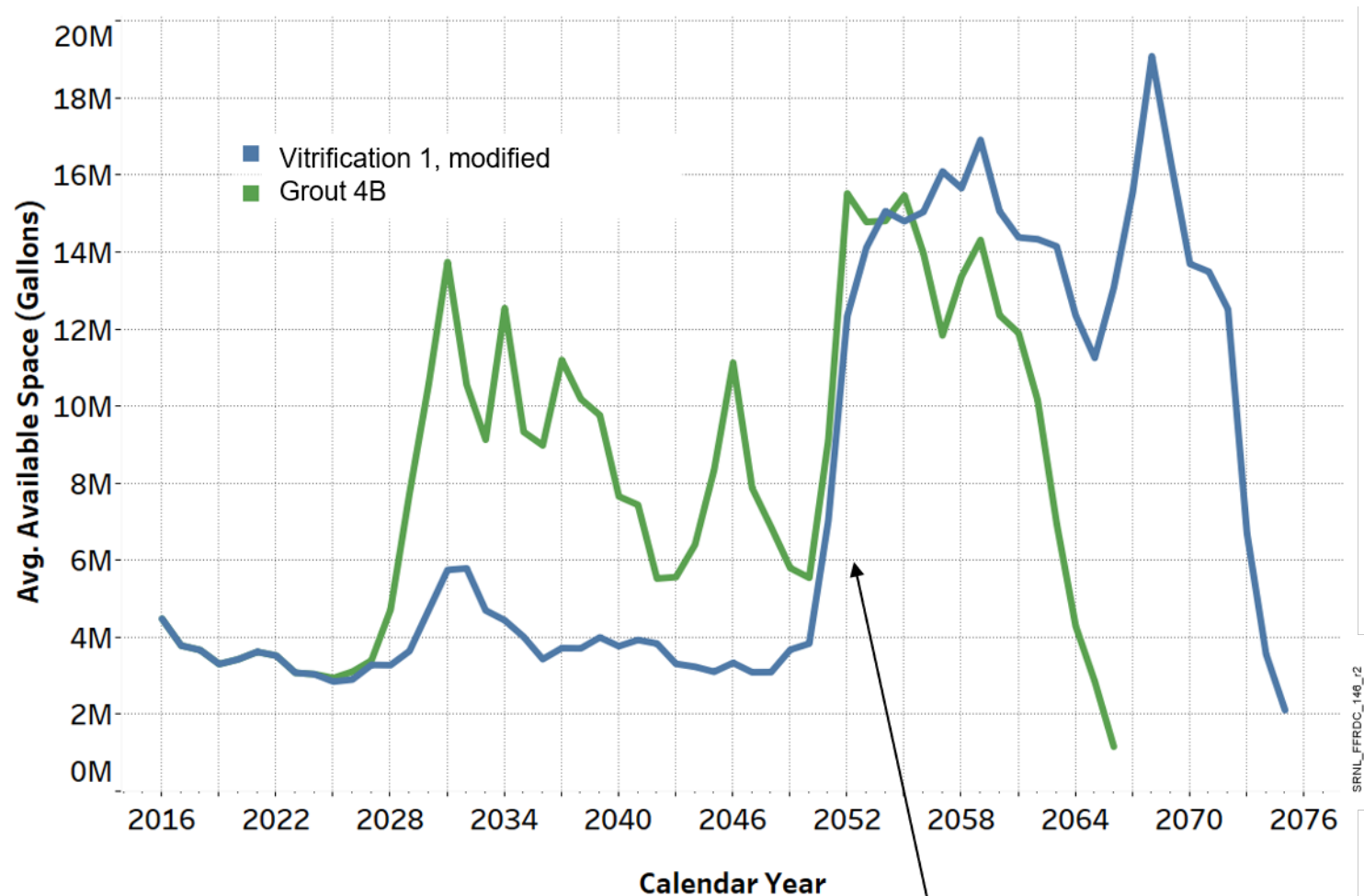
- **The facets that significantly differentiate options:**

- Capital cost is a primary issue for a single large facility (located near WTP / Integrated Disposal Facility [IDF])
 - *Significant impact on potential starting date and full HLW support*
 - *Can drive overall mission completion (e.g., treat all tank waste)*
 - *Supplemental LAW annual operating cost factors with mission length*
 - Mission length is normally driven by HLW vitrification
- Off-site disposition options may provide flexibility – but should be evaluated in context of total mission cost and schedule
 - Accelerated feed and treatment start dates improve near-term risk reduction
- Minimal capital cost options appear more viable for near-term implementation
 - Can reduce total mission, lifecycle cost, and long-term risk

Double-Shell Tank Space Utilization: Measure of Short-Term Risk

- Off-site grout generates significant DST space from 2027 through 2050 versus Vitrification 1 (modified)
- AP Farm (last farm to close) has delivered all waste to treatment by 2066 (Grout 4B) versus 2075 (Vitrification 1 [modified]).

LAW supplemental treatment is essential to manage DST space for risk reduction plus HLW feed preparation / support



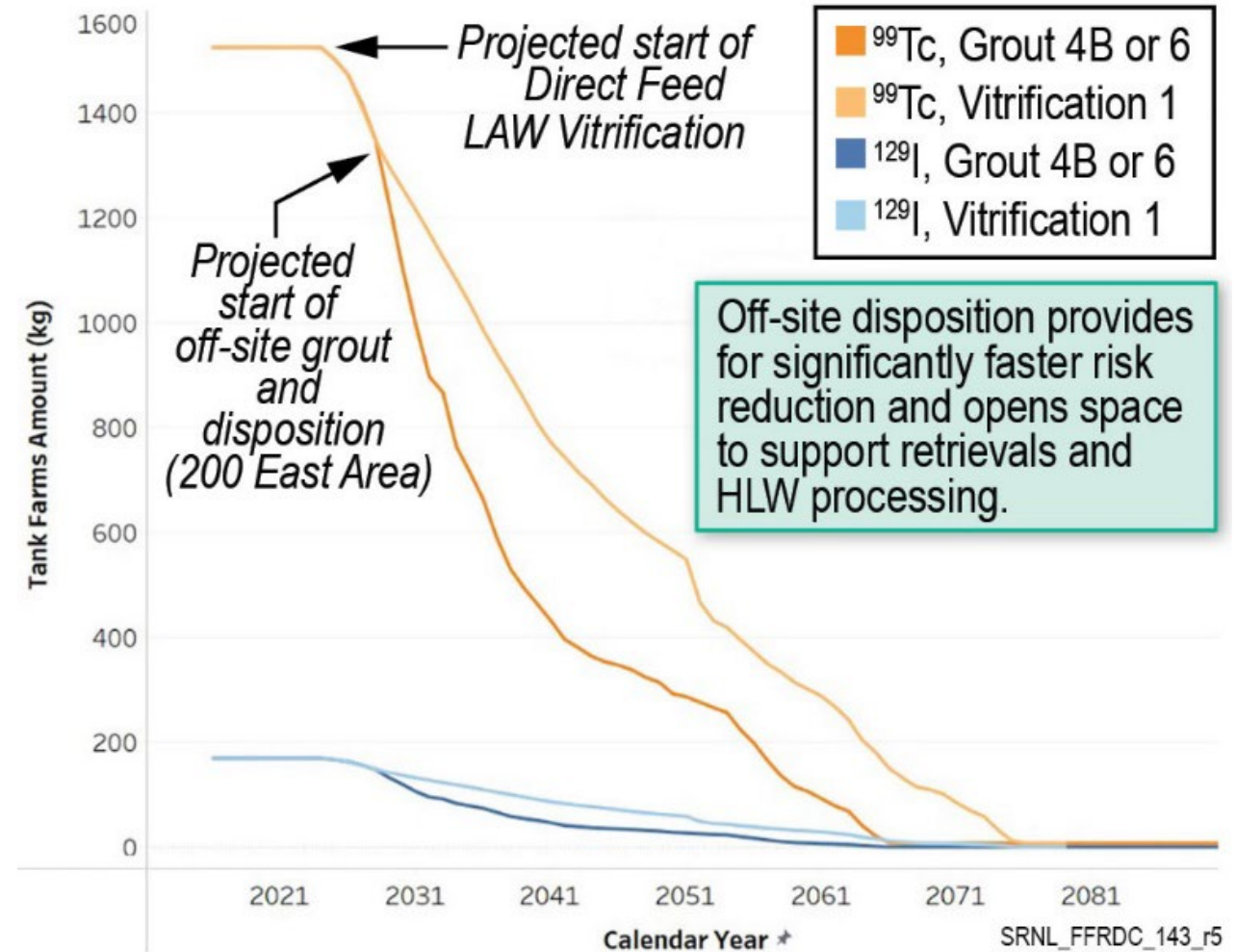
HFPEM* Facility operations begin, generating additional available space

* HFPEM = High-Level Waste Feed Preparation and Effluent Management

Retrievals and Disposition of Tc/I: Measure of Short-Term and Long-Term Risk

- Tc/I will remain constant until the start of DFLAW operations.
- DFLAW process will isolate Tc and some I into glass.
- Early off-site disposition leads to significantly faster Tc/I disposition – less than 20% Tc/I remains in tank farms at 2050.
- SST retrievals will be completed 13 years sooner in the Grout 4B alternative.
- HLW feed preparation and effluent treatment also supported 15+ years earlier in Grout 4B versus Vitrification 1 (modified).

DST space generation (via LAW supplemental treatment) improves risk reduction posture plus HLW feed preparation / support



Appendix F
Section 2.3, Figure F-6

Comparative Technetium Disposition: Measure of Long-Term Risk

Disposal	Waste Type	Treatment	Alternative 4B Ci Tc	Vitrification 1 (modified) Ci Tc
Offsite	LAW	200 West TSCR	6,500	7,500
Offsite	LAW	200 East TSCRs	10,500	N/A
Onsite	LAW	LAW vitrification	6,800	11,900
Onsite	LAW	Supplemental LAW vitrification	N/A	4,400
Offsite	HLW	HLW vitrification	1,250	1,250
Total			25,050	25,050

Notes: Tank farm inventory **25,000 Ci**
Expected loss 1%
HLW nominal content 5% (1,250 Ci)

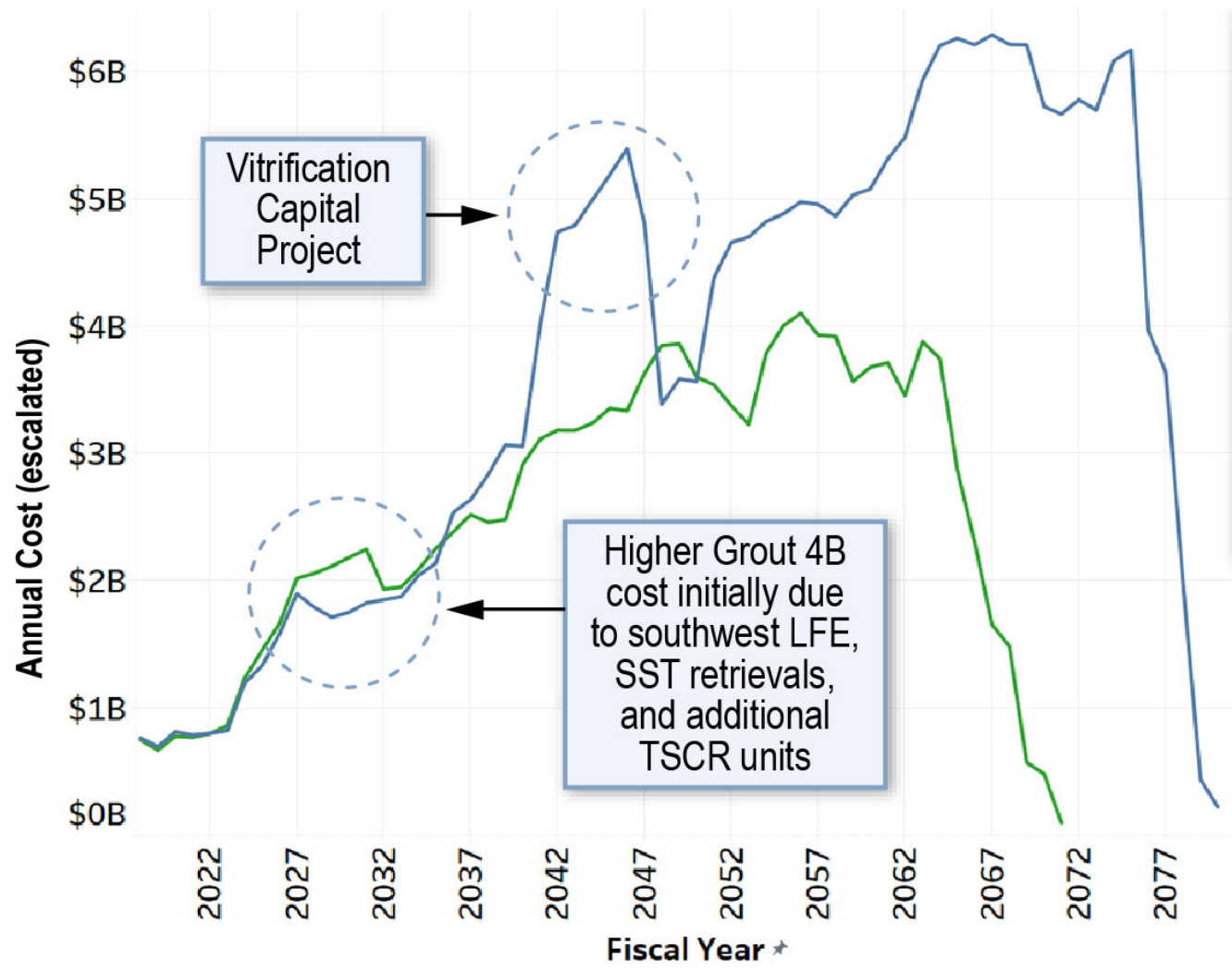
HLW = high-level waste.
IDF = Integrated Disposal Facility.
LAW = low-activity waste.
Tc = technetium.
TSCR = tank-side cesium removal.

Summary Technetium Disposition

Off-site Grout 4B		Vitrification 1 (modified)
18,250	Total offsite (Ci)	8,750
6,800	Total onsite IDF (Ci)	16,300

Note – SW TSCR processing was initially developed to allow 200-West retrievals in advance of cross-site transfer.

Lifecycle Cost Profile (Escalated)



Total Escalated Mission Lifecycle Cost

Vitrification 1, modified*	\$240B
Grout 4B Early Off-site Disposition	\$145B

\$95B mission savings due to significantly reduced:

- a. LAW supplemental treatment CAPEX and OPEX
- b. Mission length

* Scenario had unconstrained funding with a fixed target completion date (2050).

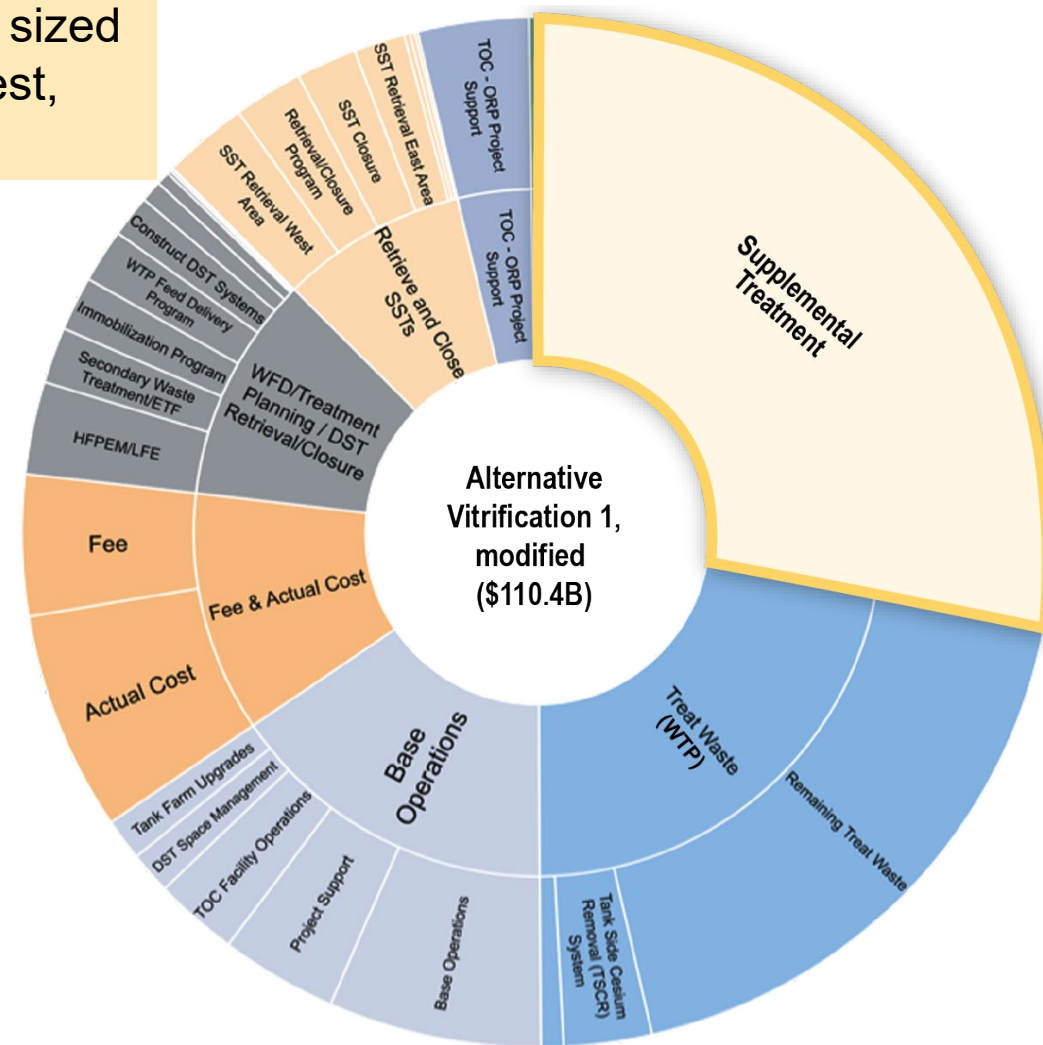
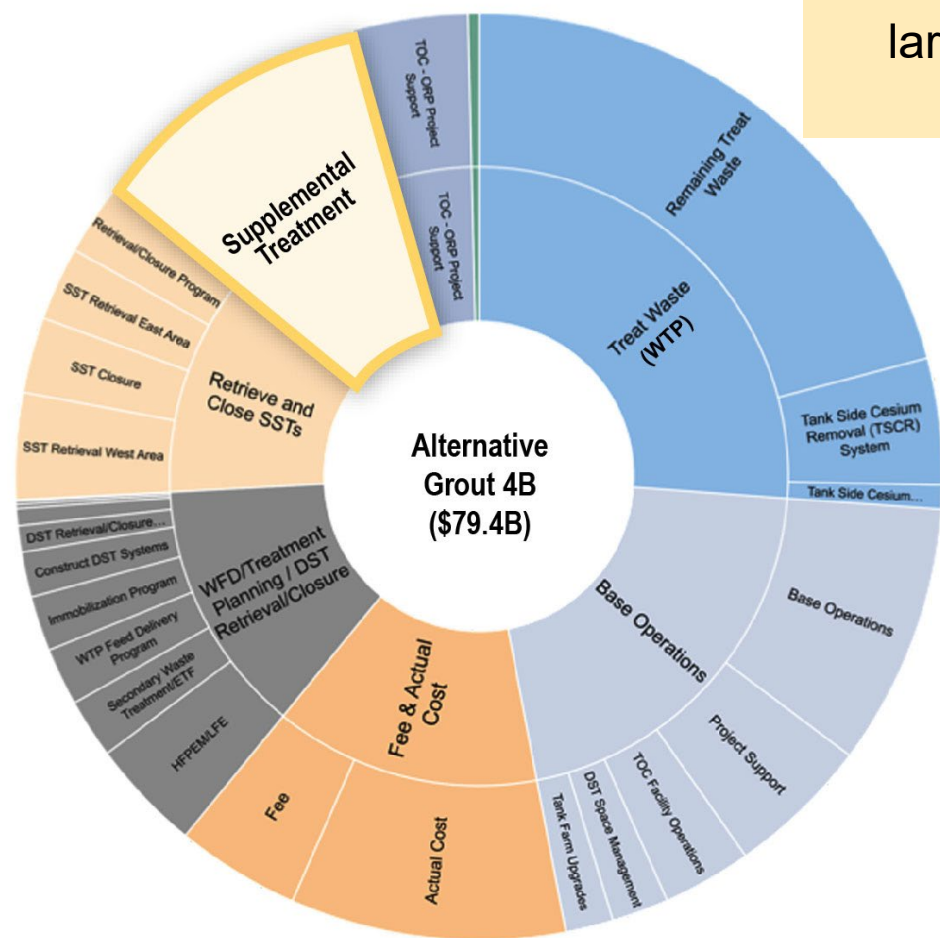
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System Planning uses a fixed 2.4% escalation factor for CAPEX and OPEX

CAPEX = capital expenditure.
OPEX = operations expenditure.
LFE = LAW Feed Evaporator

Mission Alternative Cost Comparison – by Work Breakdown Structure

WBS elements are sized largest to smallest, clockwise



LAW supplemental treatment accounts for \$21B of the \$31B cost delta – the additional \$10B is due to reduced mission length

Key Results

- SE TFPT size equivalent to 5× TSCR units (Grout 4B) provided highest possible treatment capacity with least impact to mission cost/schedule (*Vitrification 1 [modified] required 8× TSCR units*)
- B Complex retrievals start earlier in the mission in 2032 (beginning with BY Farm) to provide additional feed to supplemental LAW treatment (*versus 2050 for Vitrification 1 [modified]*)
 - Even after reordering retrievals/introducing additional staging tanks, two feed outages in early 2030s (11/2031 – 11/2032 and 8/2034 – 6/2035) demonstrate that waste can be pretreated faster than retrievals occur
- SST retrieval progress comparable to the Vitrification1 (modified) scenario for first part of the mission, but retrieval *rate* increases significantly in the Grout 4B, beginning mid-2030s
- Grout 4B completes in 2066, 9 years earlier than the Vitrification 1 (modified) scenario, which completes in 2075

These results were used to bound Grout/FBSR/Vitrification alternative performance metrics, such as:

- *Required pretreatment capacity*
- *Volume processed (total and annual)*
- *Tc curies processed and disposition*

Presentation Outline (with Feed Pre-treatment Discussion)

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Pretreatment via TSCR was assumed for all alternatives (grout/vitrification/ FBSR). A singular per gallon cost was selected based on TOPSim and cost modeling versus attempting to create multiple small capital projects across the mission scope.

1. *\$8.5M annual TSCR OPEX cost (MR-50713, this study) for 1.2 Mgal of TSCR processing (**just over \$7/gal**), plus*
2. *\$1.1M per CST IX column (two per changeout) against 200,000 gallons per batch (**\$11/gal**), leads to a cost of **\$18/gal**.*

*Note: CST consumption per gallon will significantly decrease as SST saltcake is processed – to approximately 600,000 gallons per batch (**less than \$4/gal**). Nominally 75% of LAW feed will be saltcake derived – leaving a homogenized cost between **\$12 and \$13/gal**. This value was rounded up to **\$15/gal**.*

LAW Supplemental Treatment Mission Planning Sheet: Vitrification 1

Funding Level (\$555 million/year) Consistent with Facility Completion and Operations

	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	...	2075
T&D Plus Pilot Activity funded with capital project	50	75	100	125	130	75	50																					
Conceptual Planning / Approve Mission Need - CD-0	\$10																											
Conceptual Design / Acquisition Strategy - CD-1		\$20	\$20																									
Preliminary Design / Performance Baseline - CD-2				\$50	\$75	\$100																						
Definitive Design / Approve Start of Construction - CD-3							\$150	\$175																				
Procurement / Long-Lead Procurement							\$125	\$275	\$400	\$400	\$250	\$150	\$50															
Construction									\$100	\$150	\$200	\$300	\$350	\$400	\$400	\$450	\$450	\$450	\$300	\$300	\$300	\$250	\$50					
Startup / Cold Commissioning - CD-4																						50	\$175	\$225	\$350			
Hot Commissioning / Operations (OPEX)																										\$515		\$515
FY Cost (Unescalated)	\$60	\$95	\$120	\$175	\$205	\$175	\$325	\$450	\$500	\$550	\$450	\$450	\$400	\$400	\$400	\$450	\$450	\$450	\$300	\$300	\$300	\$300	\$225	\$225	\$350	\$515		\$515
Cum Cost (Unescalated)	\$60	\$155	\$275	\$450	\$655	\$830	\$1,155	\$1,605	\$2,105	\$2,655	\$3,105	\$3,555	\$3,955	\$4,355	\$4,755	\$5,205	\$5,655	\$6,105	\$6,405	\$6,705	\$7,005	\$7,305	\$7,530	\$7,755	\$8,105	\$8,620		\$22,350
Escalation Factor	1.08	1.12	1.17	1.22	1.27	1.32	1.37	1.42	1.48	1.54	1.60	1.67	1.73	1.80	1.87	1.95	2.03	2.11	2.19	2.28	2.37	2.46	2.56	2.67	2.77	1.90		3.43
FY Cost (Escalated at 4%)	\$65	\$107	\$140	\$213	\$259	\$230	\$445	\$640	\$740	\$847	\$720	\$749	\$693	\$720	\$749	\$877	\$912	\$948	\$657	\$684	\$711	\$739	\$577	\$600	\$970	\$977		\$1,768
Cum Cost (Escalated)	\$65	\$172	\$312	\$525	\$784	\$1,015	\$1,460	\$2,100	\$2,840	\$3,687	\$4,407	\$5,157	\$5,849	\$6,570	\$7,319	\$8,195	\$9,107	\$10,055	\$10,712	\$11,396	\$12,107	\$12,846	\$13,423	\$14,023	\$14,993	\$15,970		\$51,783
Funding Level (Annual)	\$579	\$591	\$603	\$616	\$629	\$642	\$655	\$669	\$683	\$698	\$712	\$727	\$742	\$758	\$774	\$790	\$807	\$824	\$841	\$859	\$877	\$895	\$914	\$933	\$953	\$973		\$1,635
Cumulative Funding	\$579	\$1,169	\$1,772	\$2,388	\$3,017	\$3,659	\$4,314	\$4,983	\$5,667	\$6,364	\$7,076	\$7,803	\$8,546	\$9,304	\$10,078	\$10,868	\$11,675	\$12,498	\$13,340	\$14,198	\$15,075	\$15,970	\$16,884	\$17,817	\$18,770	\$19,743		\$51,963
Funding (Overage/Shortfall)	\$514	\$998	\$1,460	\$1,863	\$2,232	\$2,644	\$2,855	\$2,883	\$2,826	\$2,677	\$2,669	\$2,647	\$2,697	\$2,734	\$2,759	\$2,673	\$2,568	\$2,443	\$2,627	\$2,802	\$2,968	\$3,124	\$3,461	\$3,794	\$3,776	\$3,772		\$180
Second LAW Vit Cost - \$7.5B in FY 2023 \$																												(\$132)
Equivalent	\$ 579	\$ 591	\$ 603	\$ 616	\$ 629	\$ 642	\$ 655	\$ 669	\$ 683	\$ 698	\$ 712	\$ 727	\$ 742	\$ 758	\$ 774	\$ 790	\$ 807	\$ 824	\$ 841	\$ 859	\$ 877	\$ 895	\$ 914	\$ 933	\$ 953	\$ 973		\$ 1,635
Start 2025 - spend 10% by 2032																												2.95
4% Escalation/yr thru capital project then back to 2.4%																												1
T&D Included plus pilot (\$205M) per low end NDAA 2017 (\$545M)																												1
Estimate for key equipment replacement (melters and bubblers (NDAA 2017)) included																												83
OPEX (\$450M) plus relacement cost (\$50M) - \$500M per year																												
Note: "Viable" flat funding banks \$2.8B at start of HLW.																												

TSCR Basis (\$15 per gallon)	\$15	Appendix F
Vitrification 1 Summary of Results for Base Case and Sensitivities		Section 2.2, Table F-4

Vitrification 1 Base = Capital Cost	CD-4	Supplemental LAW Mission Complete	Flat Funding with Operations \$M	Final Cost (escalated) \$M
Base	2050	2075	\$ 555	\$ 51,783
Base -10%	2048	2074	\$ 550	\$ 51,083
Base +100%	2068	2088	\$ 645	\$ 88,359
Base with 8% escalation	2056	2075	\$ 900	\$ 71,323

LAW Supplemental Alternatives: Total Discounted Cost and OPEX Cost

Alternative	Hot Operations ^a	LAW Supplemental Treatment Complete	Total Cost Discounted (3% basis) \$M	Total OPEX Cost Discounted (3% basis) \$M
Vitrification 1	2050	2075	12,700^b	5,100
FBSR 1A	2040	2070	5,500	2,200
FBSR 1B	2040	2070	6,300	2,900
Grout 1A	2036	2068	2,700	1,600
Grout 1B	2036	2068	3,400	2,300
Grout 1C	2036	2068	3,100	1,900
Grout 2A	2036	2068	3,400	1,900
Grout 2B	2036	2068	4,300	2,800
Grout 2C	2036	2068	3,800	2,200
Grout 4A	2027	2065	3,300	2,900
Grout 4B	2027	2065	3,900	3,400
Grout 5A	2036	2068	3,300	1,600
Grout 6	2027	2065	4,100	2,700

^a Note: There may be discrepancies for the hot operations commencing dates between this table and previous charts. For the purpose of assessing Criterion 4 (lifecycle costs), a clear delineation between capital and operations was required. This adjustment is considered well within the uncertainty of cost/schedule projections.

^b As stated previously, Vitrification 1 operations are projected to be in excess of the \$450 million benchmark funding annually. For this exercise, the projected funding required was included for OPEX calculations and in the total.

^c Note: Values are rounded to nearest \$100M

Cost and Performance Metrics for Selected LAW Supplemental Treatment Alternatives

Comparison of Cost and Projected Performance of Low-Activity Waste Supplemental Treatment Alternatives

LAW Supplemental Treatment Alternative	Cumulative unescalated cost Constant FY 2023 value (\$M, rounded)				Cumulative gallons of supplemental LAW feed treated (Mgal)				Cumulative curies of technetium treated (Ci)			
	2033 ^a	2039 ^b	2047 ^c	At Treatment Alternative Mission End ^d	2033 ^a	2039 ^b	2047 ^c	At Treatment Alternative Mission End ^d	2033 ^a	2039 ^b	2047 ^c	At Treatment Alternative Mission End ^d (percent of technetium treated)
Vitrification 1 (on-site facility with IDF disposition)	2,200 4,100	5,600 6,800	8,100 10,400	23,400 27,000 [2075 ^d]	-	-	-	83 ^e	-	-	-	6,640 (27%)
FBSR 1A (on-site facility with IDF disposition)	1,600 2,100	3,500 4,600	4,800 5,900	8,400 9,900 [2070 ^d]	-	-	25	86 ^e	-	-	5,700 ^e	10,210 (41%)
Grout 1A (on-site facility with IDF disposition) ^{ff}	1,100 1,200	1,600 1,800	2,500 2,700	4,600 5,000 [2068 ^d]	-	13	37	92 ^e	-	4,500	11,000	15,100 (62%)
Grout 4B (off-site grout with off-site disposition)	1,300 1,300	2,500 2,600	4,000 4,100	6,400 6,900 [2066 ^d]	14	34	58	97	6,900	10,100	12,600	17,000 (68%)
Grout 6 (off-site grout with off-site disposition through 2039; on-site facility with GDU disposition 2040 on)	1,400 1,600	3,200 3,600	4,100 4,800	5,800 6,900 [2066 ^d]	14	34	58	97	6,900	10,100	12,600	17,000 (68%)

^a Key mission activity: 2033 – Start of HLW vitrification (assumed end of year).

^b Key mission activity: 2039 – Start of FBSR for supplemental LAW treatment (assumed end of year).

^c Key mission activity: 2047 – Start of vitrification for supplemental LAW treatment (assumed end of year).

^d The mission end date varies by treatment technology.

^e For alternative Grout 4B, the technetium curies dispositioned are taken directly from the TOPSim model run. Alternative Grout 6 is assumed to have the same feed vector – understanding that technetium treated from 2040 on (6,000 Ci) would be dispositioned onsite in IDF versus offsite. For alternative Vitrification 1, the technetium curies treated are adjusted from the Vitrification 1 (modified) TOPSim model run by adding 3× the nominal technetium curies treated by LAW vitrification over that same period. Technetium treated by dates for alternatives FBSR 1A and Grout 1A were similarly projected based on nominal LAW vitrification technetium performance – assuming the alternatives would see the same feed vector as LAW vitrification. Projected volumes for process alternatives were calculated in a similar manner using the annual feed volumes projected for the process alternatives in this study and bounded by the TOPSim modeling results.

^f Grout 1A is included in this chart to reflect the performance with respect to gallons of supplemental LAW treated and curies treated. Grout 1A is consistent with all Grout 1, 2, 3, and 5 process feed vectors.

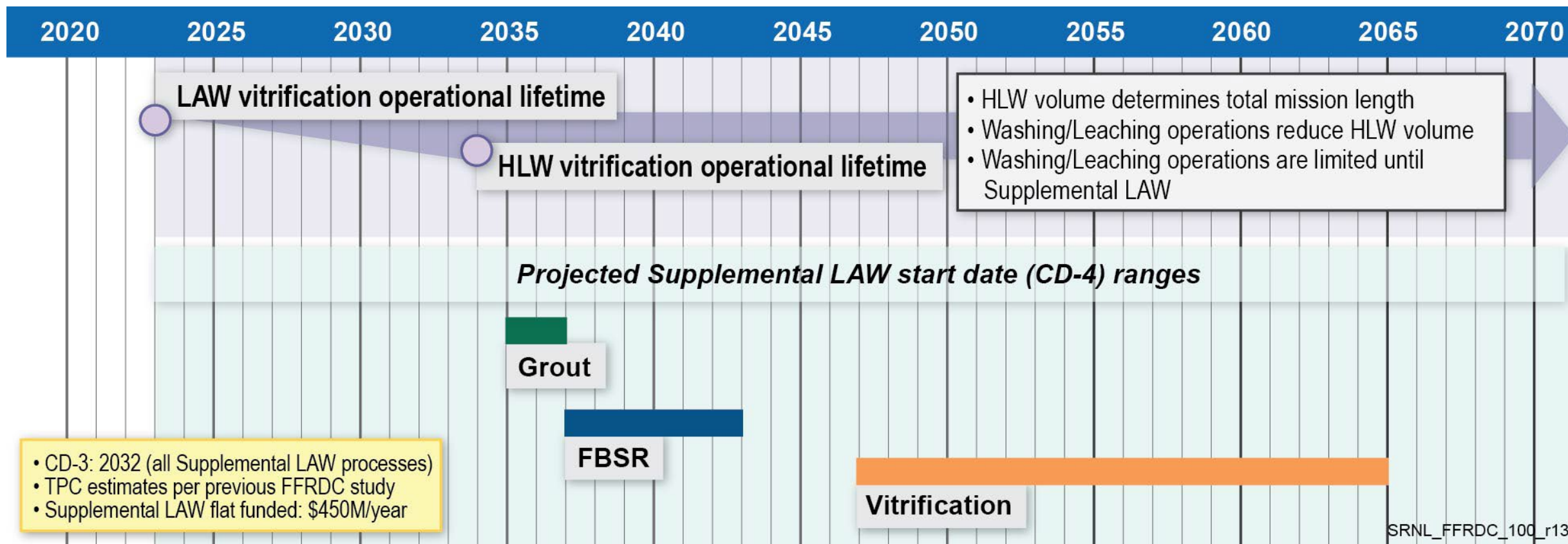
Main Body Table 3.4-1 | Volume II, Appendix F, Table F-15

Summary Chart: Alternative Vitrification 1 and Alternative Grout 4B (Off-site Grout and Disposition)

	Supplemental LAW		
	Vitrification	Early Start <i>All Off-site Grout</i>	Mission Impacts
Estimated cost to construct treatment facilities (unescalated)	\$6.8 - \$15B	<\$0.35B	Capital avoidance: \$6-15 billion
Short-Term Risk - SST Retrievals Complete - Cost (present value)	2070 (\$150/gal)	2057 (\$40/gal)	Equivalent to the contents of ~seven AP Farm DSTs dispositioned safely out of Washington State prior to HLW vitrification startup
Long-Term Risk - Tc Disposition - Cost (present value)	8,800Ci offsite 16,000Ci onsite (\$1,900,000/Ci)	18,000Ci offsite 6,800Ci onsite (\$230,000/Ci)	70% removed from Washington
Total Mission Cost (unescalated)	\$110B	\$80B	25% cost reduction

Projected Supplemental LAW Facility Start Dates

Start dates greatly impact mission length and cost



Mission Construction – Initial Bases and Metrics

The previous FFRDC report and other publications (e.g., GAO-22-104365) describe costs of various process alternatives and disposition. This study more directly incorporates LAW supplemental treatment within the total mission - the schedule is not constrained, and System Planning tools are incorporated alongside the alternatives analysis.

- Capital costs and on-site operating costs are derived from the previous FFRDC report (SRNL-RP-2018-00687).
- Mission schedule reflects System Planning comparative results (Vitrification 1 versus Grout 4B) plus the alternatives analysis (timing for the start of LAW supplemental treatment).
- LAW and HLW feed generated by crystalline silicotitanate (CST) ion exchange (IX) and HLW processing arrangements as per previous System Planning studies.
- Off-site disposition costs reflect updated estimates of grouted waste classification and vendor pricing identified during this study.
- Cost metrics are provided as per System Planning (unescalated \$) and for Criterion 4 (discounted, present value)
- Vitrification and off-site grout are summarized per GAO-17-306 (Table 2)
 - Technology alternative capital cost and/or avoidance
 - Short-term risk (\$/gal) and schedule reduction
 - Long-term risk (\$/Ci Tc) plus disposition
 - Total mission cost

System Plan style process (TOPSim) and cost modeling was performed to bound mission profiles

Brief Overview of EIS – Mission Impacts of Facilities and Constrained Schedule

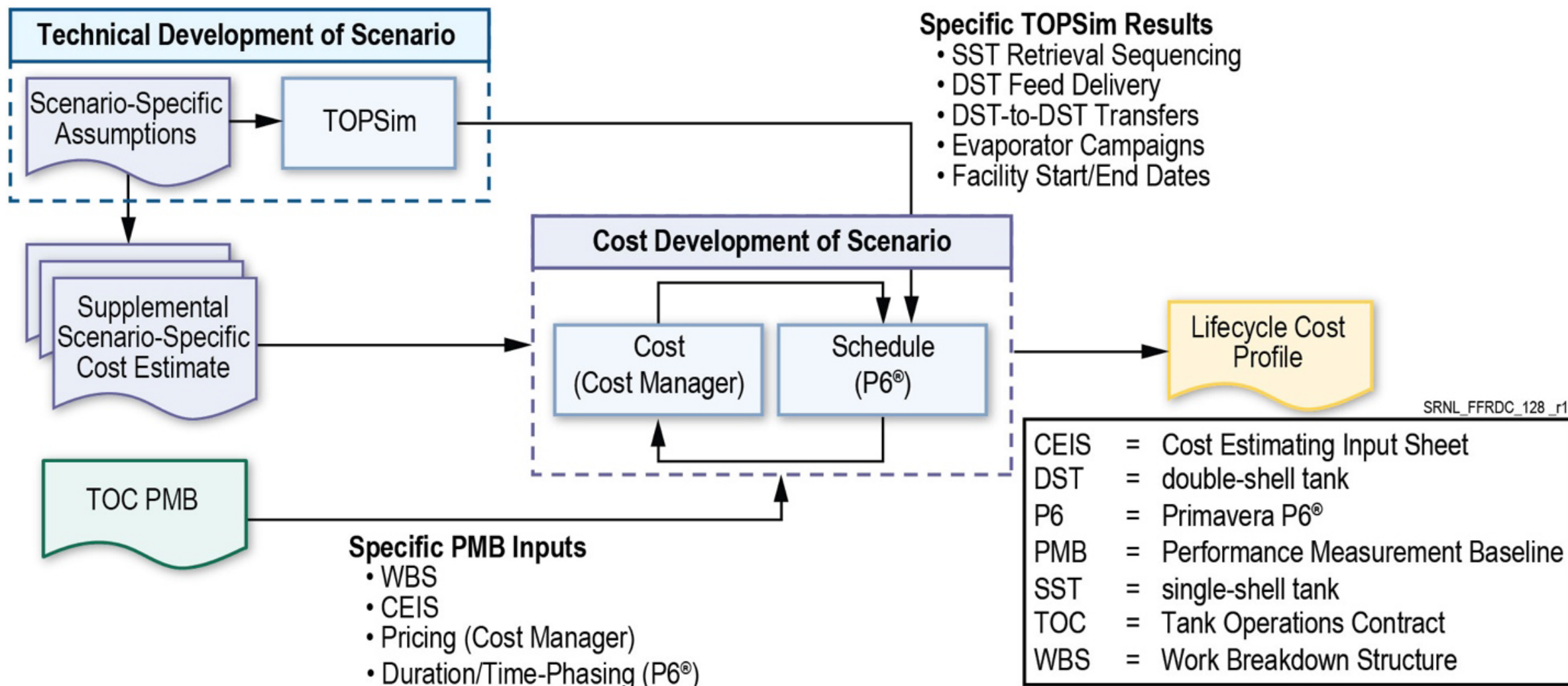
	Expanded Vitrification (EIS 2B)	WTP + Non-Thermal (EIS 3B)	Schedule slip, WTP scope changes and cost growth make direct comparisons against constrained HLW schedule challenging
WTP (HLW and LAW) ^a	HLW 2018-2043 LAW 2018-2043	HLW 2018-2040 LAW 2018-2040	
Expanded Vitrification (2× LAW)	2022-2043		
Containerized Grout (200 East)		2018-2040	
Containerized Grout (200 West)		2018-2040	TC&WM EIS Readers Guide, Tables 1,4 Summary, pages S-41, -42 Summary, Tables S-29, -30 Cost Volume, Sections 2/3
Transuranic (TRU) Waste Supplemental Treatment (CH-TRU and RH-TRU)		3.1 Mgal 1/4 Tank Waste Sludge	
200 West Area Solid/Liquid Separation Facility		2018-2040	
Construction / Operations, 2008 \$ ^b	\$8.7B / 11.3B	\$7.9B / 11.2B	
Total Cost (with disposal), 2008 \$ ^c	\$40.9B	\$39.9B	

^a TC&WM EIS Alternative 2A (no LAW supplemental treatment) projected WTP operations 2018 through 2093.

^b Costs for the treatment phase (versus retrievals, storage, disposal, etc.) as per Summary table S-29

^c Totals include data from Summary tables S-29 & S-30 and are consistent with S-31.

System Planning Methodology – Lifecycle Cost Modeling



Alternative Grout 4B Scenario Overview – Highest Level Simulation Logic

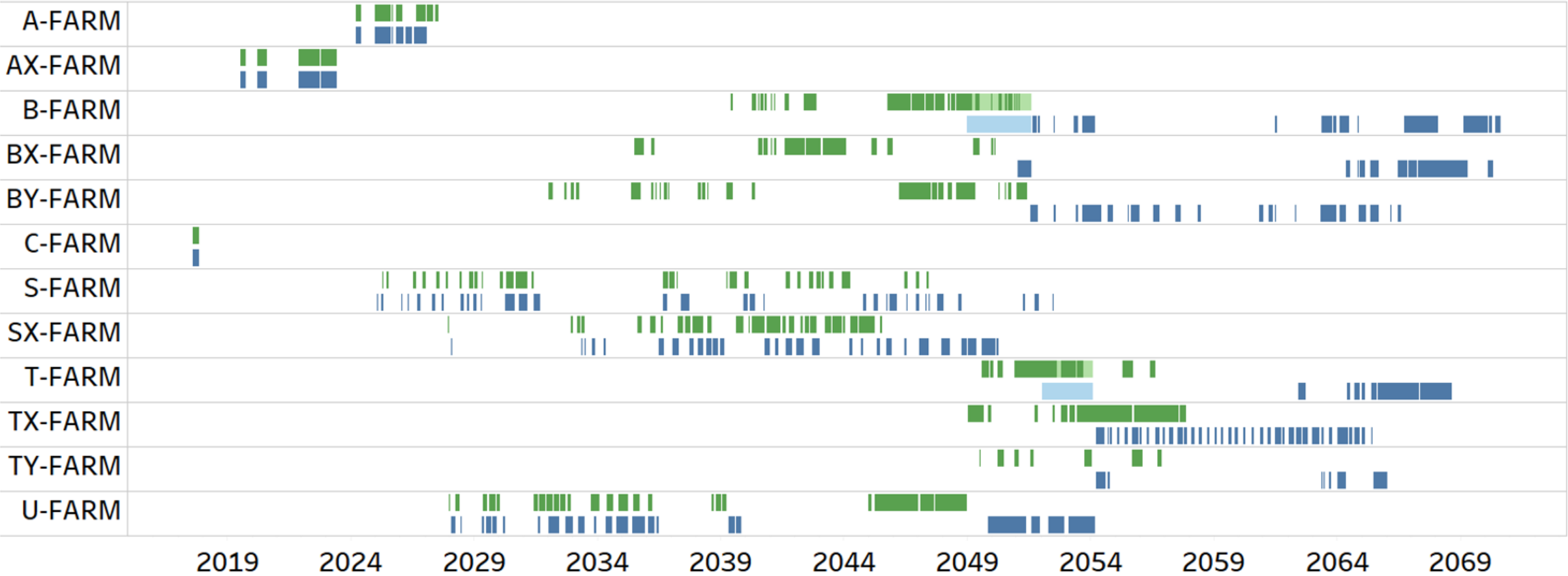
LAW Phase	Start Year	End Year	Phase Overview
Phase 1	2023	2064	DFLAW process using southeast (SE) tank-side cesium removal (TSCR) facility to pretreat supernate in SE Quadrant (A/AX/C Farm single-shell tanks [SST] and 200 East Area double-shell tanks [DST]) and send to WTP LAW Vitrification Facility; continues through the end of the mission
Phase 2	2026	2058	- New southwest (SW) TSCR comes online to pretreat supernate in SW Quadrant (S/SX/U Farm SSTs and SY Farm DSTs) before sending for LAW supplemental treatment - SW TSCR runs until all 200 West Area SSTs have been retrieved
Phase 3	2028	2064	- SE TFPT (3× TSCR capacity) and LAW feed evaporators (LFE) for both SE and SW TSCRs come online; evaporators concentrate pretreated feed to 7.5 M Na through the end of the mission - Any LAW feed in excess of what can be treated by LAW vitrification is now sent for supplemental treatment and continues through end of the mission (<i>versus 2050 for Vitrification 1</i>) - B Complex retrievals begin as space opens in SE Quadrant (<i>versus 2050 for Vitrification 1</i>)
Phase 4	2036	2064	SE TFPT capacity and supplemental LAW treatment increase so HLW vitrification paces the mission (<i>common for all simulations, only need dates change</i>)

Mission Dates & Metrics: Vitrification (1) and Early Off-site Grout (4B)

Metric	Vitrification 1 (modified) (200 East Area 2050)	Grout 4B (East Area 2028)
Treat All Tank Waste	2075	2066
Complete all SST Retrievals	2070	2057
S/SX Farm SSTs Retrieved during DFLAW Operations	5	7
Cross-Site Slurry Line Activated	2039	2039
HLW Glass Canisters	12,000	9,300
LAW Glass Containers	67,500	26,600
200 West Area LAW Supplemental Treatment Feed (Post-Evaporation)	70.4 Mgal (N/A)	51.2 Mgal (23.7 Mgal)
200 East Area LAW Supplemental Treatment Feed	53.6 Mgal	75.6 Mgal
200 East Area LAW Vitrification Feed	50.5 Mgal	36.5 Mgal
Required SE TFPT Size (TSCR Unit Equivalents)*	8	5
Lifecycle Cost Unescalated	\$110B	\$79

* TSCR unit equivalents is a measure of processing capacity required to provide all LAW feed. Later starting LAW ST systems require greater instantaneous feed capacity to meet mission requirements.

SST Retrieval Gantt Chart – Comparative Dates to Consolidate Waste into Double-Shell Tanks



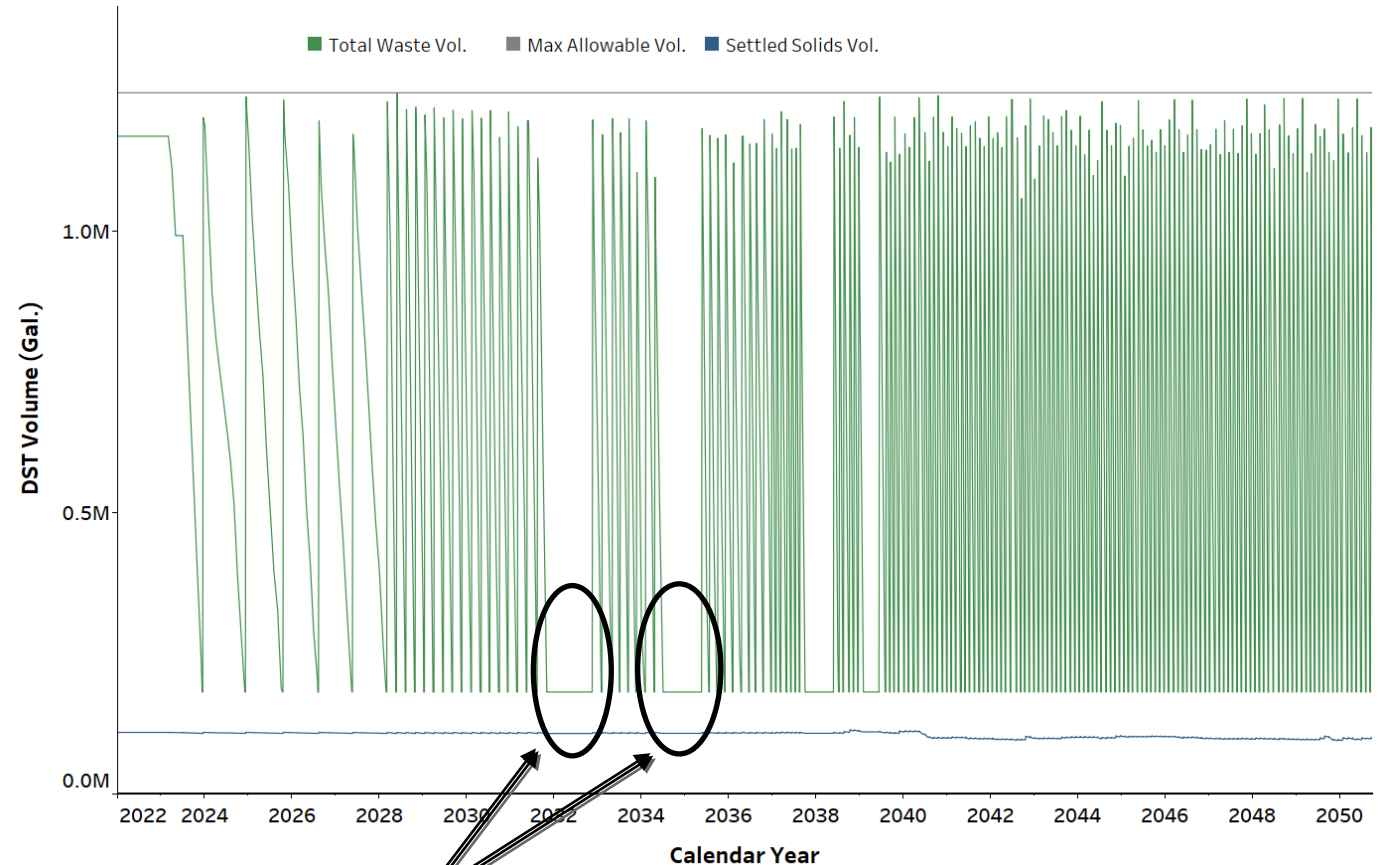
■ Retrieved to DSTs, Grout 4B
■ Retrieved to DSTs. Vitrification 1 (modified)

LAW Feed Availability: Alternative Grout 4B

- 2-year-long feed outages in 200 East Area in the early 2030s demonstrate how the LAW processing rate initially outpaces retrievals
- LAW feed is diverted from 200 West Area to supplement 200 East Area LAW when needed starting in 2039, enabling a higher rate of 200 West Area SST retrievals
- If this scenario were to be implemented, feed to LAW supplemental treatment from the SE TSCR/TFPT would need to be throttled to ensure continued feed availability for WTP LAW Facility Vitrification

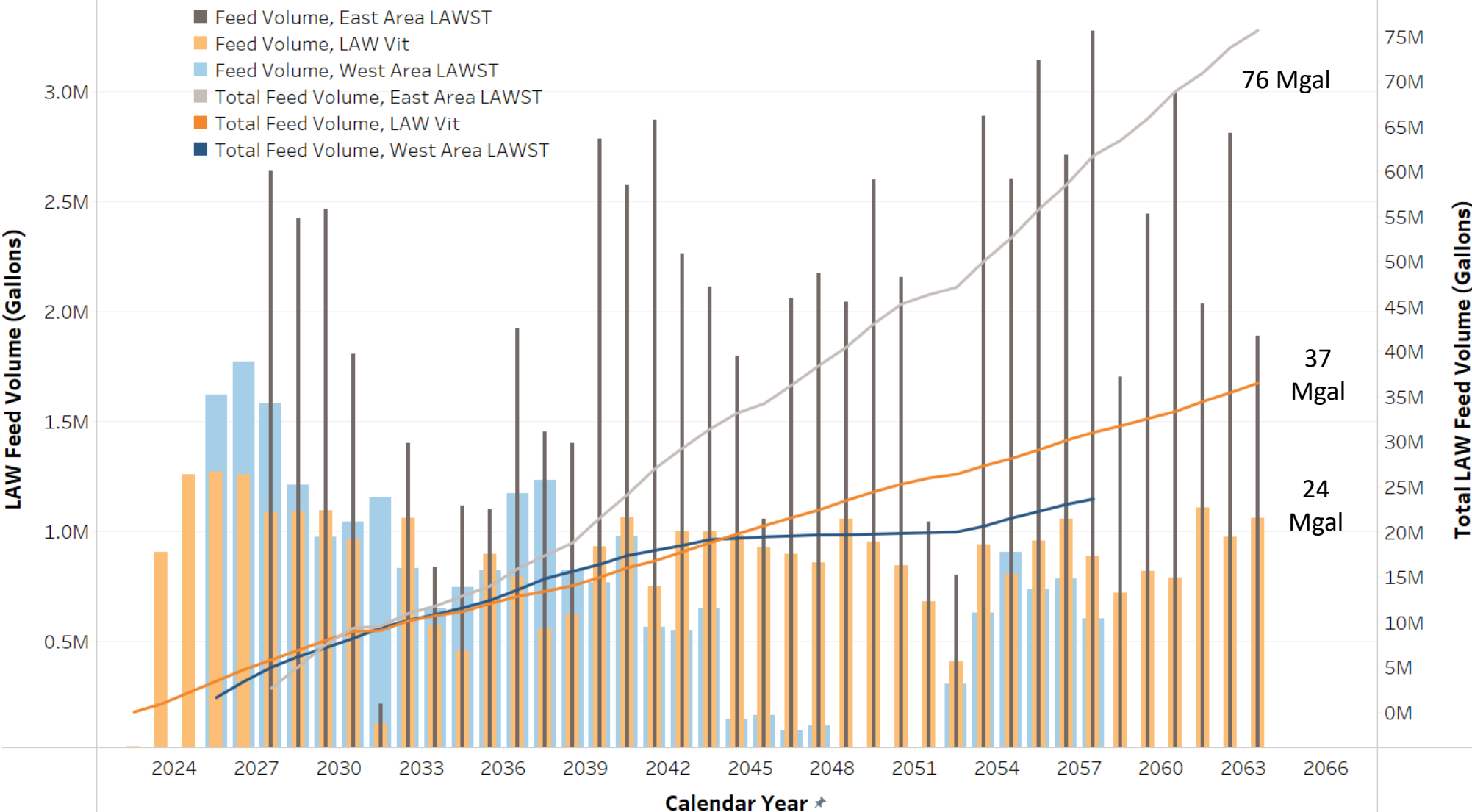
The Grout 4B TOPSim run indicates maximum DST space can be derived prior to WTP HLW hot operations. No “optimization” by either increasing retrievals or balancing feed rates was attempted.

Tank AP-107 Volume Profile



LAW/LAW Supplemental Treatment Feed Volumes by Source

The volume of waste designated for 200 East Area LAW supplemental treatment is significantly higher, as the 200 West Area lacks sufficient tankage and pretreatment capacity to enable 200 West Area retrievals to keep pace with 200 East Area.

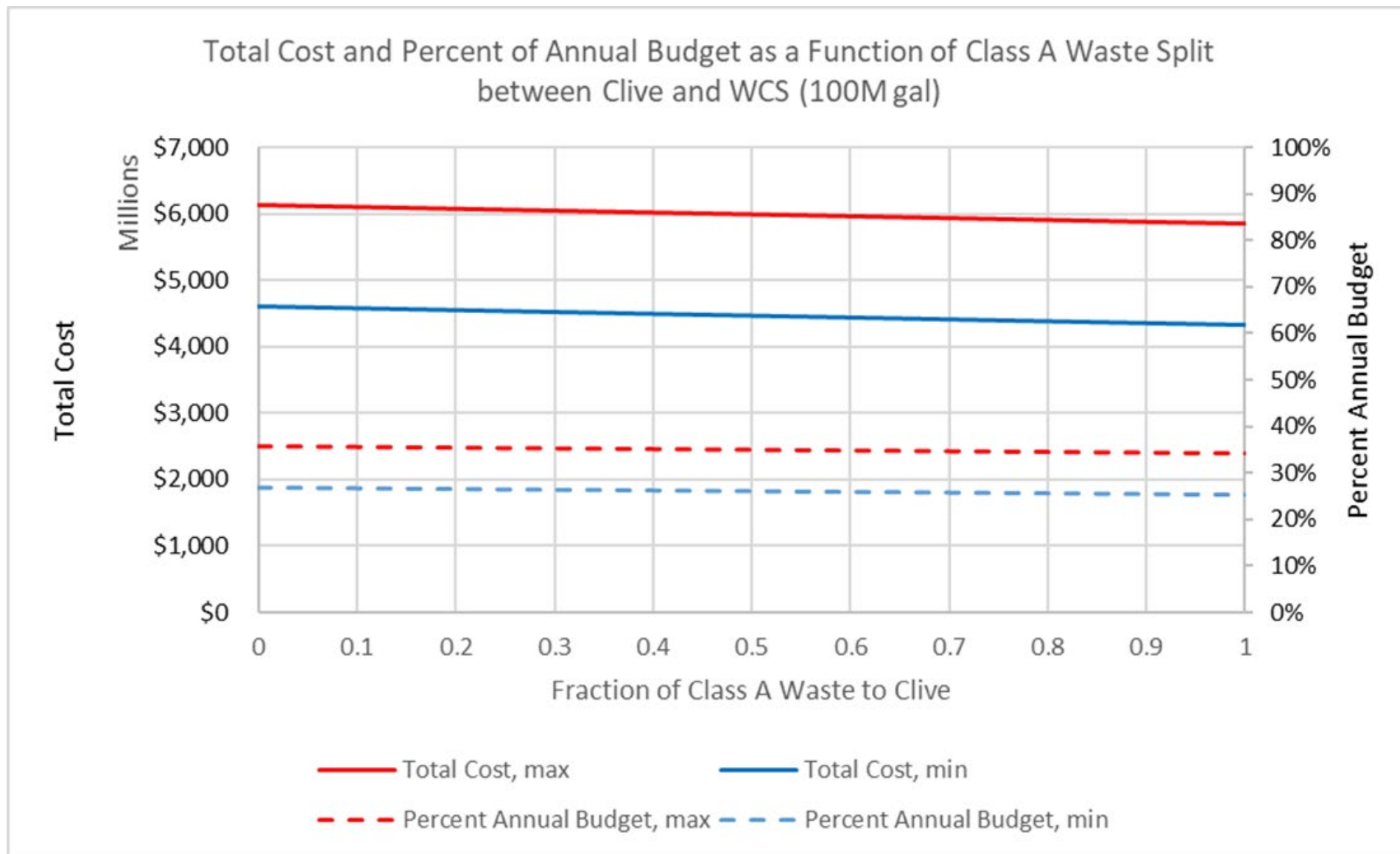


LAW Supplemental Treatment Cost Comparison

	Supplemental Pretreatment (PT) Area	Supplemental Pretreatment Cost Item	Unescalated Cost	Total Unescalated Cost
Grout 4B	200 East Area	East LFE Capital/Operations	\$330.6M	\$12.4B
		SE TSCR/TFPT	\$3.5B	
		East Load-Out Station	\$8.0M	
		Treatment/Disposal of Pretreated Supernate	\$5.7B	
	200 West Area	West LFE Capital/Operations	\$259.6M	
		SW TSCR	\$659.3M	
		West Load-Out Station	\$8.0M	
		Treatment/Disposal of Pretreated Supernate	\$1.8B	
Vitrification 1 (modified)	200 East Area	East LFE Capital/Operations	\$779.2M	\$33.9B
		SE TSCR/TFPT	\$3.0B	
		LAW Supplemental Treatment Vitrification Facility	\$24.1B	
	200 West Area	SW TSCR	\$771.0M	
		West Load-Out Station	\$8.0M	
		Treatment/Disposal of Pretreated Supernate	\$5.3B	

LAW supplemental treatment accounts for \$21B of the \$31B cost delta – the additional \$10B is due to reduced mission length

Example Off-site Grout Cost Projection: Grouting plus Transportation and Disposal



Grouting Cost
\$30 - \$45 / gal
is major factor

≈90/10 A/B split
All Class B to WCS

Base assumption:
50/50 split Class A

Vitrification 1, FBSR 1A, Grout 4B, and Grout 6

Near-Term Views of Cost of Alternatives

	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Vitrification 1	\$424	\$412	\$400	\$388	\$377	\$366	\$355	\$345	\$335	\$325
FBSR 1A	\$49	\$77	\$115	\$237	\$263	\$176	\$225	\$226	\$335	\$332
Grout 4B	\$130	\$130	\$135	\$145	\$119	\$108	\$125	\$118	\$115	\$134
Grout 6	\$130	\$130	\$135	\$150	\$133	\$120	\$152	\$168	\$176	\$250

Present Value (3% discount basis)

Vitrification 1	\$60	\$155	\$275	\$450	\$655	\$830	\$1,155	\$1,605	\$2,105	\$2,605
FBSR 1A	\$50	\$130	\$250	\$501	\$782	\$972	\$1,218	\$1,468	\$1,593	\$1,968
Grout 4B	\$137	\$278	\$428	\$594	\$734	\$864	\$1,019	\$1,169	\$1,319	\$1,499
Grout 6	\$137	\$278	\$428	\$599	\$749	\$878	\$1,050	\$1,239	\$1,434	\$1,734

Cumulative Cost (unescalated)

Annual discounted costs show impact of flat funding across mission- more expensive capital projects will require significant carryover.

Cumulative (unescalated) costs provided to evaluate applied funding requirements through HLW hot operations (CD-4)



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Grout Technology Advances and Uncertainties

Dr. Matthew Asmussen

Pacific Northwest National Laboratory

Scientist, Principal Investigator PNNL IDF PA Program

FFRDC Grout Team Lead

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



U.S. DEPARTMENT OF
ENERGY

SRNL is managed and operated by Battelle Savannah River Alliance, LLC for the U. S. Department of Energy.

Presentation Outline

- **Overview of Uncertainty in FFRDC Report**
- **Uncertainty in Long-Term Effectiveness**
- **Updated LDR**
- **Discuss Specific Recommendations**
- **Discuss Additional Changes**

NAS Recommendation (summarized):	Applicable Section(s)
No NAS recommendations related to Volume II Appendix A.	Updated discussion related to LDR organics to incorporate recent developments (Vol II Appendix A.3.6)
No NAS recommendations related to Volume II Appendix E	Updated evaluation for impact to groundwater for other species (nitrate/Cr) (Volume II Appendix E.3.1.9) Updated uncertainty discussion around non-pertechetate (Volume II Appendix E.3.1.2) and LDR organics (Volume II Appendix E.3.1.6)

Uncertainty/Confidence in Long Term Effectiveness (Criterion 1)

- **Alternatives that Utilized an Off-site Disposal Pathway had High Confidence in the Assessment of Long-Term Effectiveness**
 - Alternatives: Grout 4B, Grout 6*
 - No major drivers of uncertainty
 - Due to the absence of a pathway to potable water and likelihood to meet waste acceptance criteria
- **Alternatives that Considered Disposal On-site at the Hanford Integrated Disposal Facility (IDF) all had Moderate Confidence in the Assessments Made**
 - Alternatives: Vitrification 1, FBSR 1A, Grout 6*
 - Various drivers of uncertainty
 - The long-time frames under evaluation induce temporal uncertainty with shallow disposal at a facility with a pathway to potable water.

*As grout 6 transitions from off-site to on-site, both scenarios are considered



Clive, UT Facility



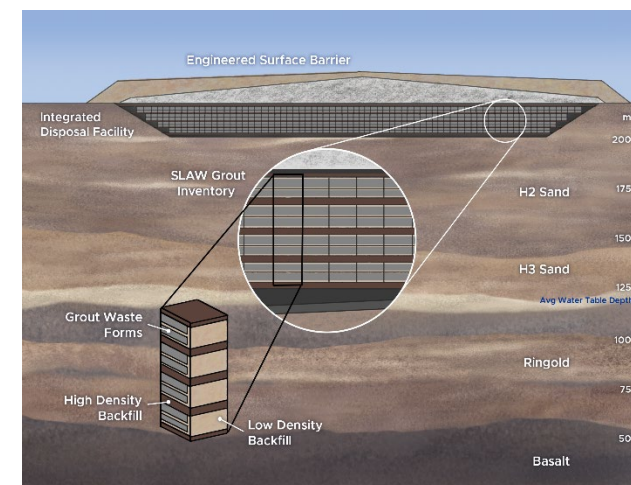
Waste Control Specialists, TX



Hanford Integrated Disposal Facility, WA

Uncertainty/Confidence in Long Term Effectiveness cont'd – On-site Disposal (Criterion 1)

- **Mobility of Iodine, Technetium, and Nitrate to Potable Water and Associated Confidence in Immobilization**
 - All “on-site disposal” alternatives: Vitrification 1, FBSR 1A, Grout 6
 - Uncertainties associated with main contaminants’ performance in grout waste forms covered in prior public meeting and in Section E.3 of report.
 - Uncertainties associated with performance of vitrified waste forms relate to long-term projections of waste form performance, on-going updates to representation in PA modeling and performance of grouted secondary waste.
 - Uncertainties associated with FBSR waste forms performance arise from the smaller dataset available on these waste forms.
 - Source term for contaminants released from waste forms in the IDF dependent on partitioning between waste streams, concentration in waste form, water infiltration rate, transport pathways and local chemistry within facility.
 - Using a risk-budget approach source term, contributions from each theoretical waste form combination can be above or below the drinking water standards.
 - *Updated to include other species, Cr and NO₃⁻ with no change in the level of uncertainty assigned*
 - The performance assessment of a large grout disposal unit (GDU) has not been updated since 1995.
- **This Uncertainty is not a Driver with Off-site Disposal with no Pathway to Potable Water**



Cross-section of IDF

Uncertainty Update on Technetium-99

Volume II Appendix E.3.1.2.2 Non-pertechnetate Uncertainty

- Speciation of technetium in Hanford tank waste impacts disposition in grout waste forms. The predominant form of technetium in tank waste is pertechnetate ion, TcO_4^- . There is also a form of technetium in a few Hanford tanks known as “non-pertechnetate” and its overall concentration is uncertain
- Non-pertechnetate may have differing behavior in grout waste forms compared with pertechnetate, introducing uncertainty in on-site disposal alternatives
 - Limited data available on non-pertechnetate behavior in grout
 - Presence of non-pertechnetate will not affect off-site disposal alternatives where a pathway to potable water does not exist.
- Updated information presented to show the current measurements of non-pertechnetate in the Hanford tanks
 - Most data comes from a fraction of the Tc in waste that passed through a column filled with ion exchange resin used for pertechnetate removal
- Some tanks with the highest measured non-pertechnetate have overall low inventories of Tc-99
- New analysis methods have been developed to quantify non-pertechnetate in waste.

Table E-6. Existing Non-Pertechnetate Data Summary				
Tank	Min % non-PT	Max % non-PT	Tc (Ci) - Current BBI	Max Ci non-PT
AN-102	48	80	482	386
AN-103	1.6	8	273	22
AN-107	48	80	302	242
AP-101	0.5	13	738	96
AP-104	69	72	93.6	67
AW-101	0.06	15	468	70
AZ-101	0	0	1310	0
AZ-102 ^a	0	0.04	176	0.1
SY-101	53	70	63	44
SY-103	54	78	484	378
			Total (Ci)	1304
			% Tc of Total Tank Waste	5%
			%Tc of DST Tc	13%
^a Note: A value of 33% non-pertechnetate is present in PNNL-23319, Table 4.7, for Tank AZ-102; however, the reference listed in the table is incorrect. This value could not be confirmed in other available references and is highly suspect.				
BBI	= Best Basis Inventory.			
DST	= double-shell tank.			
PT	= pretreatment.			

Update: LDR Organics Analysis

- **Status of R&D and Analyses (Volume II Appendix A.3.6)**

- RPP-RPT-61301, *Current Chemical Knowledge Concerning Organic Chemicals in Hanford Double-Shell Tank Waste Supernatant (Rev.1)*
 - The objective of this report was to provide a technical basis to aid in the characterizing of organic compounds in tank waste feed.
 - Concluded that current chemical knowledge indicates there were 31 regulated organic compounds used on the Hanford Site.
 - This report makes a strong case for the concept that current chemical knowledge can effectively be employed to eliminate the consideration of many compounds of regulatory concern and minimize the requirements for analytical work to meet the regulatory requirements and data quality objectives.
- RPP-RPT-63493, *Tank Waste LDR Organics Data Summary for Sample-and-Send*
 - In this work, WRPS defined and applied seven decision rules to screen out compounds that have no historical or current support for being present in Hanford tank waste.
 - The application of the seven decision rules **eliminates 75 compounds from the list of 207 LDR organics associated with Hanford Tank Waste** (SRNL-STI-2020-00228). The remaining 132 compounds are considered as potentially present and are suggested to be the target for future tank waste characterization efforts.

Update: LDR Organics Analysis

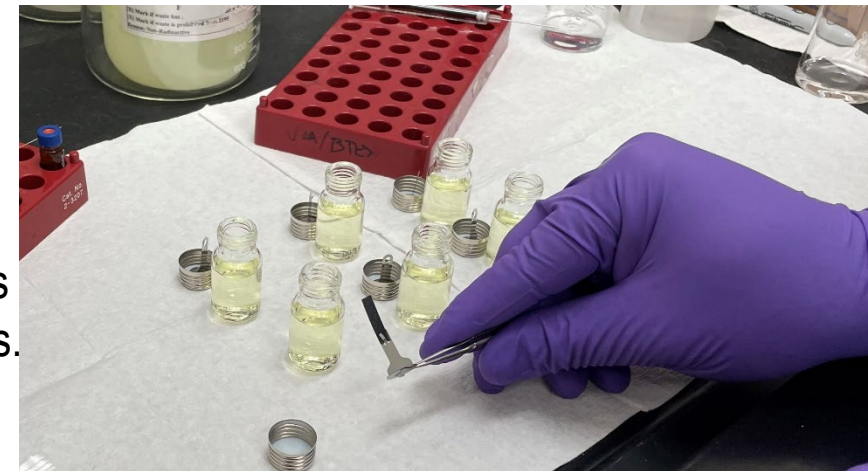
- **Status of R&D and Analyses (Volume II Appendix A.3.6)**

- RPP-RPT-64064, *Distribution of LDR Organic Compounds in Hanford Tanks Waste and The Implications to LAW Treatment by Cementitious Solidification/Stabilization*
 - WRPS staff reviewed the available data in TWINS for the 207 LDR organic compounds associated with Hanford tank waste to determine the extent to which these compounds are distributed in tank waste.
 - For the current 156 unretrieved tanks, 93 have some LDR organics data in TWINS, but only 31 have LDR organics data other than for PCBs (20 DST and 11 SST)
 - Uncertainty introduced based on the lack of sampling information for all tanks (Vol II Appendix E.3.1.6)
 - Only 18 exceedances from liquid samples and 15 from solid samples for unique samples.
 - Historic liquid samples from seven tanks (AN-107, AP-104, AP-107, AP-108, AW-102, AW-104, and AW-106) are predicted to produce a solidified/stabilized final waste form that exceeds the non-wastewater (NWW) standard for an LDR organic.
 - Only the data from AN-107 represents the current tank content.
 - These tanks are DSTs that are most likely to be retrieved and processed during DFLAW operations.
 - Only one result for a solid sample (Toluene in T-111) gives a realistic exceedance of the NWW standard.
 - PCB exceedances are not realistic given this compound's water solubility.
 - No case has more than one exceeding compound

Update: LDR Organics Sampling

- **Status of R&D and Analyses (Volume II Appendix A.3.6)**

- RPP-RPT-63952, *Analysis of Organic Chemicals in Hanford Tank Waste Simulant by Stir Bar Sorptive Extraction*
 - Select LDR organics have detection limits in existing measurement methods that are above the wastewater standard concentrations, presenting uncertainty in their possibility to exceed compliance levels
 - 222-S has evaluated the potential for using stir bar sorptive extraction and thin film solid phase microextraction methods in an attempt to lower the detection limits for organic compounds in Hanford tank waste to below wastewater standards
 - The efficiencies of the extraction of 131 VOC and SVOCs from tank waste simulants were evaluated with the methods giving promising results in lowering detection limits.
 - Further work is on-going to expand the technique.
 - Updated sampling of other tanks would greatly reduce uncertainty around global LDR organic concentrations in the tanks.



Experimental set up used for the stir bar sorptive extraction technique under development at 222-S for use with Hanford tank wastes

Update: LDR Organics Treatment

- **Status of R&D and Analyses (Volume II Appendix A.3.6)**

- SRNL-STI-2020-00228, *Evaluation of Technologies for Enhancing Grout for Immobilizing Hanford Supplemental Low-Activity Waste*
 - Expert team from PNNL, VSL, SRNL, WRPS evaluated options for the treatment of organics, including evaporation and chemical oxidation
 - Served as basis of WRPS testing program into organics treatment
- SRNL-STI-2021-00453, *Potential for Evaporation and In-situ Reaction of Organic Compounds in Hanford Supplemental LAW*
 - Conducted evaporator testing using a LAW simulant spiked with target organic compounds to identify a lower volatility limit, above which compounds would have been removed by evaporation with supporting OLI calculations
 - Results suggest that
 - Compounds that do not ionize below pH 13 and have a volatility (expressed as the Henry's Law vapor-liquid partition coefficient) greater than or equal to methanol, can be expected to have been removed by historical evaporation campaigns.
 - Volatility increases with salt content, and so Henry's Law coefficients measured in water are an under prediction of volatility in tank wastes.

Update: LDR Organics Treatment

- **Status of R&D and Analyses (Volume II Appendix A.3.6)**

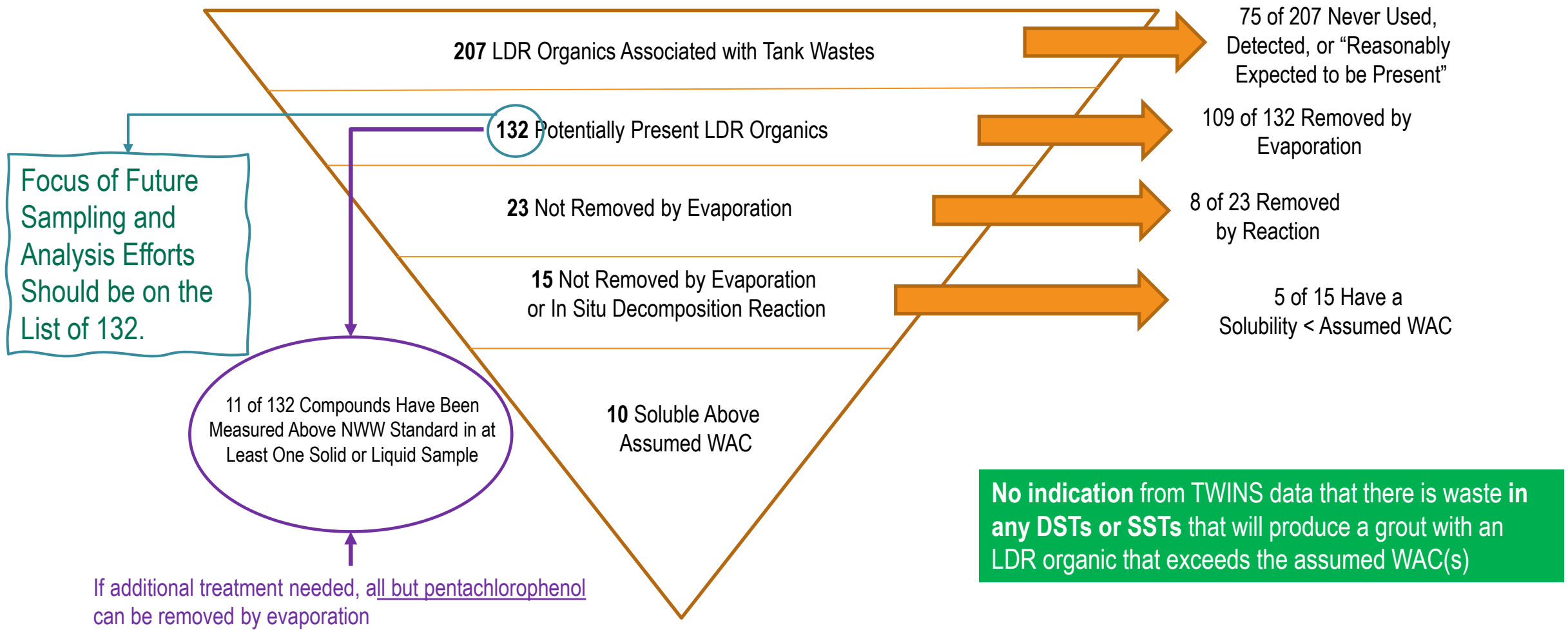
- SRNL-STI-2022-00391 *Organic Evaporation and Oxidation Testing in Support of Hanford Sample-and-Send*

- Extending existing data compilation effort to include solubility, reactivity, radiolysis, and pK_a values for all 207 LDR organic compounds associated with Hanford tank waste.
- Measured the impacts of both atmospheric and vacuum evaporation on less volatile compounds. Results showed that compounds with Henry's law coefficient at least $186\times$ below that of methanol (and that are not present as charged species) are removed from LAW by atmospheric evaporation.
- Demonstrated permanganate oxidation of tested LDR organics (phenol, 4-chloroaniline, ortho-cresol, 4,6-dinitrocresol, and n-nitrosomorpholine) is possible even in the presence high concentrations of non-regulated organic acids (comprise bulk of TOC in most tanks).

- FY23 Work is:

- Testing the removal of n-nitrosomorpholine via vacuum evaporation
- Testing chemical oxidation of organics via permanganate and persulfate
- Expanding process knowledge by expanding the list of potential *in situ* decomposition products.

LDR Organics Summary



Summary

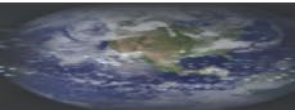
- **Uncertainty Drivers Varied Across the Alternatives (Volume II: Appendix E)**

- Uncertainty around long-term effectiveness driven by disposal locations
 - *Alternatives considering off-site disposal evaluated with a higher degree of certainty in the evaluations*
- Risk associated with schedule implementation and operations was larger for high temperature alternatives due to process complexity, off-gas handling and consumable changeouts.
- High confidence around the assessments of likelihood of successful mission completion
- Similar range of cost uncertainty across alternatives

- **Updated Information from 2017-NDAA-3134 Report (Volume II: Appendix A)**

- New information and responses to unknowns listed in 2017-NDAA-3134 report are presented in Appendix II:A
- Continually reducing uncertainties associated with disposal of LAW waste forms.

Backup



Uncertainty/Confidence in the Alternatives Analysis

- In the assessment of the various alternatives (Volume II: Appendix D), the final rankings contained a summary of uncertainty/confidence and technical risks around the assessments of the four main criteria:
 - Long-term effectiveness (environmental and safety risk after disposal) (*Criterion 1*),
 - Implementation schedule and risk (environmental and safety risks prior to mission completion, including risks driven by waste tank storage duration) (*Criterion 2*),
 - Likelihood of successful mission completion (including technical, engineering, and resource-related risks) (*Criterion 3*),
 - Lifecycle costs (discounted present value) (*Criterion 4*).
- There could be low uncertainty (high confidence) associated with an assessment that was favorable or unfavorable, or vice-versa. For example:
 - A rating of “*Effective with medium confidence in the assessment*” is one where there is moderate uncertainty (qualitative or quantitative) in the items that led to the ranking, however the assessment could change as the uncertainty is resolved.
 - A rating of “*Low probability of success with high confidence in the assessment*” is one where there is little uncertainty/high confidence that even with a breakthrough the alternative will still have low probability of success.
- The sources of uncertainty/risk in each criteria vary between the alternatives.

Overall Uncertainty/Confidence Assignments

– Low uncertainty/risk or high confidence –

- Sufficient supporting data/experience exists for **all** sub-criteria.
- The overall assessments made **are unlikely to change** with future developments.
- High confidence could be assigned to the descriptions provided of each criteria.

– Moderate uncertainty/risk or medium confidence –

- High confidence could be assigned to the descriptions provided for **most** criteria and **discrete uncertainties** were identified.
- Sufficient supporting data/experience exists for **most** sub-criteria.
- Gaining further knowledge/development **could have an impact** on the overall assessments made.
- Technical challenges identified are **considered feasible to overcome** with future development.

– High uncertainty/risk or low confidence–

- Low confidence could be assigned to the descriptions provided for **most** criteria, and **several broad uncertainties** were identified.
- **Minimal supporting** data/experience exists for select sub-criteria that are considered crucial for success of the alternative.
- Gaining further knowledge/development **could have an impact** on the overall assessments made.
- Technical challenges identified are considered **unlikely to be overcome** without significant breakthroughs.



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Fluidized Bed Steam Reforming (FBSR) Enhancements

Kevin G. Brown, Ph.D., BCEEM

Research Associate Professor, Vanderbilt University

Consortium for Risk Evaluation with Stakeholder Participation (CRESP)

Alternatives Evaluation Team

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



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FBSR Proposed for Hanford LAW

1. Introduction

2. Clarifications and Improvements

- Original draft information for proposed Hanford LAW FBSR based on 2019 FFRDC report and reviewed by N. Soelberg (INL).
- Reviewed selected technical documents as suggested by NAS reviewer(s).
- Reviewed additional documents.
 - 20+ WM papers and several technical reports on Hanford LAW FBSR and IWTU progress.
- Requested factual accuracy review of Integrated Waste Treatment Unit (IWTU) information by Idaho Completion Project (ICP) Subject Matter Experts (SMEs).

NAS Observations (summarized):		Applicable Section(s)	
3.3.2a There were comparisons to IWTU ... that are not completely correct (e.g., not a 1:1 comparison because of the differences...).		Volume II Appendix D	FBSR 1A/B §2.4.2 §3.1.1.1 Examples: 1-to-1 comparisons were not made (ICP SMEs).
Added value could be given to the report if it is corrected with respect to the original information from IWTU reports.		Volume II Appendix D	FBSR 1A/B §1.2.1.3 §3.1.1.1.2 ICP SME factual accuracy review. Typo – TO not Carbon Reduction Reformer. TO used in our evaluations (Figure 3.3-3).
TO = “Thermal Oxidizer”			
3.3.2b Table B1.2 makes the statement “Iodine performance in the final waste form is unknown.” The fate of iodine is discussed in the reports SRNL-STI-2011-00387 and in SRNL-STI-2011-00383 and leaching information is given.		Vol I, App B Vol II, App D	Table B.1.2 FBSR 1A §1.1.2.1.1 §1.2.2.1 Changes made to indicate fate of iodine in waste form is not “unknown” but “uncertain.”
		Volume II Appendix D	FBSR 1A §2.4.4.1 §3.1.1.1, FBSR 1A §3.1.1.1.6 §3.1.1.2.2 Added info on circumstantial and other lines of evidence supporting structural incorporation of I & Tc.

FBSR Proposed for Hanford LAW

2. Clarifications and Improvements (cont'd)

- Clarifications related to Product Consistency Test (PCT) as it relates to long-term waste form performance.
- Clarifications related to the Risk Assessment previously performed on a single-vendor steam reforming material.
- Clarifications based on factual accuracy review by Idaho Completion Project (ICP) Subject Matter Experts (SMEs) on IWTU information.

NAS Observations (summarized):		Applicable Section(s)
3.3.2d Section 1.1.2.1.1 states “PCT is not indicative of long-term IDF performance, no comparative performance exists for FBSR.” A Risk Assessment (RA) was performed on FBSR products... allowing only bounding PA calculations to be performed. PCT = “Product Consistency Test” SR = “steam reforming” UQ = “uncertainty quantification” VPC = “vapor-phase capture”	Volume II Appendix D	FBSR 1A §1.1.2.1.1 Updated text to include iodine partitioning, release rates, PCT limitations relative to long-term disposal, estimates for single-vendor SR material, lack of UQ, lack of observation of structural incorporation, circumstantial evidence elements present in same phase, evidence (VPC) of incorporation into sodalite cage.
3.3.2g Many of the issues at IWTU were due to INEEL personnel choosing the internal components (including choice of materials of construction), rather than THOR Treatment Technologies (TTT)... ICP = “Idaho Completion Project” SME = “Subject Matter Expert” FA = “factual accuracy” IWTU = “Integrated Waste Treatment Unit”	Volume II Appendix D	FBSR 1A/B §2.4.2 Consulted with ICP SMEs to perform FA review (IWTU). Updated: material selection (by design team working with TTT); root cause of IWTU delays (lack of technology maturation and inadequate pilot testing program not assumed for FBSR for evaluation).

FBSR Proposed for Hanford LAW

2. Clarifications and Improvements (cont'd)

- Corrected typo related to the FBSR LAW process that would use Thermal Oxidizer (TO) and not Carbon Reduction Reformer (CRR). TO was used in our evaluations.
- Clarifications related to the representativeness of the testing performed relative to expected variability and uncertainty in Hanford LAW.
- Corrections made as to use of alumina as a startup bed material (not an additive) and clay addition relative to alumina in feed (next page).

NAS Observations (summarized):	Applicable Section(s)	
3.3.2h Likelihood of successful mission when considering FBSR 1A. Relevance to the IWTU lessons learned is not exactly a 1:1 comparison. TO = “Thermal Oxidizer” CRR = “Carbon Reduction Reformer” There are disagreements to 3.1.1.1.6 that states “Only limited work has been done on variability and consistency of the granular waste form” and ends with “high consequences that waste form leaches radionuclides.” ... LAW = “Low-Activity Waste”	Volume II Appendix D	FBSR 1A/B §3.1.1.1. See previous response. 1-to-1 comparisons were not made (FBSR 1A/B §2.4.2 and §3.1.1.1). Corrected typo (CRR→TO) for Hanford. TO used in evaluations.
	Volume II Appendix D	FBSR 1A §3.1.1.1.6. Clarified text, including lack of designed studies, inadequate representation of variability and uncertainty in LAW, inferred structural incorporation that could be resolved.
3.3.2i Alumina is listed as an additive; however, it is a startup bed requirement. No alumina is added during the process, only clay. The DMR is not usually idled, and product can be recycled instead of adding excess alumina....	Volume II Appendix D	FBSR 1A/B §2.2.1.2 §2.2.1.3 Revised text -- alumina as startup bed material.
	Volume II Appendix D	FBSR 1A/B §3.1.1.2.2 Revised text -- clay content/type adjusted for alumina in feed.

FBSR Proposed for Hanford LAW

2. Clarifications and Improvements (cont'd)

- No change based on “excess clay” comment.
- Clarifications based on needs for product control system.
- Clarifications and improvements based on factual accuracy review by ICP SMEs.
 - Typo: Thermal Oxidizer (TO) not Carbon Reduction Reformer (CRR) for Hanford.
 - Shutdown and startup timing estimates.
- Additional ICP SME Comments:
 - Clarified FBSR 1A/B §3.1.1.2.3 for benefits of IWTU lessons learned for FBSR.
 - Added description to FBSR 1A/B §3.1.1.3 related to DMR idling and alumina addition.
 - Added description to FBSR 1A/B §3.3 about possible supply chain issue related to calcined coal.

NAS Observations		FFRDC Approach
3.3.2i ... disagreement with a second point in the description of the process, “excess clay ensures that off-spec product is not created.” This second bullet under 3.1.1.2.2 needs to be corrected. As it states “a composition and control model could be developed as the technology matures.” It has already been developed at SRNL and proven multiple times... UQ = “uncertainty quantification”	Volume II Appendix D Volume II Appendix D	Unknown. Section not indicated. No mention of “excess clay” is made in the draft FFRDC report. FBSR 1A §3.1.1.2.2 Clarified text, including what would be needed to develop a defensible product control system (solid phase analyses, UQ, etc.) where MINCALC™ is reasonable starting point.
3.3.2o ... All units use a CRR not a TO which would eliminate the need for propane, natural gas and/or fuel oil. The sections following 3.1.1.3 also have many incorrect statements about a cold shut down requiring 1-2 days. TO = “Thermal Oxidizer” CRR = “Carbon Reduction Reformer”	Volume II Appendix D Volume II Appendix D	FBSR 1A/B §1.2.1.3 §3.1.1.1.2 Corrected typo – Hanford would use a TO. Evaluations used TO. FBSR 1A/B §3.2.3 Revised text based on ICP SME input for shutdown: 2-3 days from operation to cold shutdown (TO versus CRR). Startup ~1-2 weeks reasonable.



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Off-Site Disposal and Transportation Description

Elena Kalinina, Ph.D.

Principle Member of Technical Staff, SNL
Transport & Offsite Disposal Lead

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



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Changes since April 2022 FFRDC Report DRAFT

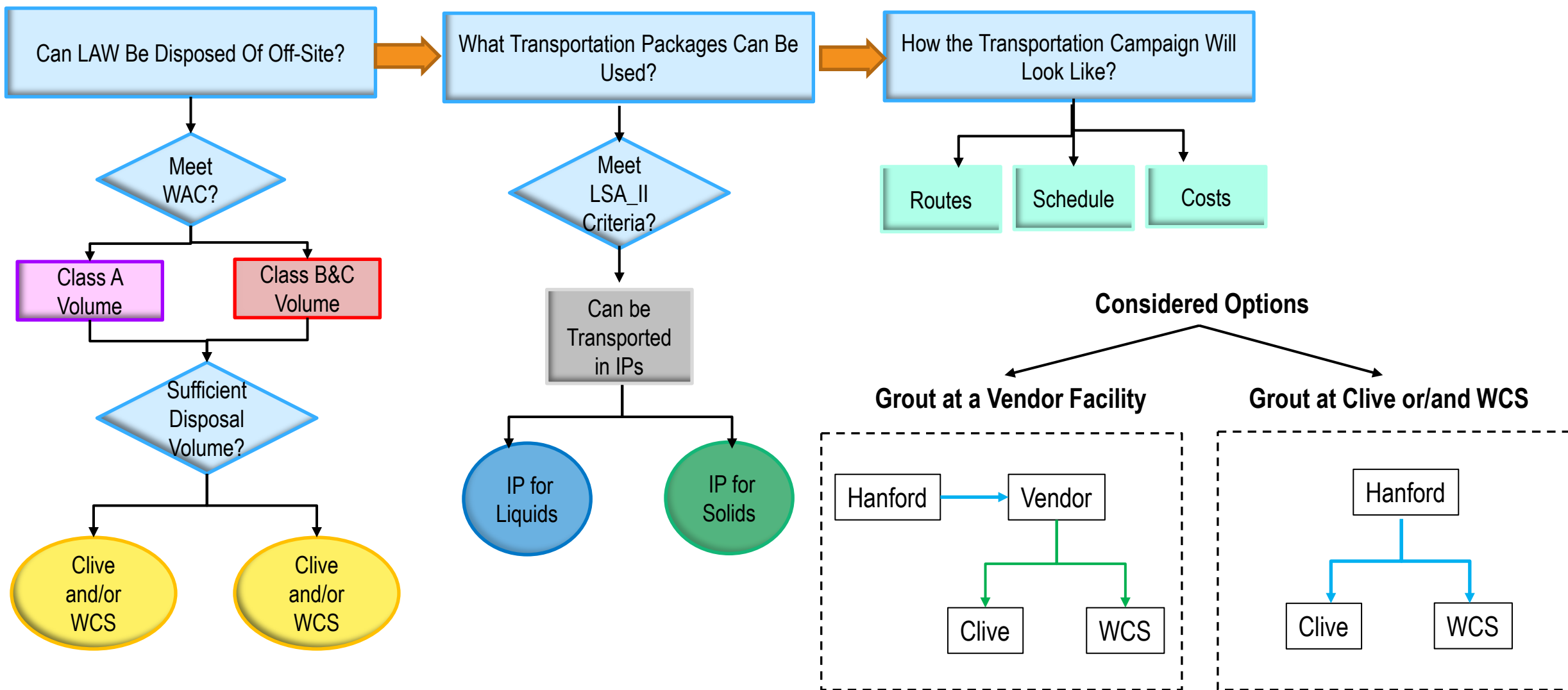
NAS Recommendation (summarized):	Applicable Section(s)
E: Expand considerations of consequences of potential impediments; such as unacceptable disposal offsite or onsite	Volume II § H.13
H: Address implications of using monthly averages of pre-treated liquid SLAW when dose limits are on a tanker-by-tanker basis	Volume II, § H.10
I: 1. Describe how tanker dose rates were calculated. 2. Reconcile inconsistency between using shielding to meet limit at 3 m with statement that is prohibited.	1. Volume II, § H.5.3. 2. Volume II, § H.5.3.

Topics

- Waste Acceptance Criteria
- Waste Class Determination
- Class A, B, and C Volumes
- Low Specific Activity (LSA) Concentration Limits
- **Non-fissile Materials Exempt**
- LSA A2 Values per Conveyance Limit
- **External Dose Limit**
- Proposed Transportation Packages for **Liquids** and Solids
- Transportation Schedule
- Transportation Routes
- Off-Site Transportation and Disposal Costs
- **Feed Vector Uncertainties**
- Programmatic Risks
- EnergySolutions Waste Disposal Facility in Clive, Utah
- Waste Control Specialists (WCS) Waste Disposal Facility near Andrews, Texas
- Summary

New topics are shown in
blue font.

Off-Site Transportation and Disposal Decision Flowchart



IP – Industrial Packages

Waste Acceptance Criteria (WAC) for Disposal

Radiological Criteria for Long-Lived Nuclides - same for Clive and WCS

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

WAC are the criteria the waste must meet to be accepted for disposal

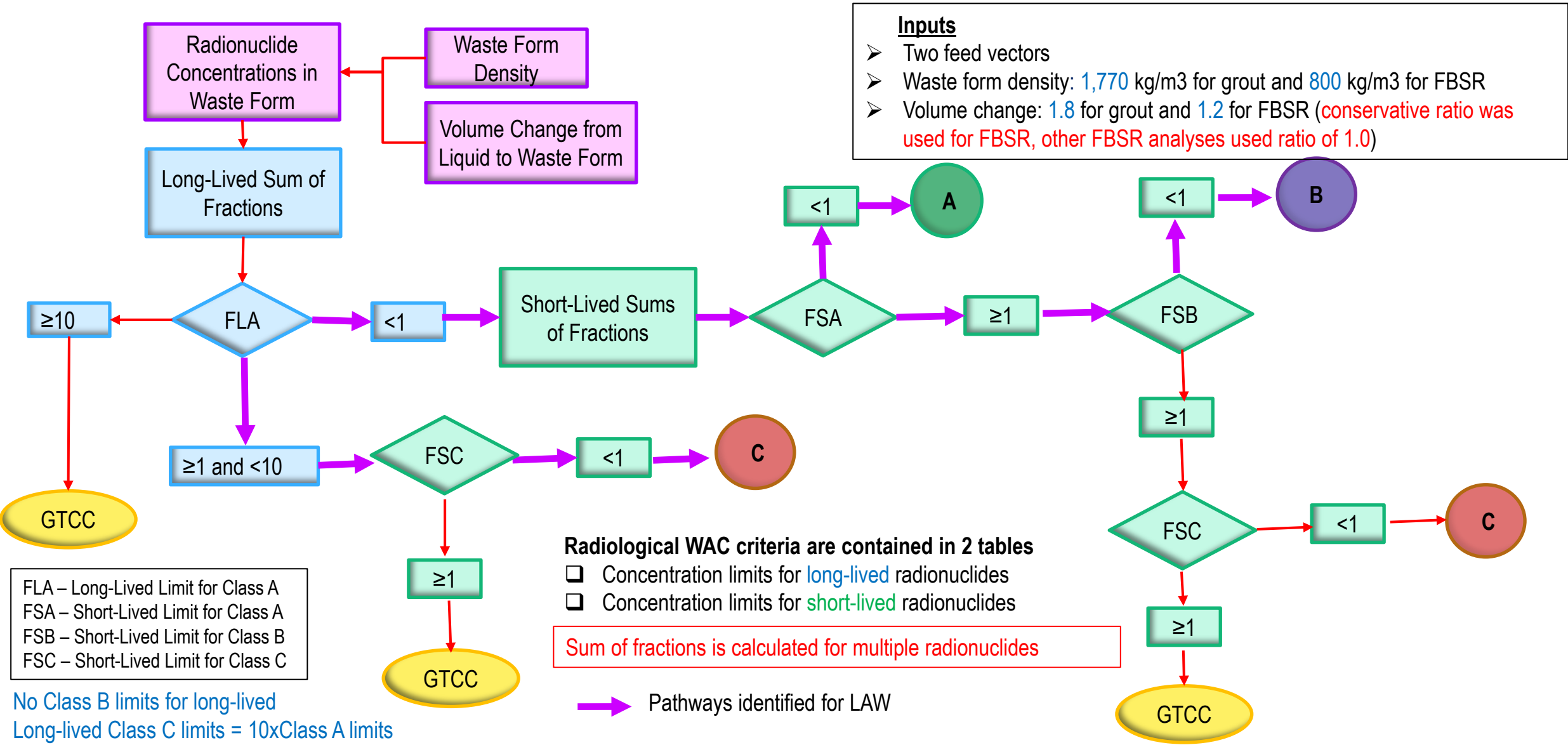
- WAC based on many factors (Criteria to protect intruder, NRC's Branch Technical Position on Concentration Averaging, operational considerations, license requirements, criteria to ensure characteristics of actual wastes are consistent parameters used to model long-term site-specific performance)

Radiological Criteria for Short-Lived Nuclides – same for Clive and WCS

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

- Each limit is the full limit
- If multiple nuclides, then **sum of fractions** must be used

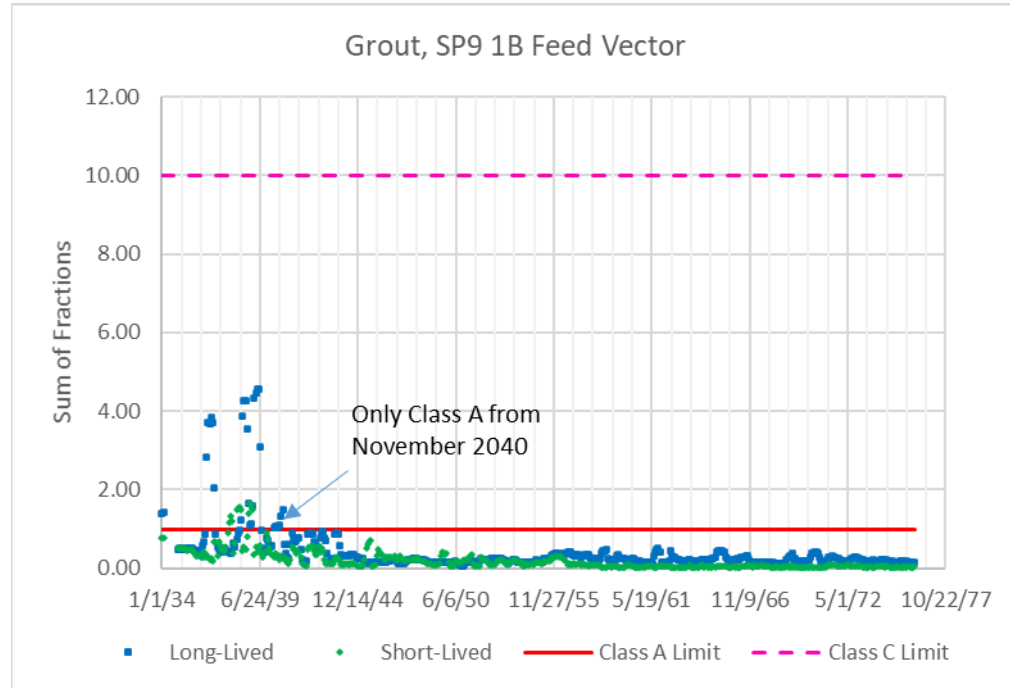
How the Waste Class Determination Was Done



Sum of Fractions for Grout Alternatives

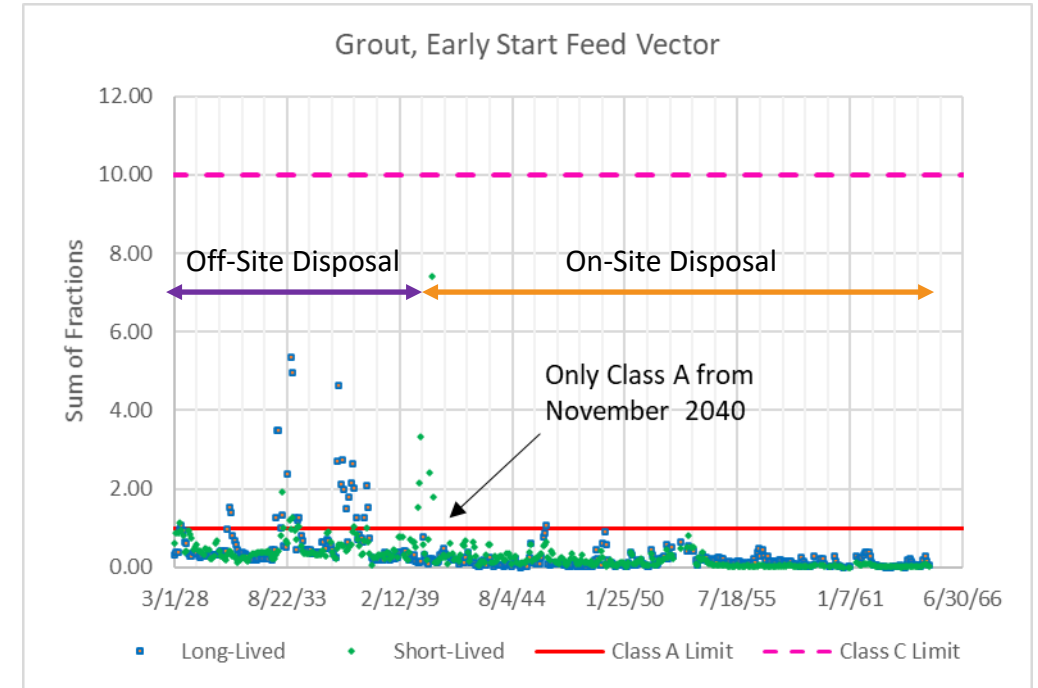
Sum of Fractions for Grout 4B Alternative

90% Is Class A



Sum of Fractions for Grout 6 Alternative

83% Is Class A (93% if All Disposal is Off-Site)



Assumptions:

- 99% of Cs-137 and Sr-90 is removed by treatment

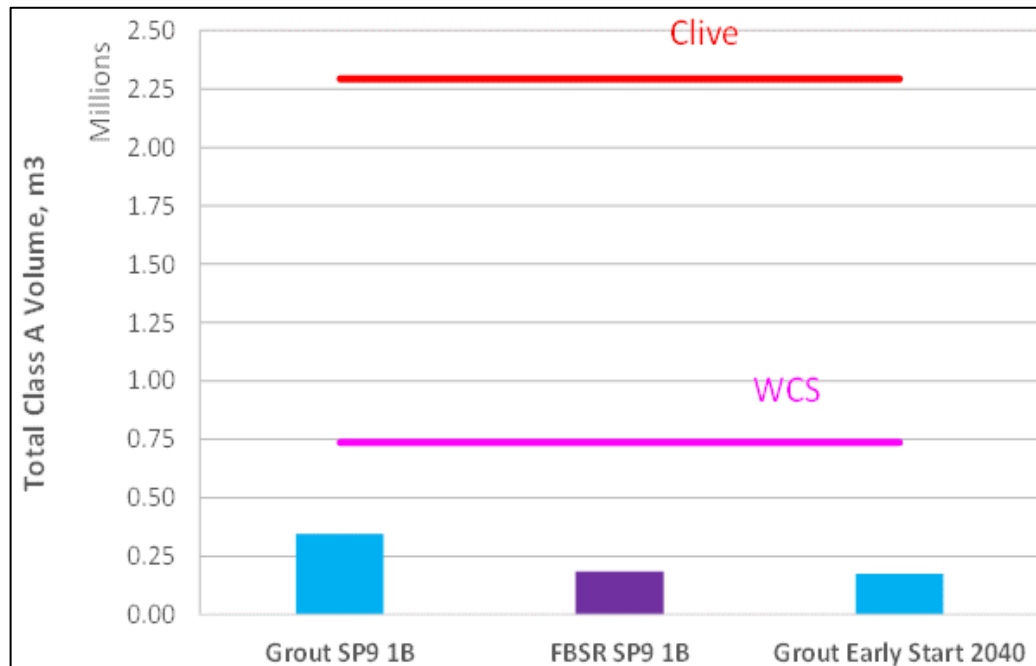
Conclusions

- The sum of fractions are significantly below the Class C limit.
- The Class C classification is driven by Am-241 and Pu-239
- 30% increase in Am-241 and Pu-239 results in 1.2% to 1.4% increase in the combined Class C waste volume.

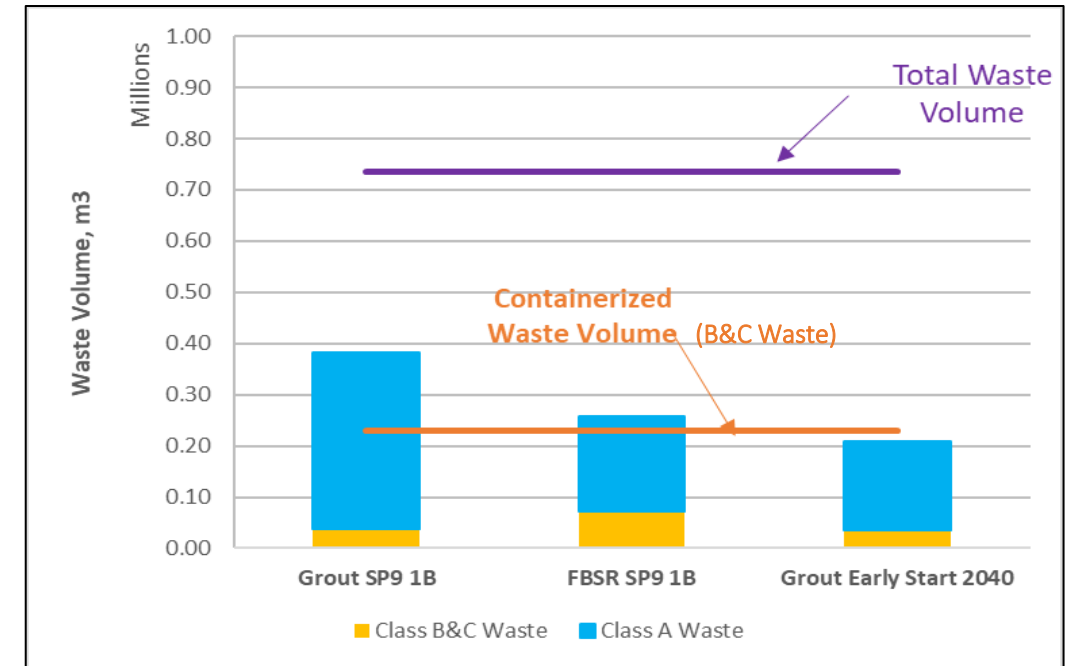
LAW Volumes Compared to the Available Off-Site Disposal Volumes

- 83% (Grout 6) and 90% (Grout 4B) is Class A waste and can be disposed off either at Clive or WCS
- The available disposal volumes at Clive and WCS are **sufficient** for disposal of all Class A waste either at Clive or WCS
- The available disposal volumes at WCS are **sufficient** for disposal of all Class A (bulk) and all Class B&C waste (containerized) at WCS
- If all Class A and B&C waste is disposed at WCS, the total activity will be 3% to 16% of the activity limit.
- In an unlikely case when onsite disposal is unavailable, all Class A waste in Grout 6 can be disposed off either at Clive or WCS and all Class A and B&C waste (0.65 M m3) can be disposed off at WCS.

Class A LAW Volume Compared to Available Disposal Volumes



Class A and B&C LAW Volumes Compared to Containerized and Total Disposal Volumes at WCS



Do Liquids, Grout, and FBSR Meet the **Low Specific Activity (LSA)** Concentration Limits?

The **Low Specific Activity (LSA)** is least hazardous category of materials with specific activity (**SA**) that satisfies the limits and descriptions set forth in **10 CFR 71.4**.

Concentration Limit Requirements

LSA-II material: Average solid **SA** < $10^{-4} A_2/g$ for solids
Average liquid **SA** < $10^{-5} A_2/g$ for liquids

Average **SA** [Ci/g] = Total Concentration [Ci/m³]/Density[g/m³]

$$A_2 \text{ for mixture} = \frac{1}{\sum_i \frac{f(i)}{A_2(i)}}$$

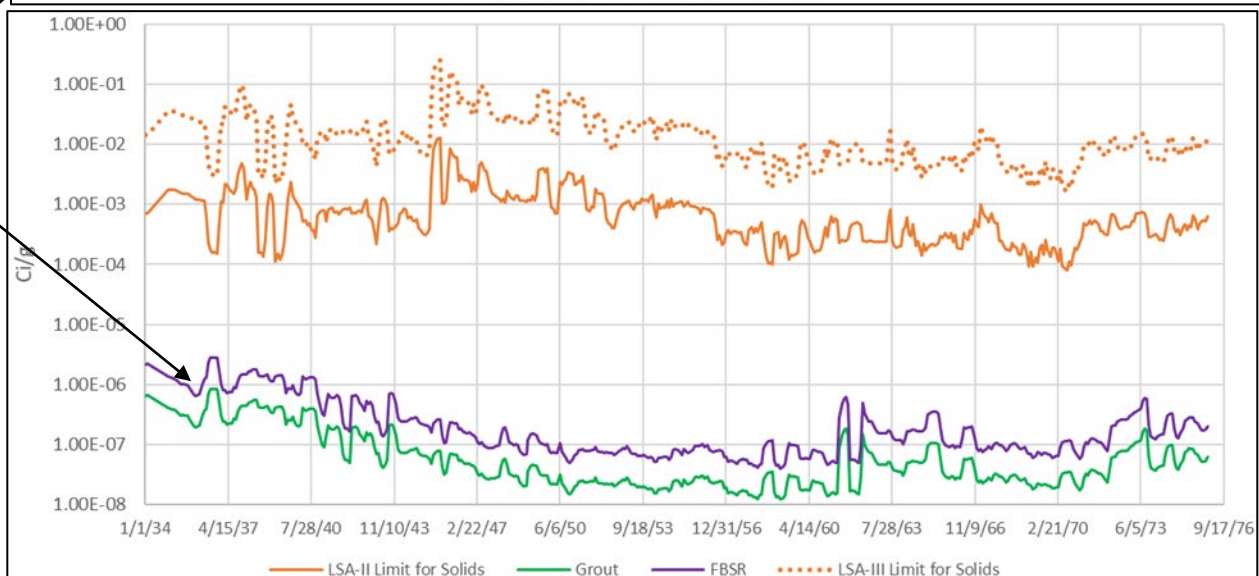
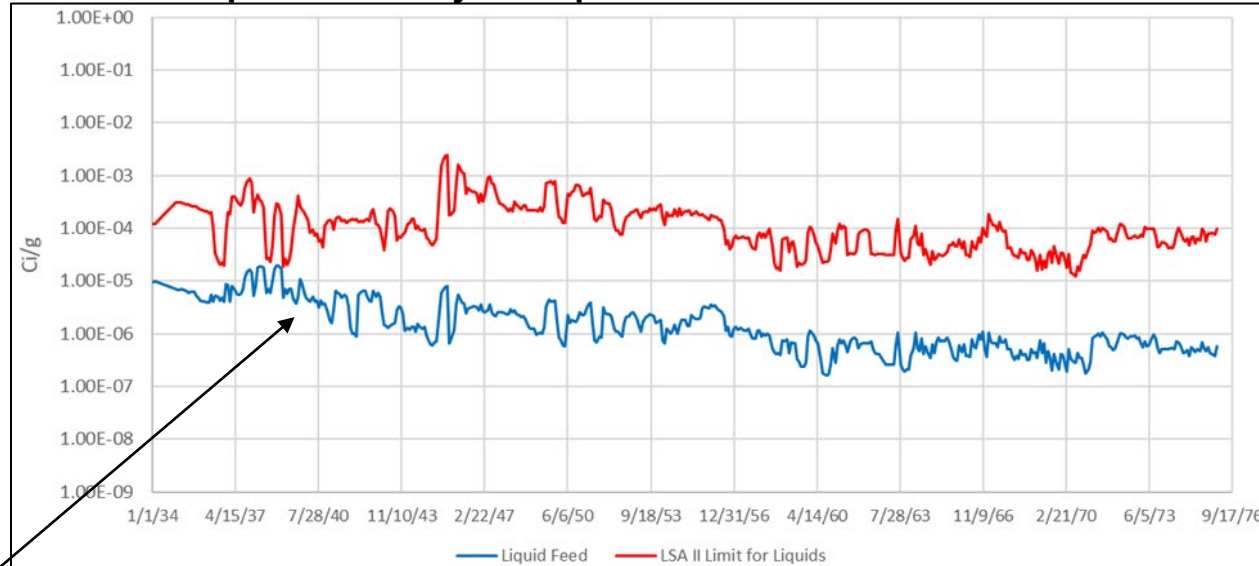
where f(i) is the fraction of activity for radionuclide I in the mixture, and A₂(i) is the appropriate A₂ value for radionuclide I.

- ❑ LSA materials may be shipped in **Industrial Packages (IPs)** that are exempt from **NRC** certification.
- ❑ IPs must meet the IP requirements.

- SA of LAW liquids is **one order of magnitude below** the LSA-II limit for liquids
- SA of grout and FBSR is **two orders of magnitude below** the LSA-II limit for solids

Meet LSA-II concentration limit

Specific Activity Examples for Feed Vector SP9 1B



Do Liquids, Grout, and FBSR Meet the **Non-fissile** Exemption and **A₂ per Conveyance** Limit?

Non-fissile Exemption (fissile isotopes: ^{233}U , ^{235}U , ^{239}Pu , and ^{241}Pu)

The LSA materials must be non-fissile or must be exempt under 10 CFR 71.15.

The grout and FBSR waste forms are exempt per paragraph (c):

(c) Low concentrations of solid fissile material commingled with solid non-fissile material.

(i). There is at least 2000 grams of solid non-fissile material for every gram of fissile material, and

The LAW liquids are exempt per:

(a) Individual package containing 2 grams or less fissile material.

The volume of liquids in a package must be limited to meet non-fissile exempt.

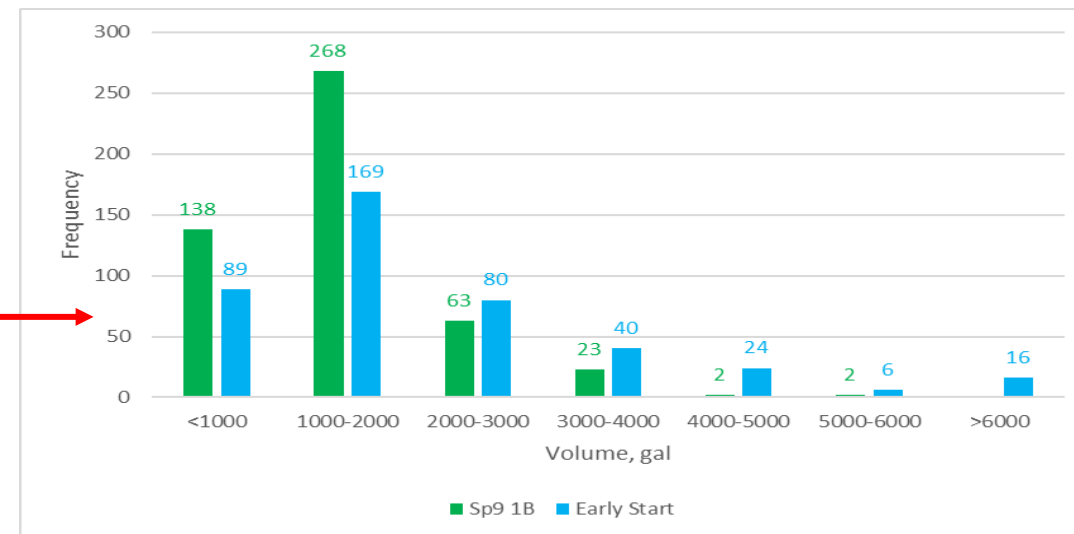
1,000 gal to 3,000 gal represents 67% (SP9 1B) and 50% (Early Start).

A₂ per Conveyance Limit

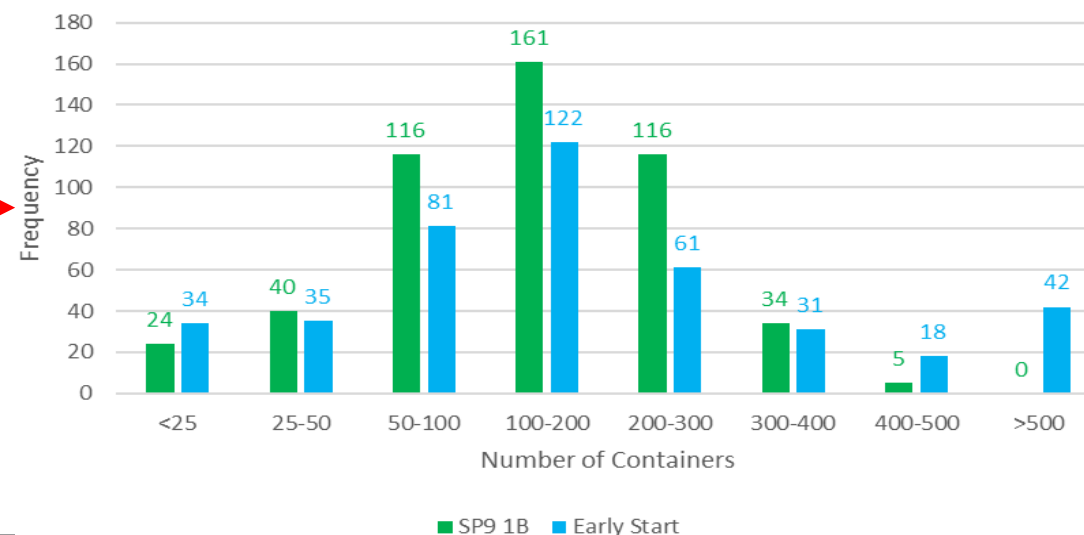
- There is no limitation on the quantity of solid materials meeting LSA II requirements for solids in a conveyance (Table 5 in 49 CFR 173.427).
- The maximum quantity in conveyance must not exceed 100 A₂ for radioactive liquids meeting LSA-II requirements for liquids.

92%-95% of the trains can carry 25 or more containers with LAW liquids without exceeding the 100 A₂ limit for LSA shipments.

Liquid Volumes Meeting Non-fissile Exempt for Liquids



Number of Containers with LAW Liquids per Conveyance



External Dose Rate Limits (Recommendation I)

➤ Per **10 CFR 71.47** the external doses must not exceed **200 mrem/hr** from the surface of the package and **10 mrem/hr at 1 m** (transport index of **10**). If these requirements are met **no other dose requirements apply**.

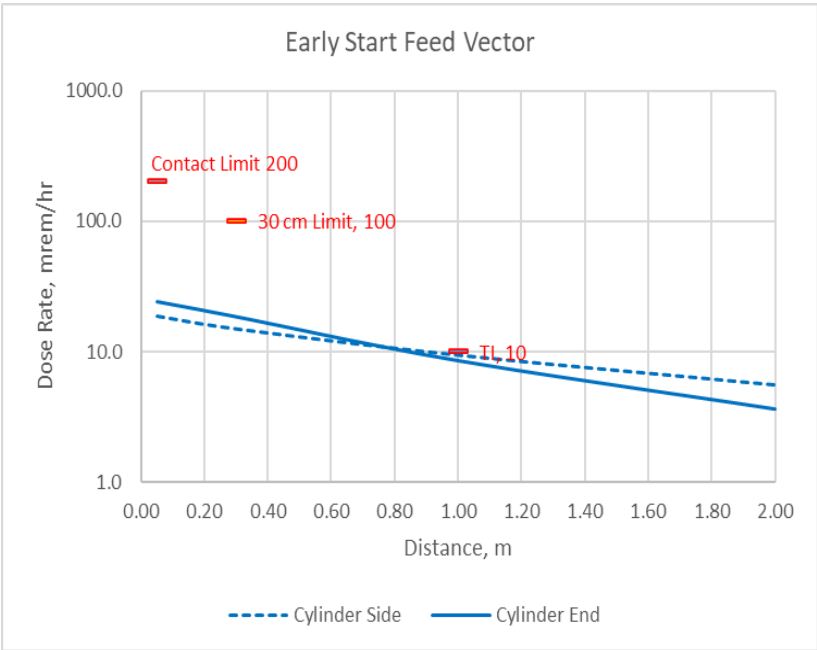
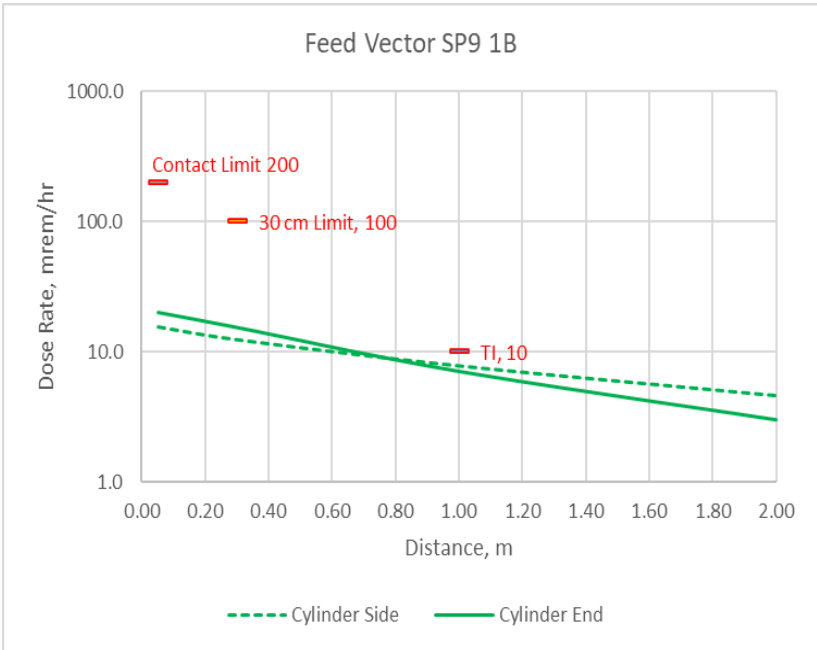
The external doses were calculated for a **5,000** ISO tank with radioactive LAW liquids.

Max concentrations of radionuclides in the feed vectors were used, except for the ¹³⁷Cs in the Early Start feed vector (94th percentile was used).

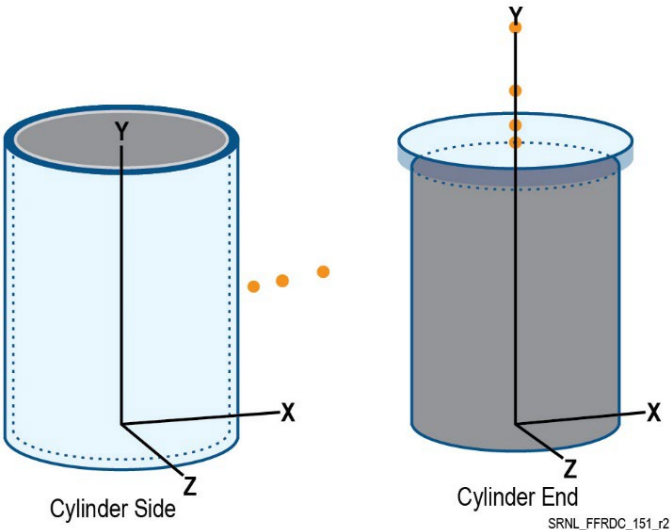
- ❑ The max external dose rates are below the limits in all the cases.
- ❑ The main contributors are ¹³⁷Cs (89%); ¹⁵⁴Eu (7%–9%); and ⁶⁰Co (1%–4%).

If liquids meet the dose limits, then grout and FBSR will also meet them (dilution and self-shielding)..

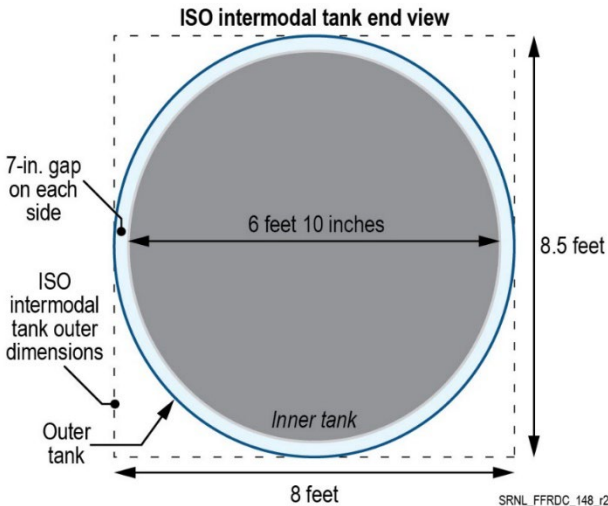
Maximum External Dose Rates



ISO Tank Geometry in MicroShield



ISO Tank Schematic



Proposed Packages

➤ DOT requires that LSA materials be transported in packages meeting Type IP-1, Type IP-2 or Type IP-3 packaging criteria (49 CFR 173.411).

LSA-II solid materials and liquids can be shipped in packages meeting Type IP-2 and IP-3 criteria

Proposed Package for Liquids ISO Tank

Per 49 CFR 173.411(4), portable tanks (ISO) may be used for IP-2 or IP-3.

ISO tanks (4,000 to 6,000 gal) are:

- Built based on ISO standards
- Inspected and certified
- Supplied with container safety certificate from manufacturer
- Completed with liner/protective coating inside the container for reactive cargo
- Capable of withstand extreme pressure and damage
- Able to maintain a specific temperature
- Intermodal - can be transported by truck, by rail, and by ship

ISO Containers with Radioactive Liquids Arriving at Clive (Utah)



Proposed Package for Solids – Soft-Side Container (8.4 m³)

The soft side containers:

- Are designed, tested, and certified to Type IP-2 for soil, sand, gravel, and construction debris.
- Passed all required tests under DOT 49 CFR 173.465,
- Are suitable for safe transport and disposal of radioactive materials
- Offer cost savings over traditional metal containers and wooden boxes.

Example of Soft Side Container for LSA Materials



Transportation Schedule

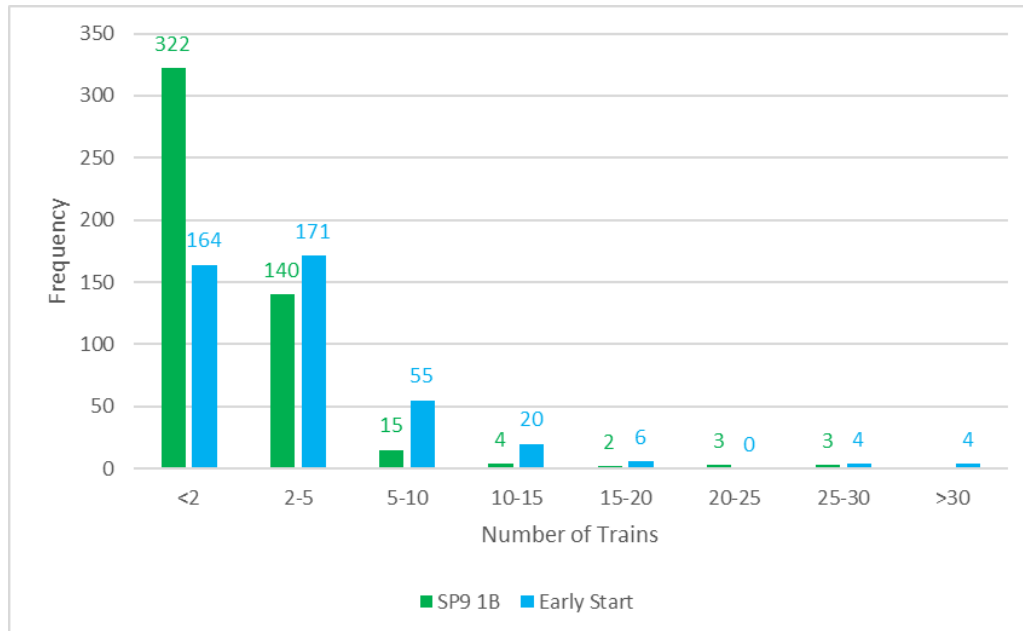
Transport of Liquids

The number of trains per month was calculated assuming:

- The ISO tank is 4,000-gal
- The volume of liquids is restricted by the non-fissile material exemption
- The number of ISO tanks in a train is limited by 100 A2.

- In **93%** (SP9 1B) and **79%** (Early Start), five trains or fewer per month will be required to transport the liquids.

Number of Trains with ISO Tanks per Month



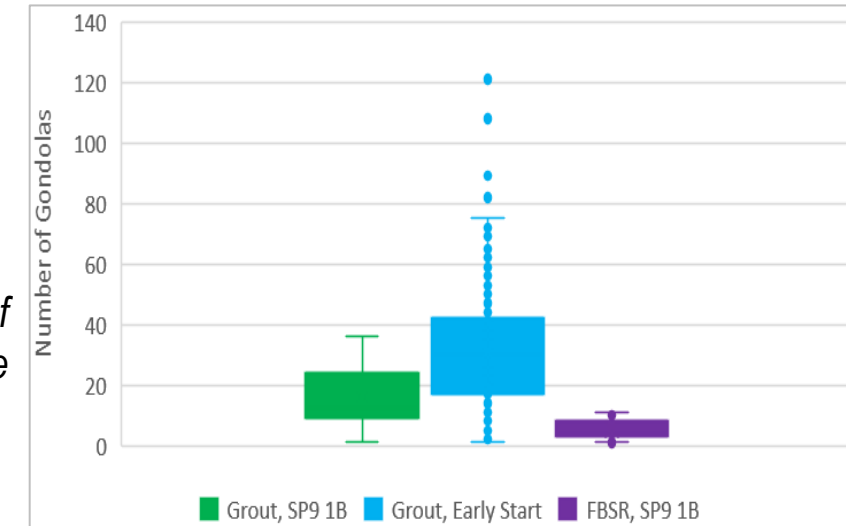
Transport of Solids

The number of gondolas per month was calculated assuming:

- 6 soft side containers of grout or 13 of FBSR per gondola
- One train per month carrying 90 gondolas would be required, except a few months in grout Early Start.

Number of Gondola per Month

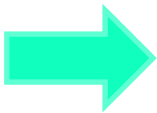
- ❖ Number of bags is limited by weight, not volume.
- ❖ Unit trains transport 90 cars of one type of freight in one car type for one destination



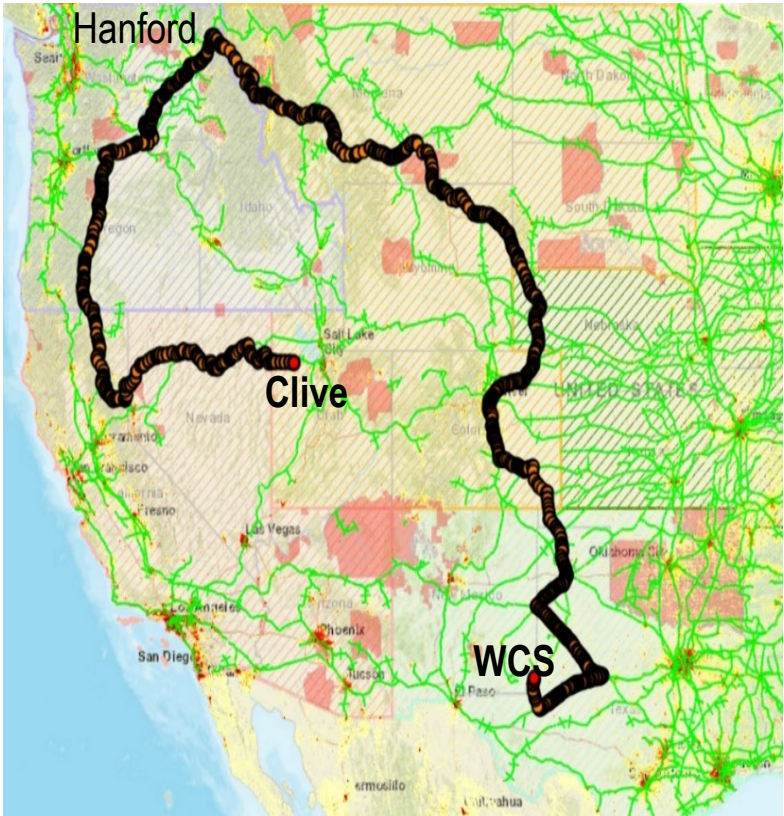
Transportation Routes to Clive and WCS

Route Characteristics

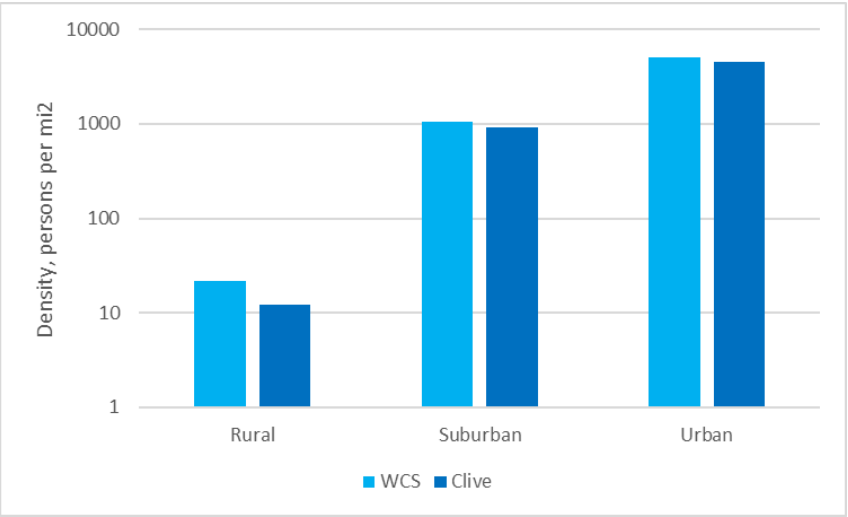
Route Parameter	Route to WCS (Texas)	Route to Clive (Utah)
Total population, persons	1,779,152	341,089
Total distance, mi	2,502.99	1,213.49
Number of states crossed	10	5
Total rural distance, mi	2,064.12	1,119.75
Total suburban distance, mi	400.95	87.84
Total urban distance, mi	37.92	5.9



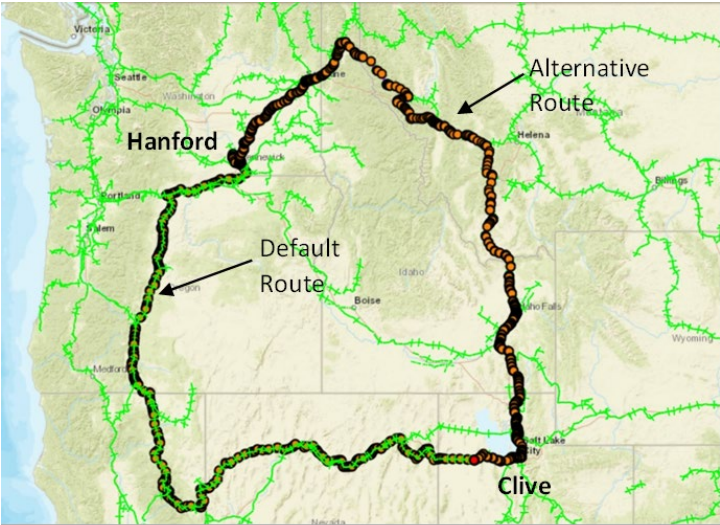
Transportation Routes to Clive and WCS



Population Densities along the Routes

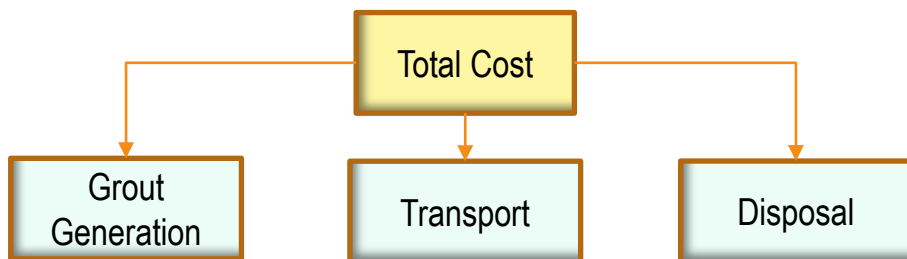


Default and Alternative Transportation Routes to Clive



Rail carriers determine routes via the use of the [Rail Corridor Risk Management System \(RCRMS\)](#), which analyzes routes based on various risk factors. The **lowest-risk routes** are chosen.

Off-Site Transportation and Disposal Costs – Liquid is Grouted at a Vendor Facility



- ❖ If grout is generated at Clive and/or WCS, the grout and disposal costs will be the same as when grout is generated by a vendor.
- ❖ Transportation will be slightly different.

Assumptions

- Class A goes to Clive and to WCS, different split fractions assumed.
- Classes B and C go to WCS

➤ The total cost is dominated by the grout generation. As a result, in “All Class A to WCS” it is only 4- 6% higher than “All Class A to Clive”

Rail Transport Costs

- \$14,000 per loaded gondola to WCS
- \$7,000 per empty gondola to Clive
- \$5,000 per empty gondola (WCS and Clive)

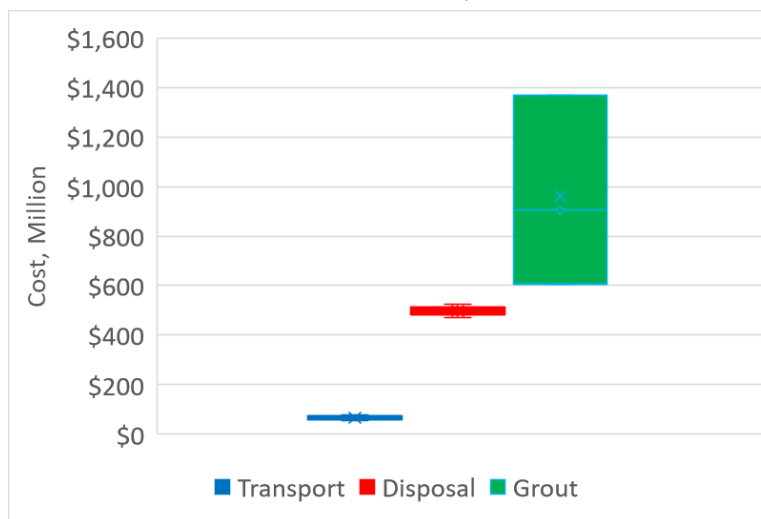
Grout Generation Costs

- \$20 per gal (industry min)
- \$30 per gal (average)
- \$45 per gal (industry maximum)

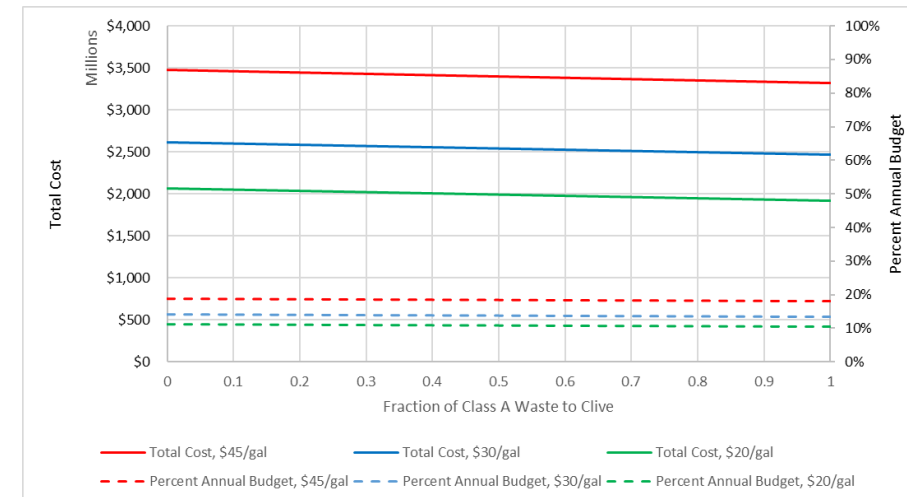
Disposal Costs

- \$1,160 per m3 Class A at Clive
- \$1,460 per m3 Class A at WCS
- \$7,830 per m3 Class B and C at WCS

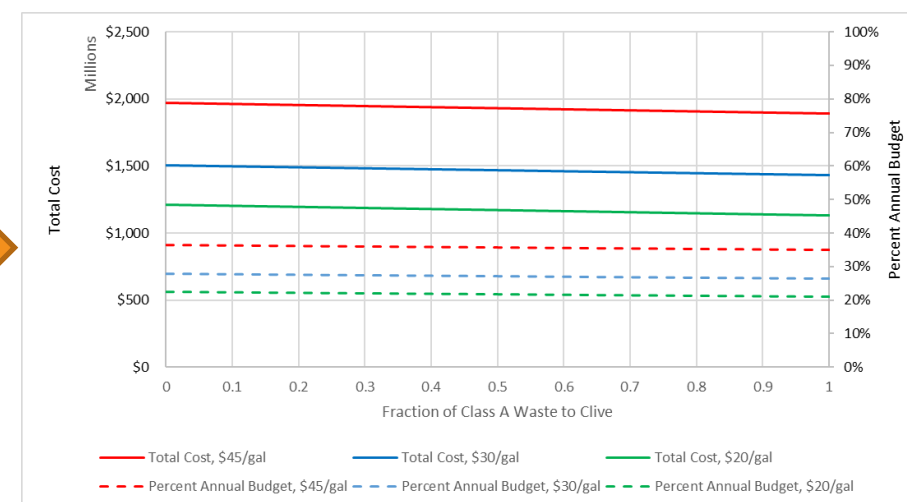
Cost Elements, Grout 6



Total Cost as a Function of Fraction of Class A to Clive Grout 4B



Grout 6



Impacts Related to Feed Vector (Recommendation H)

➤ Feed vectors describe **average** monthly concentrations of 46 radionuclides over the time of waste generation

❑ Impact on Meeting LSA-II Criteria for Specific Activity

- The SA is one order of magnitude below the LSA-II limit for liquids and 2 order of magnitudes for grout and FBSR. .
- 30% higher concentrations of ^{239}Pu and ^{241}Am results in 5.4% increase (max) in difference between LSA-II limit for liquids and SA. Even smaller impact would be for grout and FBSR.
- IAEA recently revised the A_2 values. The new A_2 value for ^{241}Am is 2 times higher and its **radiological toxicity is 2 times lower**.

❑ Impact on Meeting LSA-II Criteria for the External Dose Rates

- The external dose rates were calculated assumed maximum concentrations of radionuclides in the feed vectors.
- The ISO tank volume was 5,000 gal. The actual volumes will be smaller.
- In an unlikely event when the activity of ^{137}Cs in the ISO tank exceeds 2.3 Ci, a smaller container can be used instead.

❑ Impact on Meeting Waste Acceptance Criteria

Waste Classification Results for the Original and Sensitivity Cases

Waste Class	Feed Vector SP9 1B		Early Start Feed Vector	
	Original Case	Sensitivity Case	Original Case	Sensitivity Case
A	90.12%	88.91%	93.15%	91.72%
B	3.98%	2.64%	2.42%	1.94%
C	5.90%	8.45%	4.43%	6.34%



1.2% to 1.4%
increase in the
combined Class B
and Class C
waste

Sensitivity case considered
30% higher concentrations
of Micro Shield ^{239}Pu and
 ^{241}Am

Programmatic Risks Related to Transportation and Disposal (Recommendation E)

U.S. Department of Energy Liquid Radioactive Waste Shipments

Time period	Liquid	Volume (gal)	DOE facility	Origin	Destination	Transport mode	Purpose
2017	LLW	1,000	West Valley	NY	WCS, TX	Truck	Treatment and disposal
2012	Radiologically contaminated aqueous hydrogen fluoride	4,700	Portsmouth Gaseous Diffusion Plant	OH	WCS, TX	Truck	Treatment and disposal
2010-2020	LLW	150,000	Separations Process Research Unit	NY	Richland, WA	Truck	Treatment and disposal
Up to 2005	LLW	1,500,000	Rocky Flats	CO	Clive, UT		Treatment

- **Transportation of radioactive materials has been accomplished routinely and safely in the U.S. and in many countries around the world.**
 - DOE has extensive experience in shipping radioactive materials and in ensuring their transportation safety.
 - DOE works closely with state, tribal and local jurisdictions on transportation-related topics.
 - DOE has established a NTSF to engage at a national level with stakeholders regarding DOE's shipments of radioactive materials.

Annual Waste Volume at Clive Compared to Mean Annual Volumes of Grout and FBSR



Redundancy of two potential disposal sites with regard to ~90% of the waste

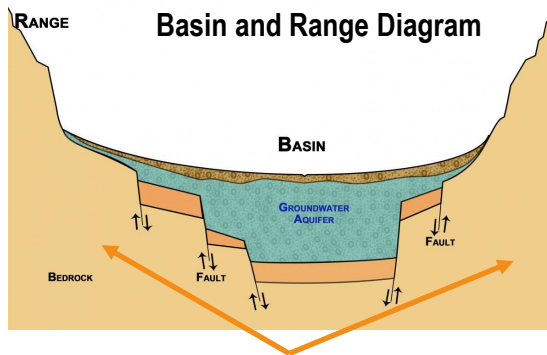
- **In the unlikely event that one of the two off-site facilities becomes unavailable**
 - Sampling and analyzing the waste to ensure compatibility with the immobilization process
 - Any waste deemed incompatible with the immobilization process is directed to LAW vitrification in a “sample-and-send” approach
 - Ensuring that off-site permits/permit modifications and agreements with off site facilities are in place prior to initiation of any on-site grouting or any shipment of liquid supplemental LAW for off-site treatment/disposal.

EnergySolutions Waste Disposal Facility in Clive, Utah

- DOE investigated 29 candidate sites for the uranium tailings disposal.
- After 8 years of characterization and evaluation, DOE selected the Clive site located in Utah's West Desert.
- The main reasons were:
 - Remote location
 - Low precipitation – 8.53 in/yr.
 - Groundwater is not potable and not suitable for irrigation and livestock
 - Low-permeability clay soils

EnergySolutions began the commercial waste disposal activities at the facility in 1988.

- The state of Utah is authorized by the NRC as an Agreement State and has regulatory authority over the Clive facility.
- In 2015, the state created the Division of Waste Management and Radiation Control (DWMRC) that has regulatory oversight over the Clive facility



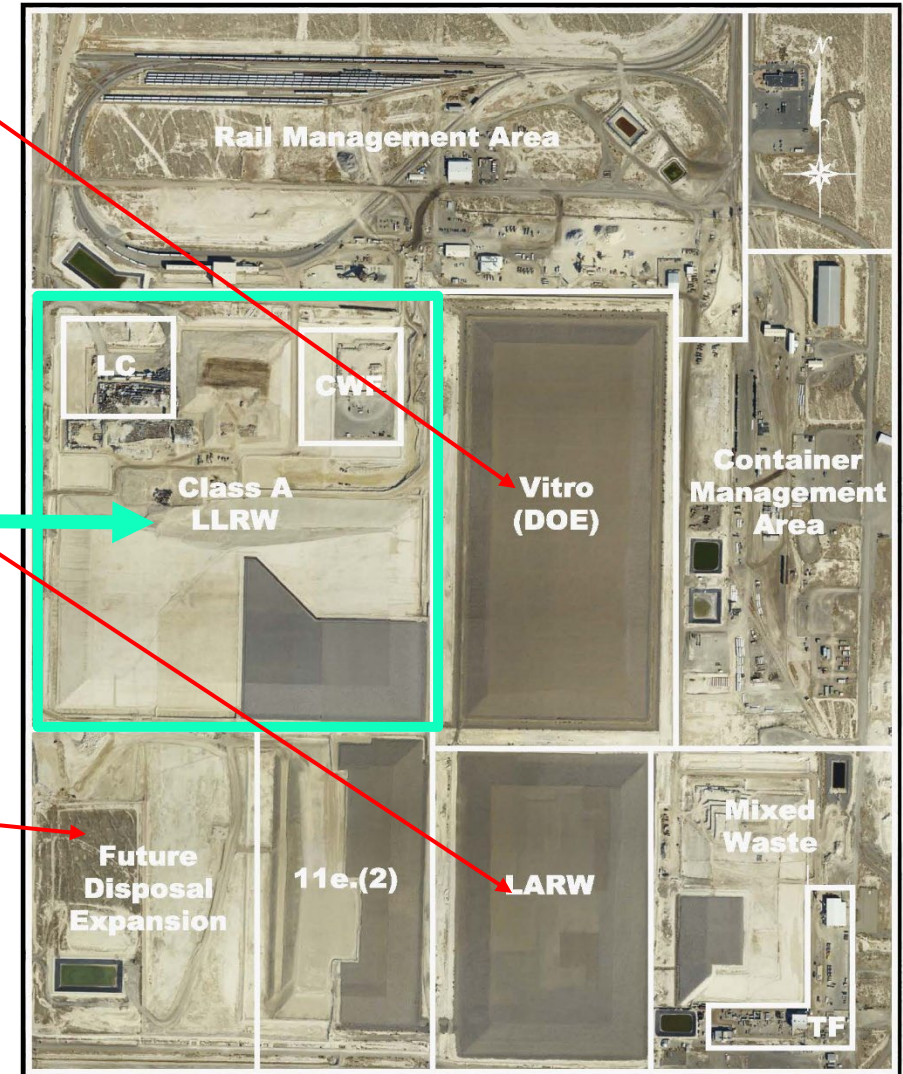
There is no groundwater flow through the ranges



Clive Disposal Embankments (Cells)

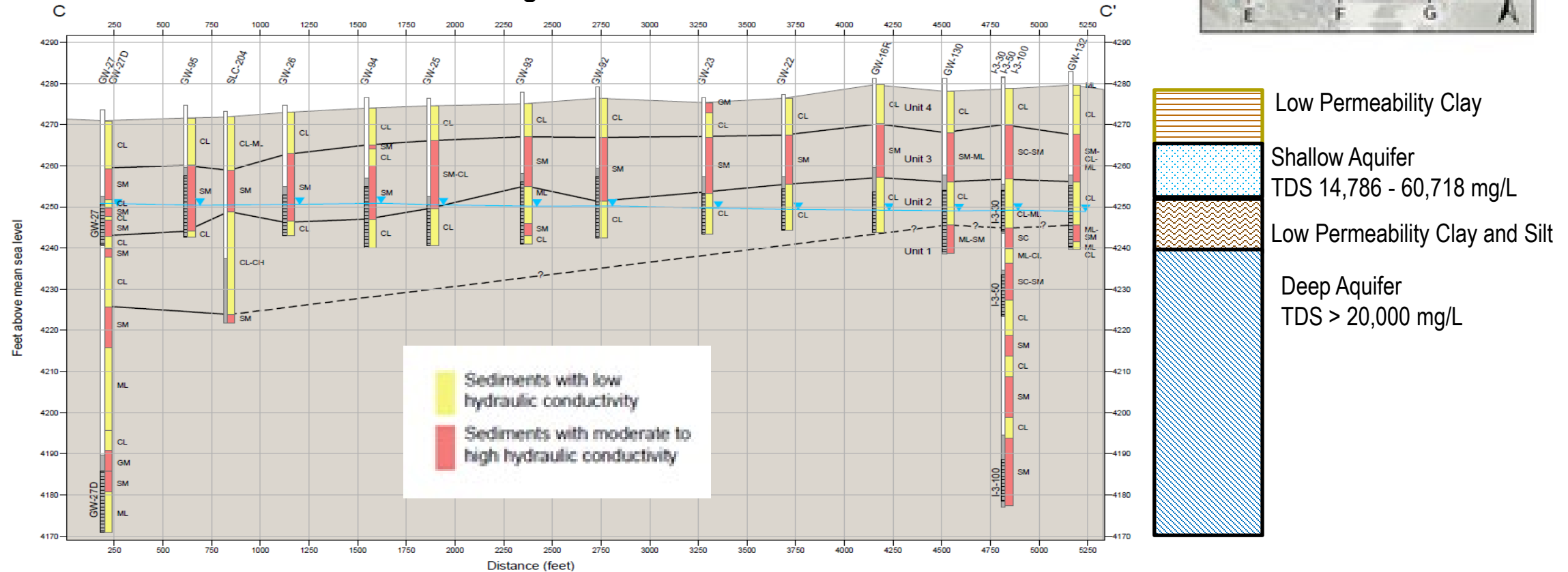
- The Vitro tailings were relocated to Clive in 1984 – 1988. This area is owned and monitored by the DOE.
- LARW embankment was closed in 2005
- At present, waste is placed in disposal cells:
 - Class A West (CAW)
 - Mixed waste
 - 11e.(2)
- The most recent amendment (2012) was to combine 2 embankments into the Class A West (CAW) embankment.
CAW is where the **LAW from Hanford** would be placed.
- The future disposal expansion will house the depleted uranium (DU) if the DU disposal license is granted.
- Clive received waste from EPA, DOE, DoD, utilities, and other commercial entities.

Clive Facility Layout



Hydrogeologic Cross-Section through the Clive Site

- Groundwater beneath the facility is classified as a **Class IV saline groundwater** (TDS > 10,000 mg/L)
- Naturally occurring concentrations of arsenic, selenium, thallium, radium, and uranium exceed EPA and Utah drinking water standards

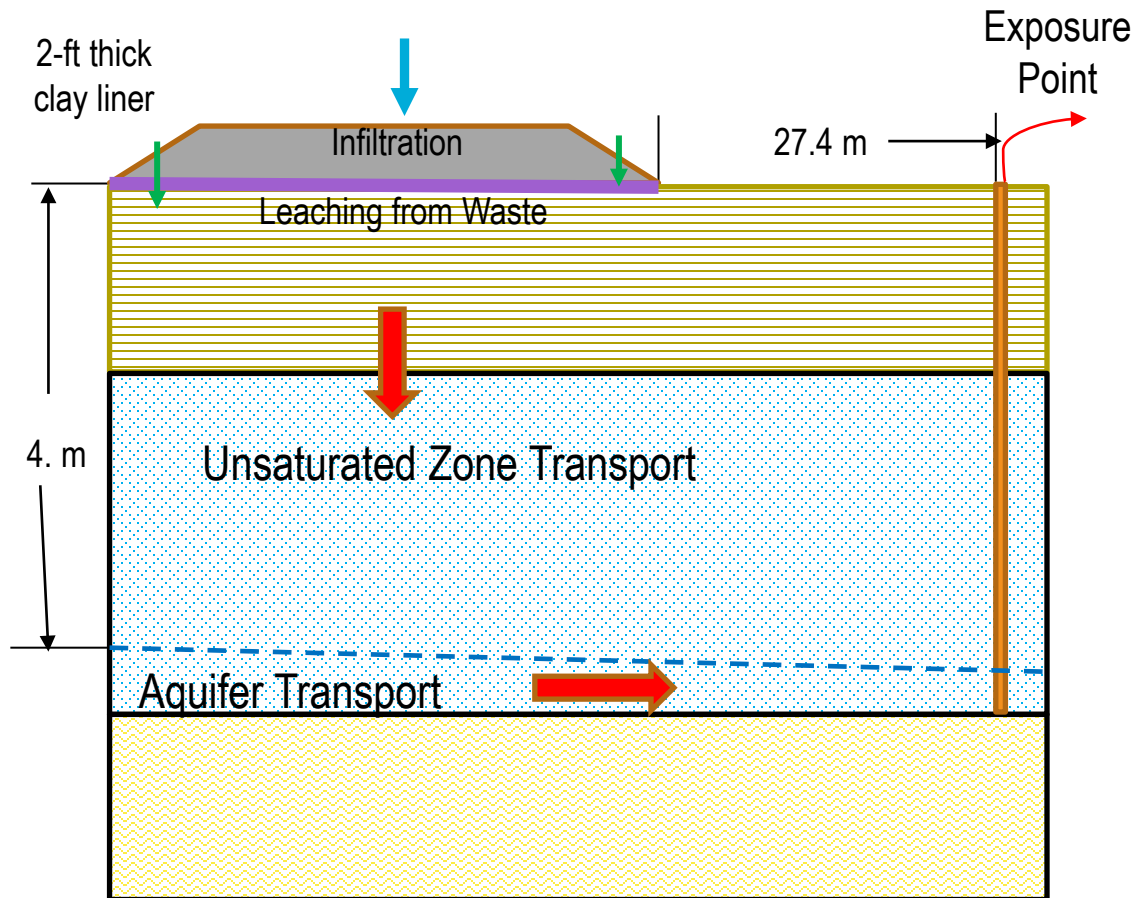


2021 Hydrogeologic Report, renewal of the EnergySolutions Ground Water Quality Discharge Permit, No. UGW450005.

Disposal Performance Assessment

- **10 CFR 61.41, Protection of the General Population from Releases of Radioactivity**
 - Concentrations of radioactive material released to the general environment in groundwater, surface water, air, soil, plants, or animals must not result in an annual dose exceeding **25 mrem** to the whole body, **75 mrem** to the thyroid, and **25 mrem** to any other organ of any member of the public.
 - *None of the exposure pathways at the site are viable because human activity at Clive has historically been very limited due to the lack of potable and irrigation water. However, the groundwater pathway was analyzed in great detail.*
- **10 CFR 61.42, Protection of Individuals from Inadvertent Intrusion**
 - Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after institutional controls are removed. The standard used by NRC and others for LLW has been **500 mrem** annual dose.
 - *Utah regulations require special provisions to protect inadvertent intruders from disposed LLRW only for Class C LLRW.*
- **Radiation hazards associated with Class A waste are such that: should intrusion into disposed waste occur following the 100-year institutional control period, doses were projected to be within acceptable limits**
- **In addition, the intruder protection is warranted by the facility remoteness from population centers, lack of resources at the site, and the embankment cover system.**

Groundwater Protection Levels (GWPL)



- Clay cover degrades immediately, and the infiltration water moves through the cover instantaneously
- Kd values (partition between sorbed and dissolved): site-specific Kd or the lowest measured soil Kd values from literature

- Groundwater protection levels (**GWPL**) must be met per Ground Water Quality Discharge Permit (GWQD).
- The radionuclide concentration limits must not be exceeded for at least 500 years following closure of the facility.



*The groundwater pathway was analyzed to provide evidence that concentrations in the compliance monitoring well are below the **GWPLs***

- Groundwater model evaluated **260** radionuclides and **13** metals. **92** radionuclides and **7** surrogates were explicitly modeled
- **Results**
 - None of the **99** radionuclides exceeded the **GWPLs** at the water table within 500 years
 - **16** radionuclides exceeded the GWPLs at the water table at some time after 500 years and their transport in the shallow aquifer was modeled.
 - All radionuclides modeled would remain below the **GWPLs** at a compliance well.
 - None of the metals would arrive or exceed **GWPLs** at the water within 200 years compliance period established for heavy metals

Waste Control Specialists (WCS)

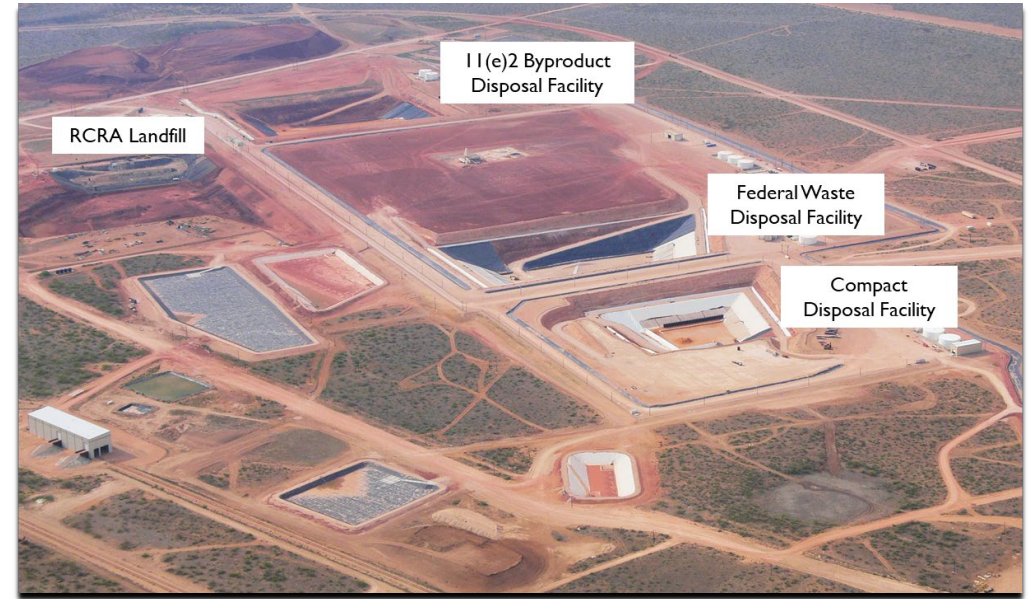
- Commercial facility operated by Waste Control Specialists LLC
- Located in west Texas (near Andrews)
- Sparsely-populated area
- Semi-arid climate: rainfall 16 in./yr, evaporation 60 in./yr
- Underlain by 600-foot thick low permeability red-bed clays
- No potable groundwater beneath the site
- Licensed by Texas, an NRC “Agreement State”
- Licensing process took 5 years (August 2004 - September 2009)
- Licensed for Class A, B & C LLW and Class A, B & C MLLW
- Received first Federal LLW shipment in 2012

Federal Waste Disposal Facility (FWD)

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

If all Class A, B, and C is disposed at FWD, the total activity will range from **480,000** to **1,390,000 Ci** (**9%** to **25%** of the limit) depending on alternative.

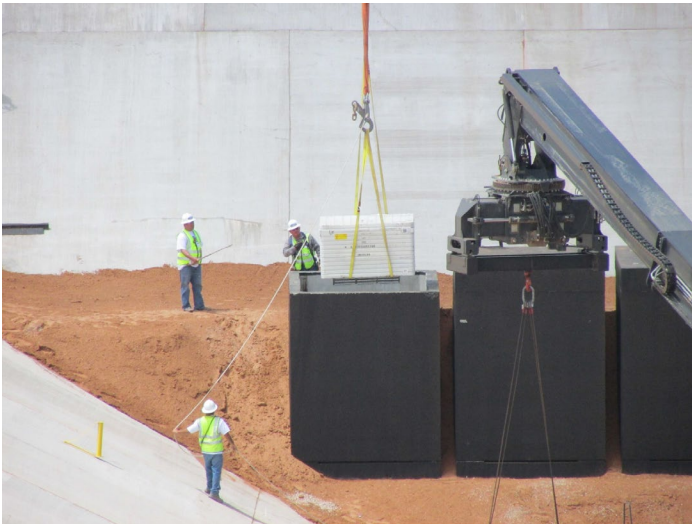
WCS Site Layout



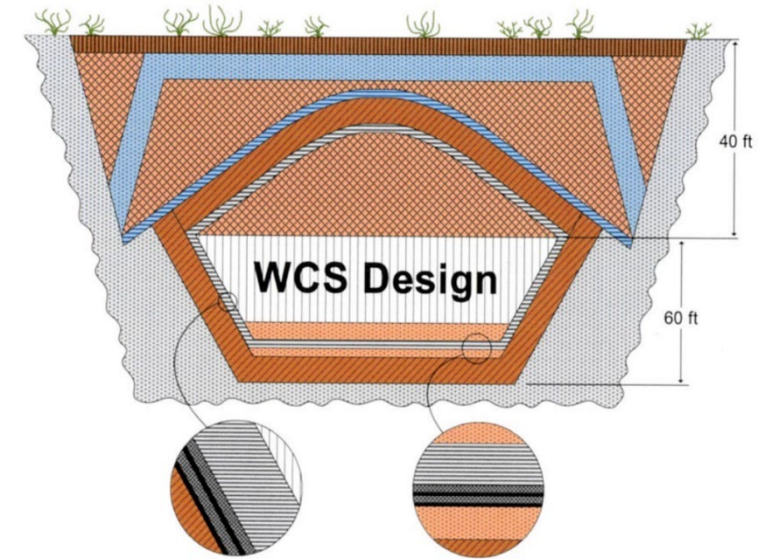
Design of Federal Waste Disposal Facility

- Wastes are emplaced **25 to 45 ft** (~8 to 14 m) below the land surface
- Natural barrier:
 - **600 ft** thick low permeability red clay with hydraulic conductivity ~ 1×10^{-9} cm/s (for comparison, concrete is 1×10^{-10} cm/s)
- Engineered barriers:
 - 7-ft (2-m) thick, multi-layer liner (11.8 in. (0.3 m) reinforced concrete + RCRA compliant geosynthetic layer)
 - Class B and C-wastes disposed in modular concrete containers (MCCs)

Rectangular MCC



The MCCs are 6-in. (150 mm) thick, steel-reinforced concrete containers.

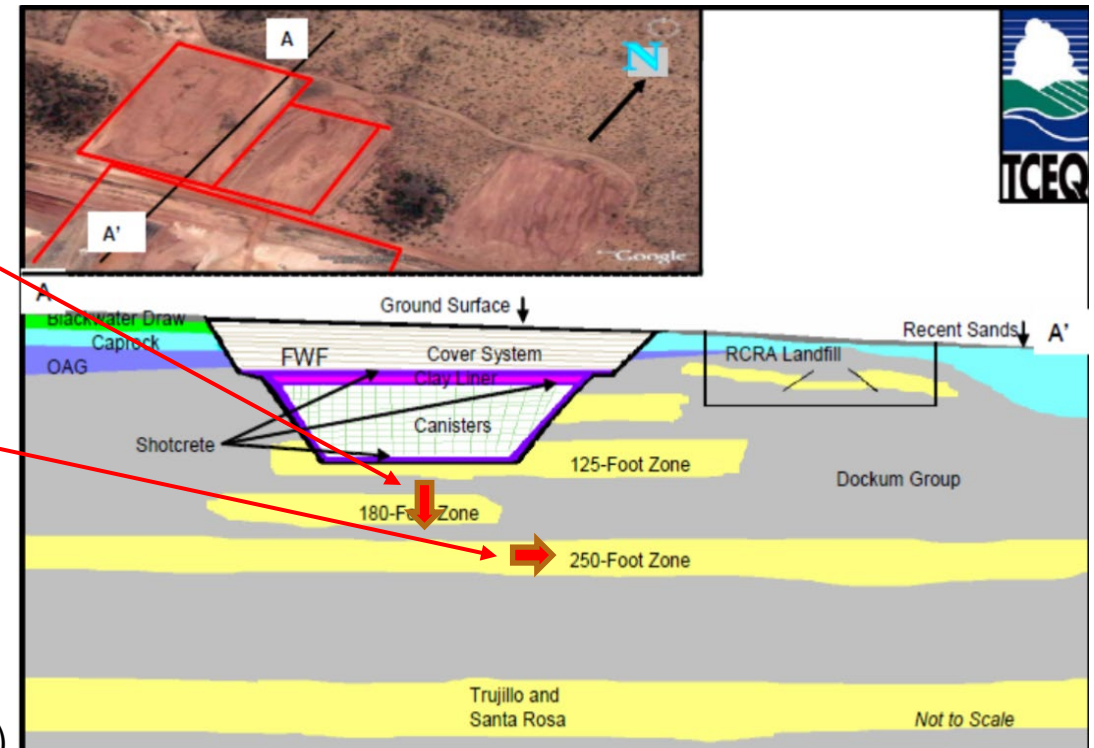


Legend	
	Undisturbed Ground
	Clay Liner (10^{-9} cm/s H.C.)
	Clay Liner (10^{-7} cm/s H.C.)
	Protective Soil/Sand
	Geosynthetic Liner
	Concrete Liner
	Low Level Waste
	Leveling Fill
	Biointrusion Layer
	Drainage Layer
	Evapotranspiration Layer

Groundwater Pathway

- In the updated 2011 PA the groundwater pathway dose was determined to be zero.
- Downward flow in the unsaturated red clay:
 - Current climate conditions: 0 to 0.02 mm/yr
 - Future-climate conditions: 0.01 to 0.3 mm/yr
- 225-foot zone
 - First from the surface
 - laterally continuous saturated zone
 - Low permeability sandstone and siltstone
 - Yield insufficient to support a household or for livestock in a year
 - TDS from 3,800 to 4,700 mg/L, not potable water
- Performance Assessment (PA) Assumptions
 - Groundwater is withdrawn from a well at the edge of the disposal facility
 - Water is used for drinking and livestock watering (although not; for conservatism)
 - The water is assumed to be potable (although not; for conservatism)
 - The total withdrawal includes the 225-ft zone yield and the additional water needed to support a household from an uncontaminated external source (although not; for conservatism)

Conceptual Cross Section of the WCS FWF



Source: TCEQ 2008, Figure EA-4

225-foot zone is called 250-foot zone in the source figure and 225-foot zone elsewhere

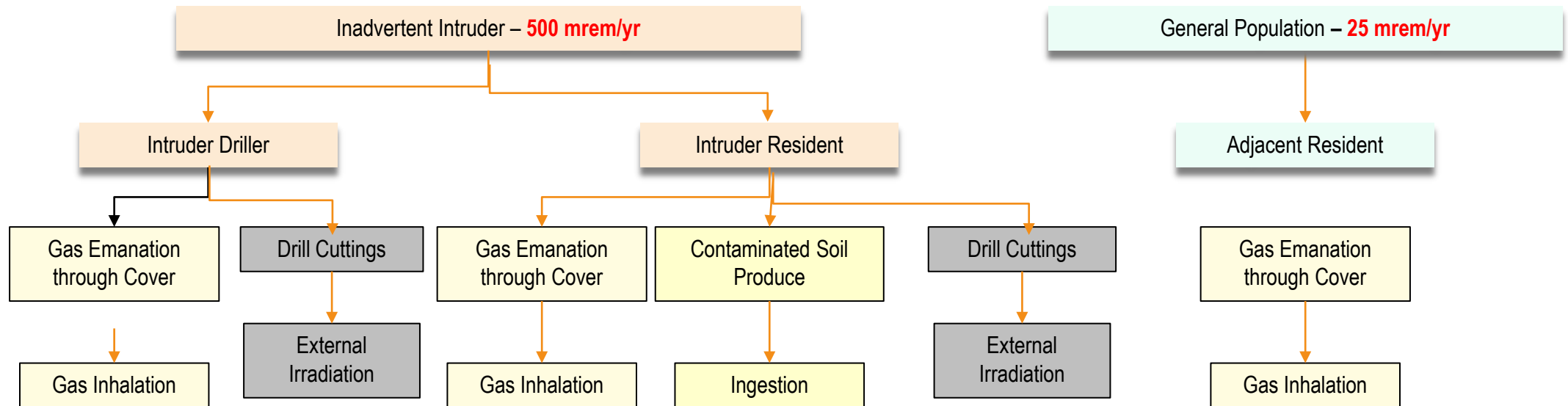
Key Exposure Pathway and Timing of Peak Doses

- **Per 30 Texas Administrative Code §336.709 (1)** “A minimum period of 1,000 years after closure or the period where peak dose occurs, whichever is longer, is required as the period of analysis”.
 - Peak dose of 0.009 millirem per year at 564,000 years is driven by Ra-226

Timing of Peak Doses

Decay Classification	Transport Classification	Radionuclide Example	Time of Peak Dose with No Waste Intrusion (years post-IC)	Time of Peak Dose with Waste Intrusion (years post-IC)
Short-lived	Low mobility	⁹⁰ Sr, ¹³⁷ Cs	N/A	0
Short-lived	High mobility	³ H	0-100	0-100
Long-lived	Low mobility	⁷⁹ Se	1,000,000+	10,000-100,000
Long-lived*	High mobility	¹²⁹ I, ¹⁴ C	10,000-100,000	1,000-10,000
Long-lived	High mobility	⁹⁹ Tc	100,000-1,000,000	100,000-1,000,000
In-growth	High mobility	²²² Rn	1,000,000+	1,000,000+

Key Exposure pathway



Summary

- 83% (Grout 6), 90% (Grout 4B), and 72% (FBSR 1B) is Class A.
- All Class A (grout or FBSR) can be disposed of at Clive and/or WCS based on the available disposal volumes for bulk waste.
- All Class B&C (grout or FBSR) can be disposed of at WCS based on the available containerized disposal volume.
- All Class A and B&C (grout or FBSR) can be disposed of at WCS based on the available containerized and bulk disposal volumes and total Ci limit.
- In an unlikely case when onsite disposal is unavailable, all Class A and Class B&C in Grout 6 can be disposed off-site
- Grout, FBSR, and liquids meet all LSA-II criteria and can be transported in IPs - soft-sided containers (grout/FBSR) and ISO tanks (liquids).
- Grout and FBSR have no limitations related to non-fissile exemption and A_2 per conveyance. Liquids have both limitations.
- In 93% (SP9 1B) and 79% (Early Start), five trains or fewer per month will be required to transport the liquids.
- One train per month carrying 90 gondolas would be required, except a few months in grout Early Start.
- Feed vector uncertainties have no impact on meeting LSA-II criteria and WAC.
- The total transportation and disposal cost is dominated by the cost of grouting and the total cost is only 5- 7% higher when all Class A goes to WCS.
- The split of Class A waste between Clive and WCS will affect the transportation risks due to the differences in transportation distances and population along the routes.
- Both, Clive and WCS are located in sparsely populated areas with no surface water. The climate at both sites is arid/semi-arid with low precipitation and low infiltration. Both, Clive and WCS **do not have potable water**.
- The natural and engineered barriers at both sites provide adequate protection for members of public and inadvertent intruders.
- The latest license amendments are recent and are based on sound scientific and engineering analyses. The amendment review and approval by the state authorities included public hearings and comments.



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On-Site Disposal Description

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FFRDC RCRA Legal & Regulatory Team Lead

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



SRNL is managed and operated by Battelle Savannah River Alliance, LLC for the U. S. Department of Energy.

- **All Changes Affected Appendix G, Section G.2.1**
 - Performance Assessment – added information regarding modeling results
- **Waste Capacity**
 - Updated to include waste disposal capacity assumptions from Performance Assessment
 - Updated estimated disposal volumes from Immobilized LAW, Grout, FBSR, and secondary waste

NAS Recommendation (summarized):	Applicable Section(s)
No NAS recommendations related to Appendix G for IDF	N/A

Performance Assessment

- ***Performance Assessment for the Integrated Disposal Facility, Hanford Site, Washington (RPP-RPT-59958)***
 - Most recent performance assessment. Publicly released in 2019. Analyzes long-term impact of near-surface disposal through modeling.
 - Technical basis supporting the PA is maintained through continued updates that evaluate changes to the PA inputs and assumptions. An annual assessment of these changes is performed to ensure that the conclusions of the PA are still valid. Most recent update is *Integrated Disposal Facility Performance Assessment Special Analysis: Updated Vadose and Saturated Zone Transport Calculations* (RPP-CALC-64672).
- **DOE LLW disposal requirements in DOE M 435.1-1 require that a PA “must provide reasonable expectation that the facility will not exceed the performance objectives for a period of 1,000 years following closure of the facility.” The 2019 IDF PA performed analysis for the required 1,000-year period, but also from 1,000 to 10,000 years, and an extended runout to 500,000 years after closure.**
 - Pathways evaluated included groundwater, air, and inadvertent intruder.
 - Constituents evaluated included radionuclides such as Tc and I, and dangerous chemicals.
 - Model simulations for all pathways show that the initial dose is dominated by ^{99}Tc and ^{129}I . Other radionuclides contribute insignificant doses relative to the total dose. Analysis of the 500,000-year post-closure period shows that peak doses occur in the first 10,000 years, and radium-226 (^{226}Ra) becomes a dominant contributor after 200,000 years.

IDF Estimated Waste Disposal Volumes

Estimated Disposal Volumes (m³) to the Integrated Disposal Facility

Waste Type	System Plan ^a	LAW Supplemental Treatment Alternatives ^b		
	Scenario 1 m ³	Grout Onsite m ³	Grout Offsite m ³	FBSR m ³
Immobilized LAW	190,000 ^{c,d}	110,000 ^e	110,000 ^e	110,000 ^e
Grout (primary waste)	0	300,000 ^f	0	0
FBSR	0	0	0	200,000 ^g
Secondary waste	41,000	24,000	24,000	28,000 ^h
Total % IDF capacity	230,000 26%	440,000 49%	140,000 15%	340,000 38%

^a ORP-11242, 2020, *River Protection Project System Plan*, Rev. 9, U.S. Department of Energy, Office of River Protection, Richland, Washington.

^b Secondary waste volumes calculated based on the assumed ratio of secondary waste projected for the full immobilized LAW inventory in the IDF PA, Table 3-26 (0.218 ratio) (RPP-RPT-59958, *Performance Assessment for the Integrated Disposal Facility, Hanford Site, Washington*).

^c Taken from Scenario 1 of ORP-11242 [Rev. 9], Table ES-4, assumes 5.51 MT of immobilized LAW per container and a density of 2.58 kg/L (MT/m³) for the LAW glass.

^d The LAW supplemental treatment alternative Vitrification 1 would result in equivalent waste disposal volumes as the IDF PA Baseline Case.

^e Based on the amount of WTP LAW glass, assuming 41% of volume is attributed to supplemental LAW (assumed in Scenario 1 of System Plan [Rev. 9]).

^f Taken from Scenario 1 of ORP-11242 [Rev. 9], Table ES-4.

^g Calculated based on the grout volume for supplemental LAW from ORP-11242 [Rev. 9], Table ES-4, and assumes the volume multiplier of waste to grout as 1.8, and of waste to FBSR product as 1.2. (Note that the liquid-to-solid volumetric ratio was conservatively assumed to be 1.2 in transport and disposal calculations related to FBSR. The FBSR volumetric ratio assumed in all other analyses discussed in this report was 1.0.)

^h FBSR assumes a ratio of 0.018 units of secondary waste per unit of primary waste generated (RPP-RPT-63580, *Calculating the Non-Monetary Impact of Operating a Fluidized Bed Steam Reforming Facility*) and added to volume of secondary waste from vitrification.



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Summary of Selected Alternative Criteria Assessments

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Savannah River National Laboratory
FFRDC Alternatives Evaluation Team Lead

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



U.S. DEPARTMENT OF
ENERGY

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Presentation Outline

- **Summary of Criteria Assessments**
- **Review NAS Recommendations D, E, J**
- **Additional Changes**

NAS Recommendation (summarized):	Applicable Section(s)	
D: Discuss regulatory approval; esp. adverse consequences of rejection of grouted supplemental LAW for IDF or offsite	Main Body	§ 6.1
	Main Body	§ 6.2
	Appendix I.D	§ 3.7 Transport risks
E: Expand consideration of consequences of potential unacceptability of grouted supplemental LAW for transportation, disposal at IDF, or offsite disposal	Main Body	§ 6.1
	Main Body	§ 6.2
	Appendix I.D	§ 3.7 Transport risks
J: Elaborate on the potential negative consequences of unavailability of off-site disposal	Main Body	§ 6.1
1. Permission denied/withdrawn	Main Body	§ 6.2
2. What is known about public acceptance	Appendix I.D	§ 3.7 Transport risks
3. Provide information on orphaned waste	Appendix II.H	§ H.3.5-3.6 Transport experience
	Appendix II.C	§ C.1.3 Working inventory

Vitrification 1 - Single Vitrification Plant - Selection Criteria Summary

1. Long-Term Effectiveness

- Residual threat to health and environment upon successful completion
 - + *Nitrates/nitrites and waste organics destroyed; low mobility of rads/metals that remain in glass*
 - *NH₃ and organics produced; NH₃, Hg are in secondary wastes; Some I-129 in secondary wastes - TBD*
- Long-term risks upon successful completion
 - + *High confidence in destruction of nitrates/nitrites, waste organics; long-term sequestration of rads/metals that remain in glass*
 - *Uncertainty in fate and partitioning of Hg, I-129, to secondary wastes, melter idling impact on Tc fate*

2. Implementation Schedule and Risk

- + *Low volume of primary waste; low transportation risk*
- *Delayed start-up increases risk of tank degradation; worker hazards; high greenhouse gas emissions, chemical and power use; high atmospheric vapor release and secondary liquid; extended duration of operations; risk of further delay*

3. Likelihood of Successful Mission Completion

- + *Replicates first LAW melter technology, reducing technology uncertainty*
- *Complex, integrated process with high maintenance needs; insufficient funds to start-up by need date at benchmark level*

4. Life Cycle Costs - (see earlier presentation)

FBSR 1A - Fluidized Bed Steam Reforming – On-site Disposal - Selection Criteria Summary

1. Long-Term Effectiveness

- Residual threat to health and environment upon successful completion
 - + *Nitrates/nitrites/waste organics destroyed; Tc sequestered in waste form; moderate volume of primary waste*
- Long-term risks upon successful completion
 - + *High confidence in destruction of nitrates/nitrites, waste organics, non-pertechnetate; long-term sequestration of rads that remain in granular product*

2. Implementation Schedule and Risk

- + *low transportation risk*
- *Intermediate delayed start-up has risk of tank degradation; worker hazards; high greenhouse gas emissions, chemical and power use; extended duration of operations; risk of further delay due to cost and technical issues*

3. Likelihood of Successful Mission Completion

- + *Similar to other equipment (but dissimilar feed waste stream); lessons learned from IWTU*
- *Very highly complex, integrated process with high maintenance and process control requirements; unique waste form; needs significant pilot-scale testing to reduce uncertainty; insufficient funds to start-up by need date at benchmark level*

4. Life Cycle Costs - (see earlier presentation)

Grout 4B - Off-site Vendor for Grouting – Off-site Disposal - Selection Criteria Summary

1. Long-Term Effectiveness

- Residual threat to health and environment upon successful completion
 - + *Reduced long-term ammonia issue (WTP LAW continues); no rad impact to Hanford groundwater; Hg, Tc, & I in primary waste form offsite; minimal secondary waste*
 - *Nitrates/nitrites not destroyed (but no impact); 1.8X waste volume increase*
- Long-term risks upon successful completion
 - + *Minimal added impact of ammonia; high confidence in no impact to Hanford groundwater*
 - o *High confidence in LDR organic resolution*

2. Implementation Schedule and Risk

- + *On-time start-up decreases risk of tank degradation; minimal worker hazards; low greenhouse gas emissions, chemical and power use; minimal atmospheric discharges; minimal technical risk of waste form production issues*
- *Moderate transportation risk; high volume of primary waste; LDR organics not resolved*

3. Likelihood of Successful Mission Completion

- + *Similar to existing processes; robust/flexible; low complexity; commercially available equipment; demonstrated in TBI; adaptable; low likelihood of failure for technical reasons; sufficient funds to start-up by need date*
- *If LDR organics are not sufficiently resolved, requires more to WTP LAW melters*

4. Life Cycle Costs - (see earlier presentation)

Grout 6 - Phased Off-site and On-site Grouting in Containers - Selection Criteria Summary

1. Long-Term Effectiveness

- Residual threat to health and environment upon successful completion
 - + *Reduced long-term NH₃ issue (WTP LAW continues); low potential rad impact to Hanford groundwater; Hg, Tc, & I in primary waste form disposed offsite/onsite; minimal secondary waste*
 - *Nitrates/nitrites not destroyed (but limited impact); 1.8X waste volume increase*
- Long-term risks upon successful completion
 - + *Minimal added impact of ammonia; high confidence in limited potential impact to Hanford groundwater; lack of potential migration due to low water infiltration rates, vault barrier*
 - o *High confidence in LDR organic resolution; uncertainty in impact of non-pertechnetate*

2. Implementation Schedule and Risk

- + *Early start-up minimizes risk of tank degradation; minimal worker hazards; low greenhouse gas emissions, chemical and power use; minimal atmospheric discharges; minimal technical risk*
- *Moderate transportation risk; high volume of primary waste; LDR organic resolution or LAW vit*

3. Likelihood of Successful Mission Completion

- + *Similar to existing processes; robust/flexible; low complexity; commercially available equipment; demonstrated in TBI; vault demonstrated (SRS); adaptable; low likelihood of failure for tech. reasons; sufficient funds to start-up by need date*
- *If LDR organics are not sufficiently resolved, requires more waste to WTP LAW melters*

4. Life Cycle Costs - (see earlier presentation)

Recommendations are Related to Potential Negative Consequences of Unavailability of Offsite Disposal

- **Disposal site Unavailability is Unlikely (Main Body § 3.3.4, 6.1)**
 - All waste is analyzed to confirm compatibility with treatment and disposal
 - *Alternative is routing to LAW Vitrification*
 - Multiple grouting vendors available
 - Extensive knowledge base of grout formulations and production experience (Vol. II, Appendix A)
 - DOE has extensive experience in shipping liquid and solid radioactive waste (see Vol. I. §D.3.7 and Vol. II, appendix H)
 - *Shipments compliant with DOT and NRC requirements*
 - *DOE established National Transportation Stakeholders Forum to ensure safety of transportation and local capability for accident response*
 - Two disposal sites are currently available with sufficient capacity (see Vol. II. appendix G)
 - *Both currently receive NRC Class A (~90% of LAW); WCS also accepts B & C*
 - Ensure agreements and permit modifications (if needed) are in place prior to initiation
 - Estimated max of 750 containers (~10 m³ each) could be “in jeopardy” if revocation is sudden (Vol. II. § C.1.3)
- **Strategy if Disposal Sites Become Permanently Unavailable (Main Body § 6.2)**
 - Pursue identification of other disposal facilities
 - Continue to work with state regulators and stakeholder to identify viable solutions
 - Pursue application of new and emerging technologies and approaches for disposition

Additional Changes

- **Volume II. Appendix D (Selection Criteria Assessments, a.k.a. Taxonomies)**

- Greenhouse gas emissions (Criterion 2.3.6; under Implementation Schedule and Risk)
 - *Clarified that carbon dioxide/greenhouse gases only emitted during treatment (not “long-term” in Vol. II, App. D, criterion 1.1.1.5)*
 - *More detail added on carbon dioxide emissions/energy needs*
 - *Added minor contributors (e.g., calculated CO₂ from sugar and carbonate minerals in vitrification, coal in FBSR)*
- Change life cycle costs to “discounted present value”
 - *More consistent with other information in report*
 - Did not change overall results

- **FBSR**

- Added detail to FBSR alternative selection criteria
 - *Updated to clarify differences with IWTU*
 - *Provided more detail on radionuclide incorporation into waste form*
 - The FBSR presentation provided more detail

- **Appendix I.B (Summaries of Selection Criteria Assessments, a.k.a. Taxonomies)**

- Generally improved short descriptions
- Added detail to carbon dioxide emissions/energy needs
- Changed cost to discounted present value



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Assessment Summary and Results

Matt Champagney, PMP

Vice President – Engineering and Planning Directorate, Parsons

FFRDC Decision Framework & Analysis SME

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



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Presentation Outline

- Introduction
- Analysis Methodology Summary
- Drivers of Top Tier Evaluations
- Pairwise Comparisons
 - Performance vs. Promptness
 - Performance vs. Feasibility
 - Promptness vs. Feasibility
- Lifecycle Cost Comparisons
- Comparisons of Four Representative Alternatives
 - Summary Table
 - Graphical Comparisons
 - Cost Avoidance and Schedule Acceleration Relative to Vitrification 1

NAS Recommendation (summarized):	Applicable Section(s)	
L: Comparisons should be quantified; particularly for Section 4.0	Main Body	§ 4.3
	Main Body	§ 5.0

Analysis Methodology Summary – Criteria Recomposition, Alternative Analysis

- **23 Alternatives Defined by Team**

- 8 alternatives screened for being redundant or clearly dominated by other alternatives

An alternative is considered said to be dominated if there is another alternative that scores at least as well on every decision criterion, and better on at least one

- **For Remaining 15, Evaluations Performed at Lowest Tiers of Taxonomy Using Established MOEs**

- **Lowest-Tier Criteria “Rolled up” to the Next Tiers in the Taxonomy, with Key Drivers Identified and Documented at Every Subsequent Step in the Recomposition**

- **Chose Representative Alternatives for Each Technology**

- Vitrification 1

- FBSR 1A

- Grout 4B

- Grout 6 (hybrid)

Drivers of Top-Tier Evaluations

1. Long-Term Effectiveness – “*Performance*” (environmental and safety risk after disposal)

1. Residual threat to health and environment upon successful completion – potential for mobility of nitrates/nitrites, organics, radionuclides, metals
2. Long-term risks upon successful completion – confidence in process or technology and waste performance in disposal facility

Note: Only alternatives assessed as likely to comply with anticipated regulations and applicable standards for mobility and toxicity of wastes at project completion were evaluated in the Report. Alternatives unlikely to comply were screened out.

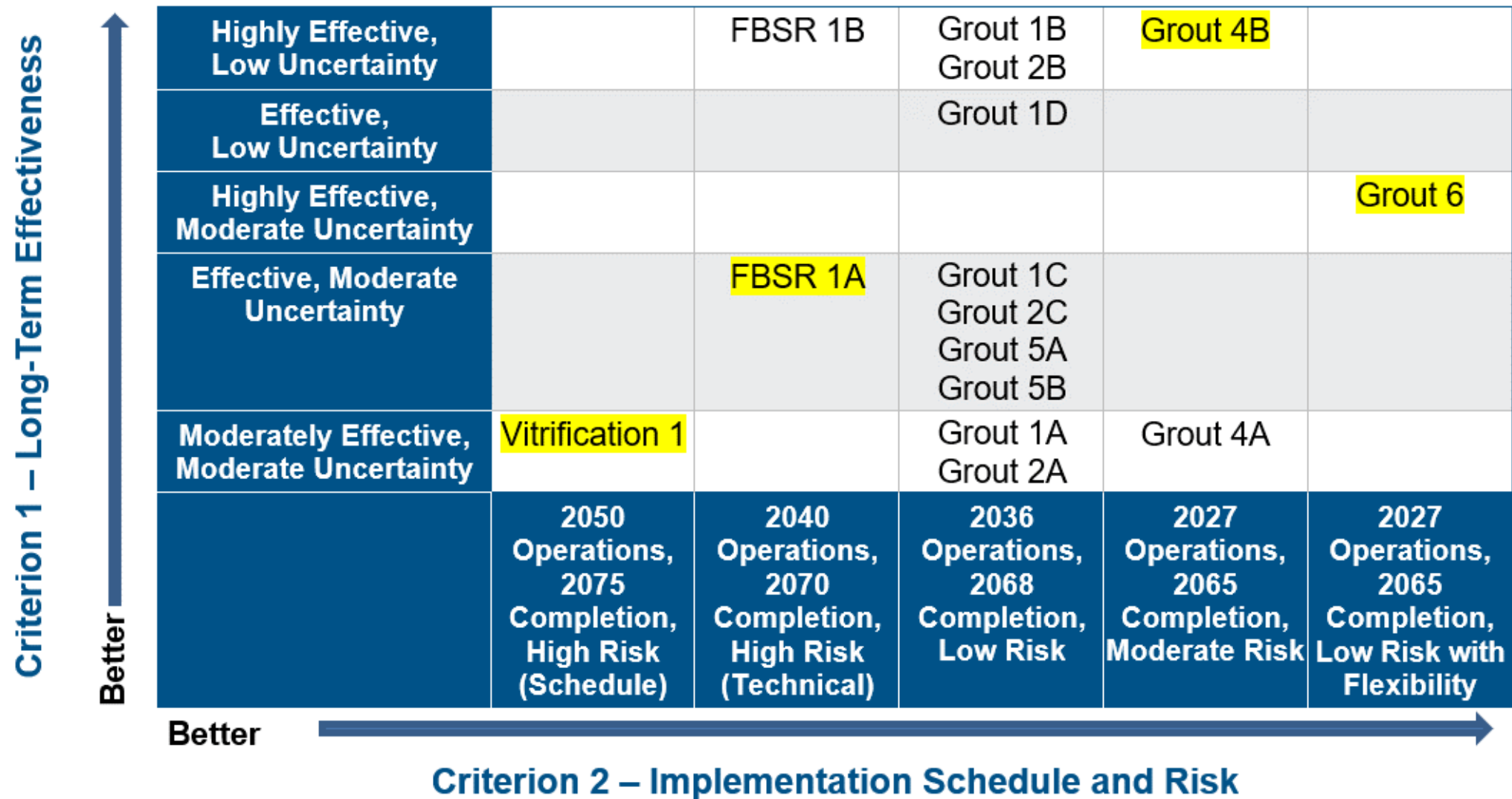
2. Implementation Schedule and Risk – “*Promptness*” (environmental and safety risks prior to mission completion, including risks driven by waste tank storage duration)

1. Specific risks or benefits related to ongoing tank degradation – driven by duration to start treatment as well as overall mission duration
2. Risks to humans (other than tank degradation) – worker hazards
3. Risks to the environment (other than tank degradation) – greenhouse gas emissions, chemical and power usage, transportation risks
4. Duration – risk of further delay due to funding requirements and technical issues that extend mission exacerbate previously stated risks

3. Likelihood of Successful Mission Completion – “*Feasibility*” (including technical, engineering, and resource-related risks)

1. Likelihood and consequences of failing to complete due to technical problems – technology maturity, process complexity, adaptability
2. Likelihood and consequences of failing to complete due to resource shortfall – equipment availability, intensity of resource requirements

Pairwise Comparison: Performance vs. Promptness



Pairwise Comparison: Performance vs. Feasibility

Criterion 1 – Long-Term Effectiveness

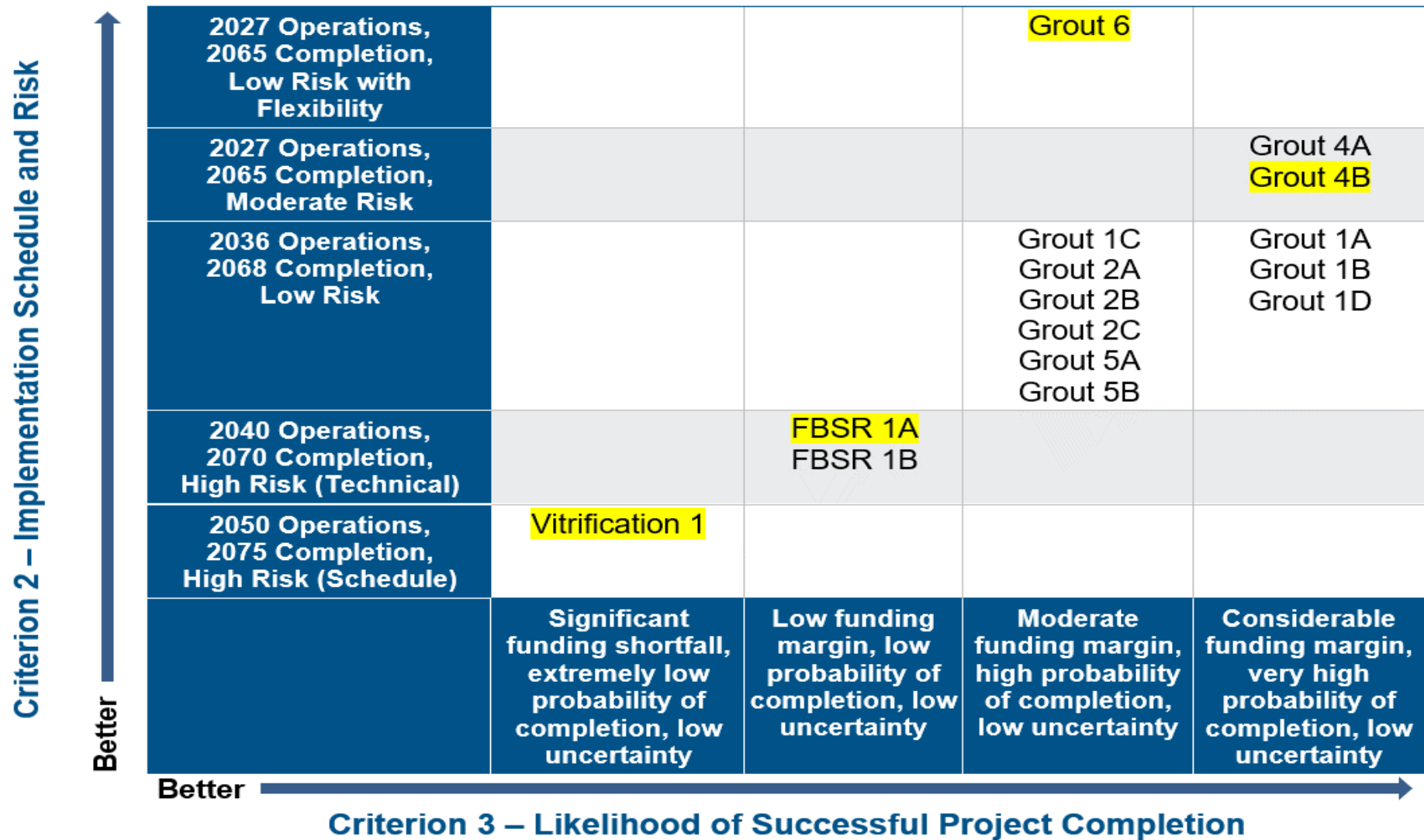
Better ↑

Highly Effective, Low Uncertainty		FBSR 1B	Grout 2B	Grout 1B Grout 4B
Effective, Low Uncertainty				Grout 1D
Highly Effective, Moderate Uncertainty			Grout 6	
Effective, Moderate Uncertainty		FBSR 1A	Grout 1C Grout 2C Grout 5A Grout 5B	
Moderately Effective, Moderate Uncertainty	Vitrification 1		Grout 2A	Grout 1A Grout 4A
	Significant funding shortfall, extremely low probability of completion, low uncertainty	Low funding margin, low probability of completion, low uncertainty	Moderate funding margin, high probability of completion, low uncertainty	Considerable funding margin, very high probability of completion, low uncertainty

Better →

Criterion 3 – Likelihood of Successful Project Completion

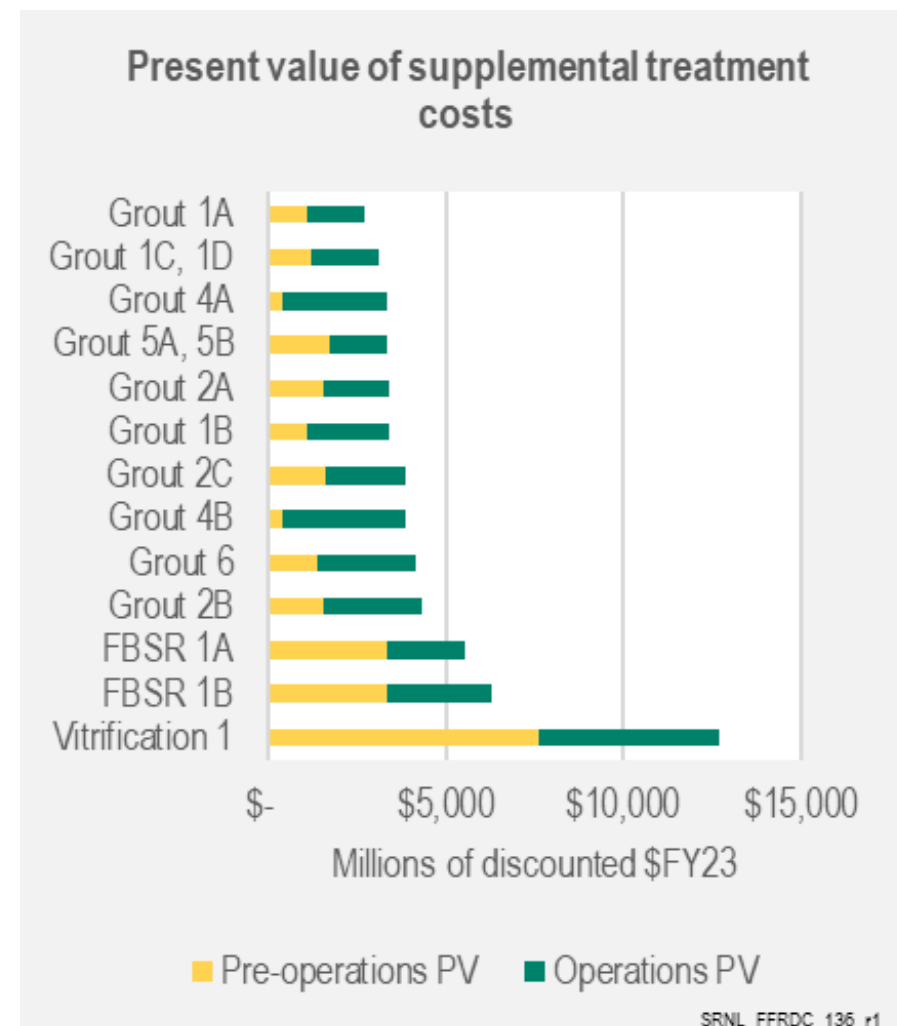
Pairwise Comparison: Promptness vs. Feasibility



Criterion 4 – Lifecycle Costs (Discounted Present Values)

Alternative	Pre-Operations	Operations	Total
Grout 1A	1,108	1,622	2,730
Grout 1C, 1D	1,200	1,915	3,115
Grout 4A	411	2,927	3,338
Grout 5A, 5B	1,735	1,614	3,349
Grout 2A	1,544	1,851	3,395
Grout 1B	1,108	2,306	3,414
Grout 2C	1,636	2,211	3,847
Grout 4B	410	3,444	3,854
Grout 6	1,393	2,734	4,127
Grout 2B	1,544	2,774	4,318
FBSR 1A	3,375	2,152	5,527
FBSR 2A	3,374	2,905	6,279
Vitrification 1	7,608	5,092	12,700

FBSR = fluidized bed steam reforming.

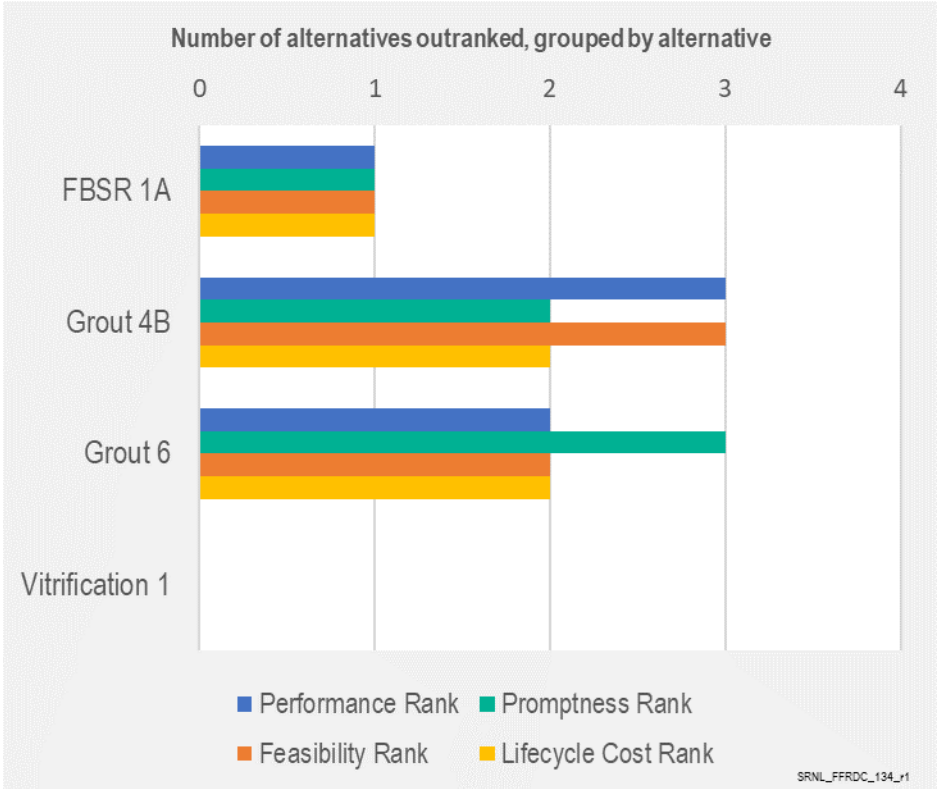
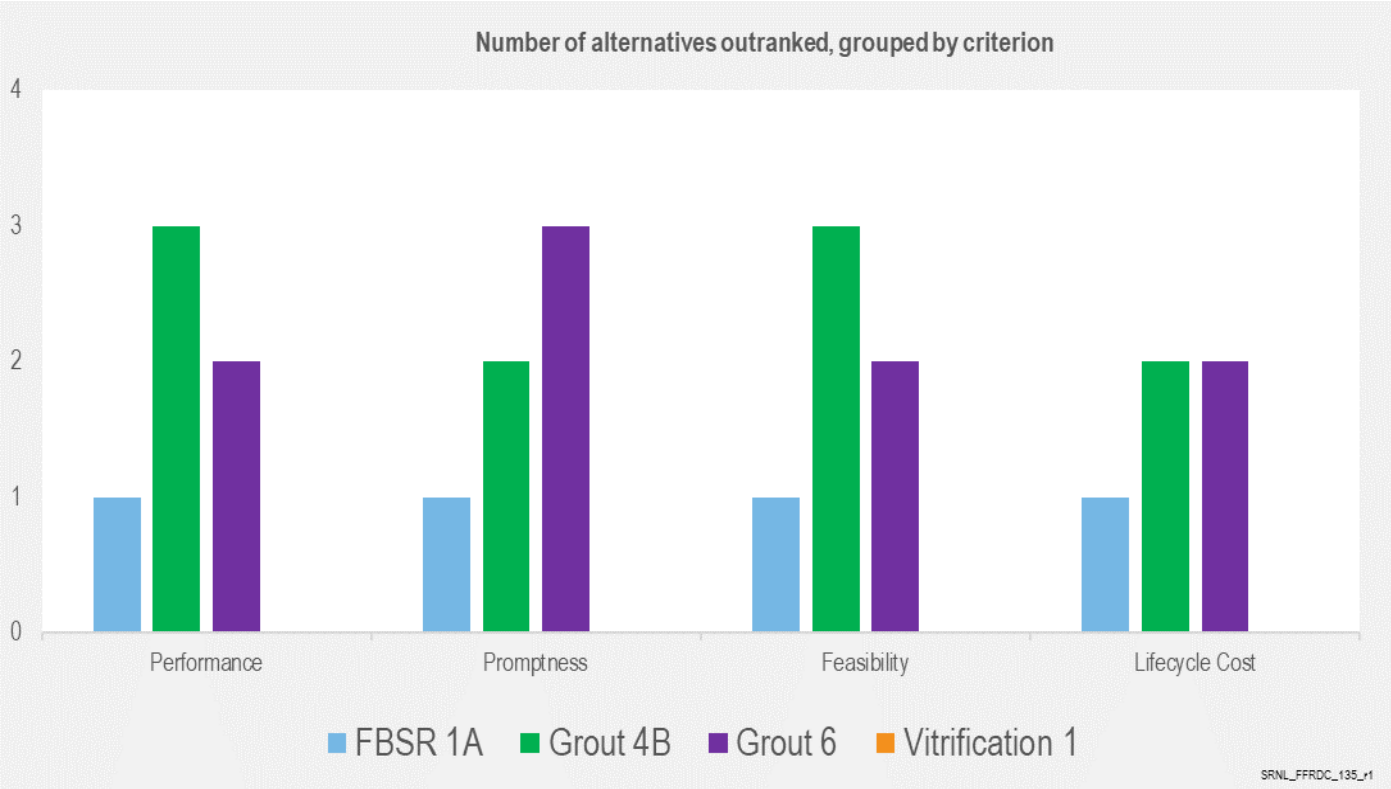


High-Level Comparison of the Four Representative Alternatives

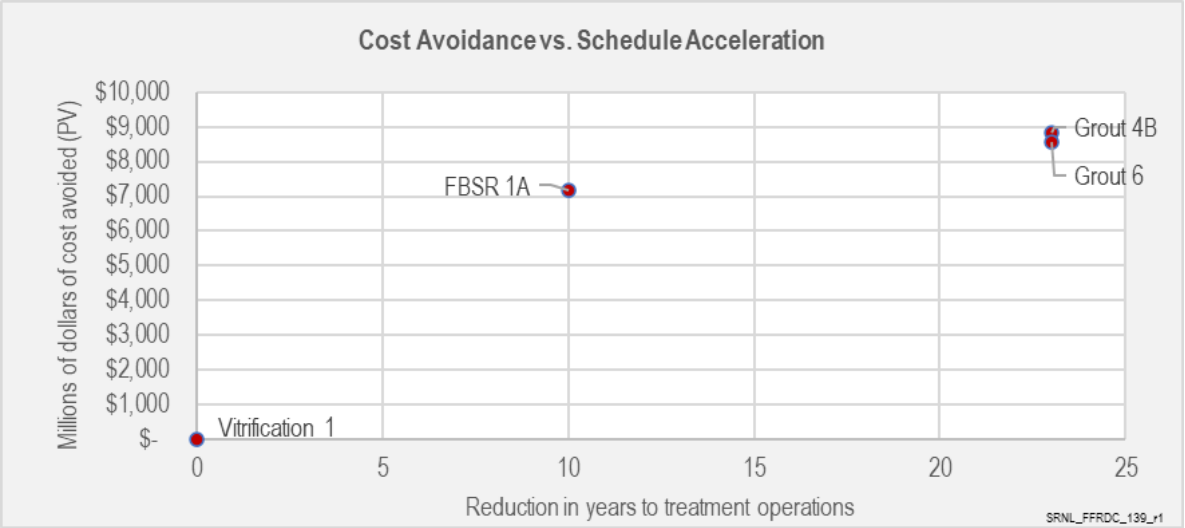
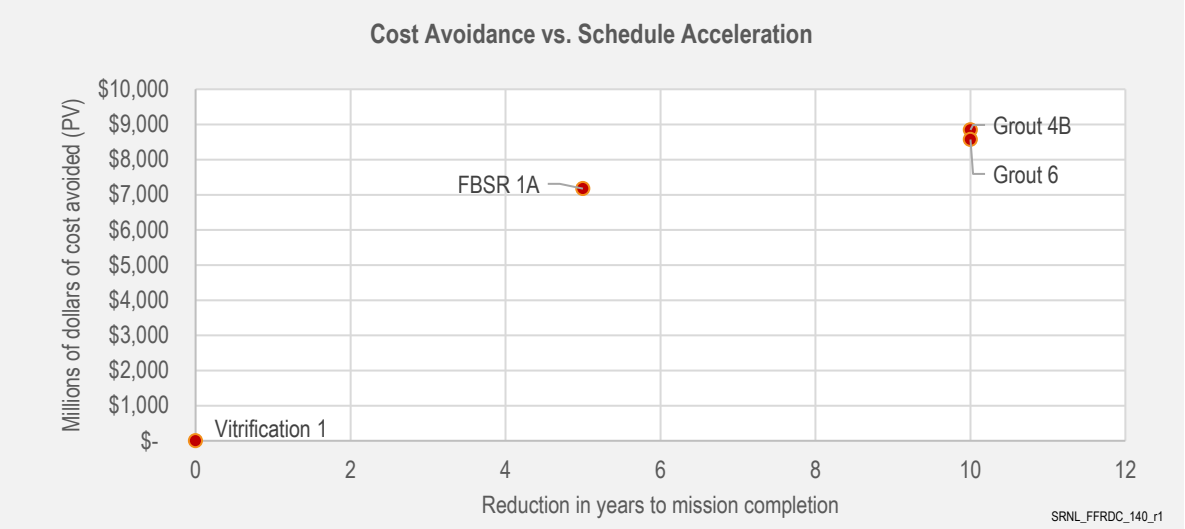
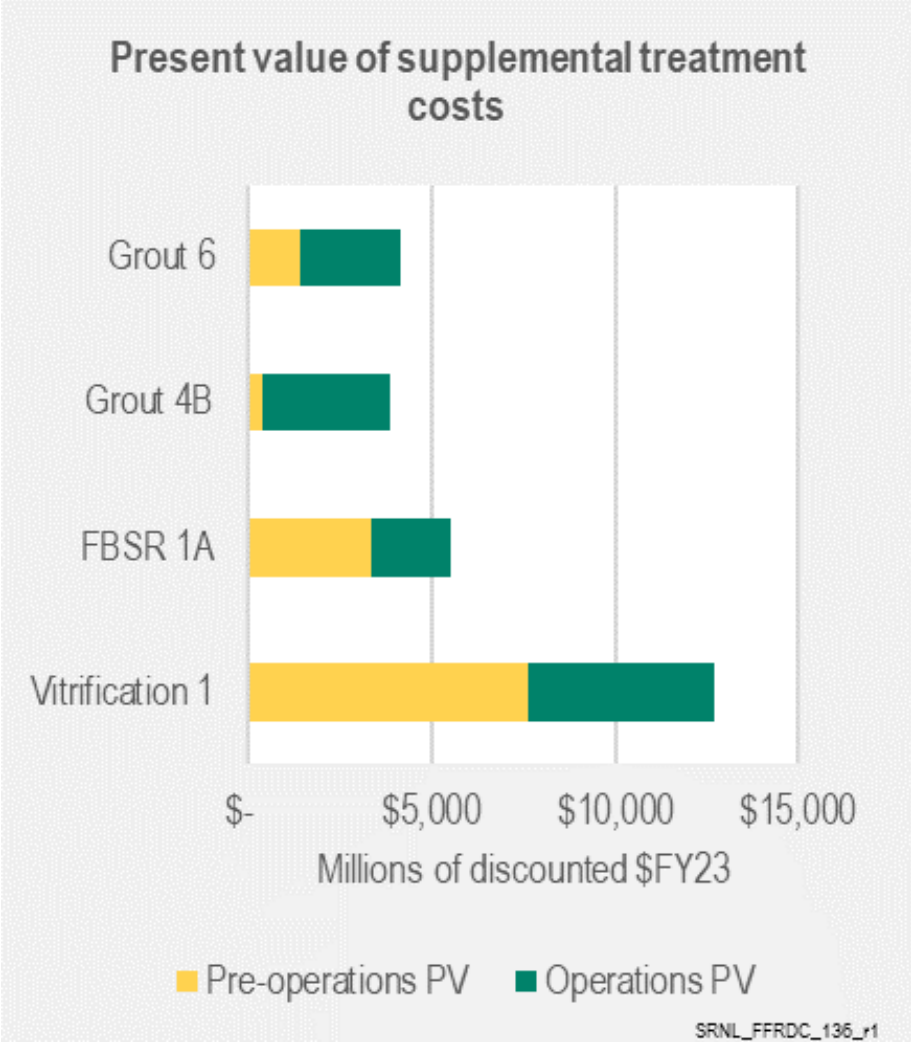
Vitrification 1: Disposal onsite at Hanford	FBSR 1A: Solid monolith product disposal onsite at Hanford	Grout 4B: Off-site grouting/disposal	Grout 6: Phased Approach Off-site grouting/disposal, then on-site grouting/disposal
Criterion 1: Long-term effectiveness (environmental and safety risk after disposal)			
Highly effective for primary waste; moderately effective for secondary waste. Medium confidence in the assessment.	Effective. Medium confidence in the assessment, due to technology immaturity.	Highly effective. High confidence in the assessment.	Highly effective. Good to high confidence in the assessment.
Criterion 2: Implementation schedule and risk (environmental and safety risks prior to mission completion, including risks driven by waste tank storage duration)			
High risk due to significant cost-based startup delays and operations limits. Moderate technical implementation risk. Construction finishes and treatment starts in 2047, mission does not complete without significant additional annual budget.	High risk due to construction time required and technical execution risk. Construction finishes and treatment starts in 2039; mission completes 2070.	Low risk due to earliest potential start of treatment in 2027, minimal construction, low-temperature process, likely capacity, and modest transportation and operations costs. Limited facilities (e.g., evaporator and load-out station) needed; mission completes 2066.	Very low risk due to earliest potential start of treatment in 2027, flexible timing of conversion to on-site low-temperature process, and inexpensive operations. Grout plant construction finishes 2039; mission completes 2066.
Criterion 3: Likelihood of successful mission completion (including technical, engineering, and resource-related risks)			
Very low probability of successful completion due to resource intensity.	Low probability of successful completion due to technical risk.	Very high likelihood of successful completion.	High likelihood of successful completion.
Criterion 4: Lifecycle cost (discounted lifecycle costs)			
\$7.6B construction; \$5.1B operations (total operations costs exceed benchmark budget by \$1.2B)	\$3.4B construction; \$2.2B operations	\$0.4B construction; \$3.4B operations	\$1.4B construction; \$2.7B operations

Rank Value Comparisons of Four Representative Alternatives

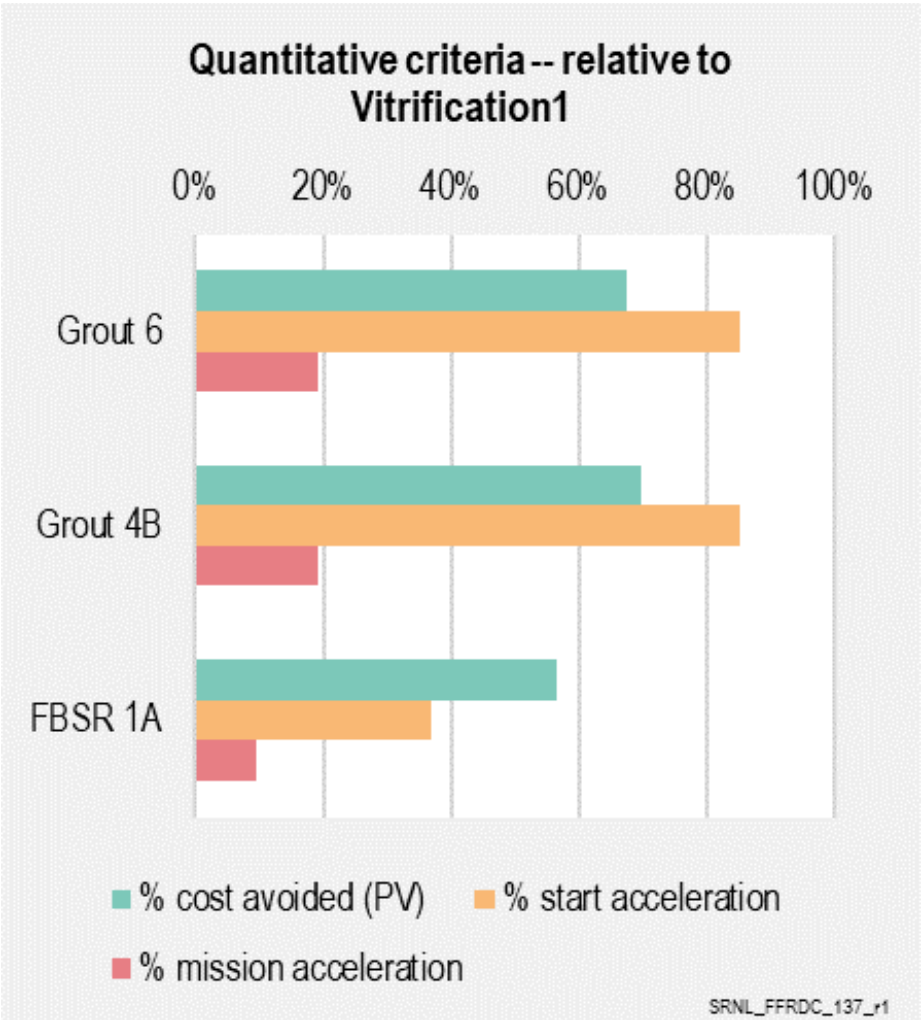
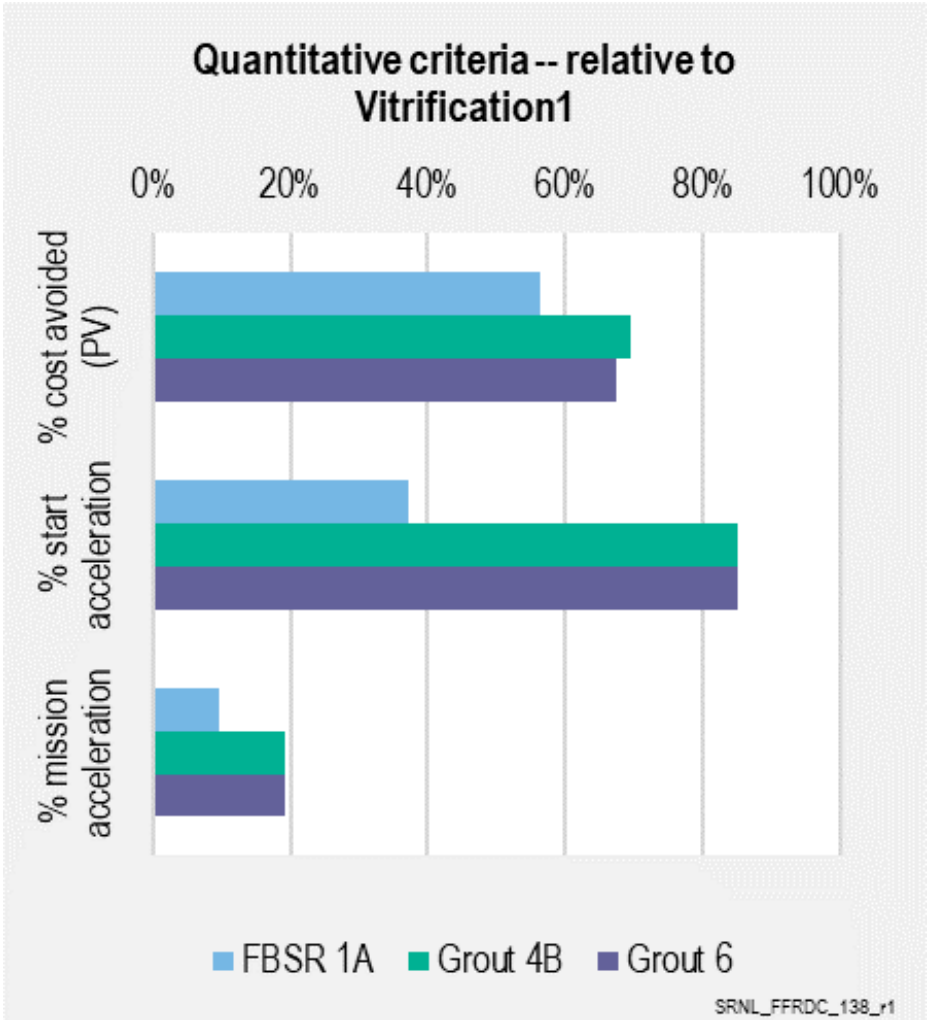
Figures show the rank value comparisons for the four representative alternatives, grouped by criterion and alternative, respectively. Because Vitrification 1 does not outrank any other alternatives, its representative bars do not appear in these figures.



Present Value Costs and Cost vs. Schedule Comparisons of Four Representative Alternatives



Comparisons of Quantitative Criteria Relative to Alternative Vitrification 1



Analysis Summary Methodology – Criteria Identification and Decomposition

- **“Decision-Informing Criteria” (Taxonomy) Developed to Evaluate the Effectiveness of Each Alternative**
 - e.g., “Long Term Effectiveness” which assesses factors such as waste form performance
- **Analytical Approach: Hierarchical Decomposition and Recomposition**
- **Six “top-level” or “tier 1” Criteria Defined by the FFRDC Team**
 - Patterned After NEPA / RCRA / CERCLA / AEA (DOE 435.1) Decision Factors
- **Tier 1 Criteria Decomposed to Identify Underlying Factors Affecting the Criteria; Additional Decomposition Performed to Capture all Relevant Factors**
 - Example: Criterion 1, Long-term effectiveness was broken down as far as tier 5
- **Established “Measures of Effectiveness” (MOE) to Evaluate Each Criterion at the Lowest Tiers of the Taxonomy and Included an Explanation of Each Parameter**



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Recommendation Development

Dr. David Tate

Senior Analyst, Institute for Defense Analyses

FFRDC Team Decision Framework and Analysis Lead

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



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Formulation of the FFRDC Recommendation

- **Considerations**
- **Ground Rules**
- **Rationale**
- **Participants**

NAS Recommendation (summarized):	Applicable Section(s)
M: If any recommendation is offered, the process leading to the recommendation needs to be fully transparent. • Participants • Methodology • Manner and degree of accounting for criteria 5 and 6 in the recommendation	Main Body § 6.2

Considerations for Recommendation Development

- **After Assessment, the FFRDC Team Considered Whether a Recommendation Was Appropriate**
- **The Team Agreed on Specific Ground Rules for the Discussion:**
 - In the absence of consensus, no recommendation would be made
 - Any recommendation would not attempt to assess Criteria 5 and 6, but would be based solely on technical and implementation factors and their assessed risks
 - Any recommendation would therefore require additional review in light of Criteria 5 and 6
 - Since every alternative was assessed as effective with medium confidence (or better) for long term performance, any recommendation would be primarily driven by Criteria 2, 3, and 4
- **Consensus Was Reached on the Relative Importance of the Differences Among Alternatives**
 - Differences with regard to Criterion 2, Implementation Schedule and Risk, were deemed most significant
 - Differences with regard to Criterion 3, Probability of Successful Completion, were deemed next-most significant
 - Differences with regard to Criterion 4, Life Cycle Cost (discounted present value) were deemed third-most significant

Pairwise Comparison: Criterion 2 vs. Criterion 3

Criterion 2 – Implementation Schedule and Risk

Better ↑

2027 Operations, 2065 Completion, Low Risk with Flexibility			Grout 6	
2027 Operations, 2065 Completion, Moderate Risk				Grout 4A Grout 4B
2036 Operations, 2068 Completion, Low Risk			Grout 1C Grout 2A Grout 2B Grout 2C Grout 5A Grout 5B	Grout 1A Grout 1B Grout 1D
2040 Operations, 2070 Completion, High Risk (Technical)		FBSR 1A FBSR 1B		
2050 Operations, 2075 Completion, High Risk (Schedule)	Vitrification 1			
	Significant funding shortfall, extremely low probability of completion, low uncertainty	Low funding margin, low probability of completion, low uncertainty	Moderate funding margin, high probability of completion, low uncertainty	Considerable funding margin, very high probability of completion, low uncertainty

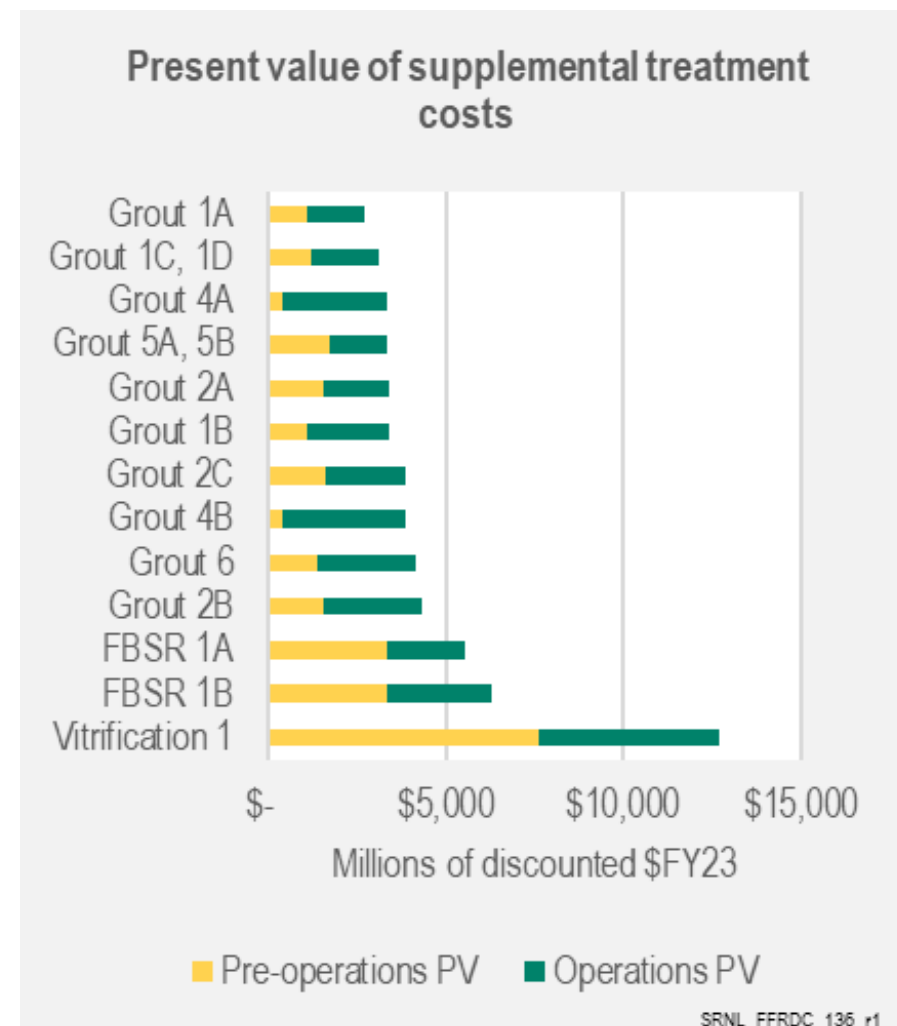
Better →

Criterion 3 – Likelihood of Successful Project Completion

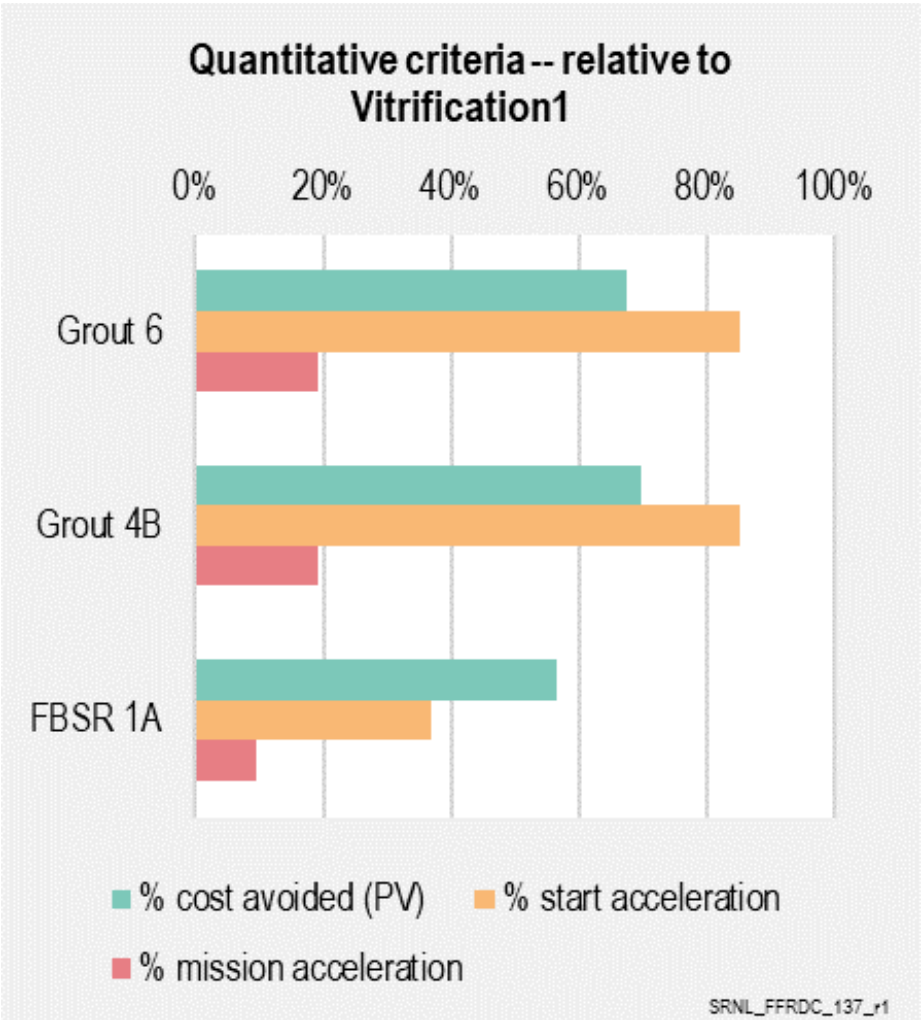
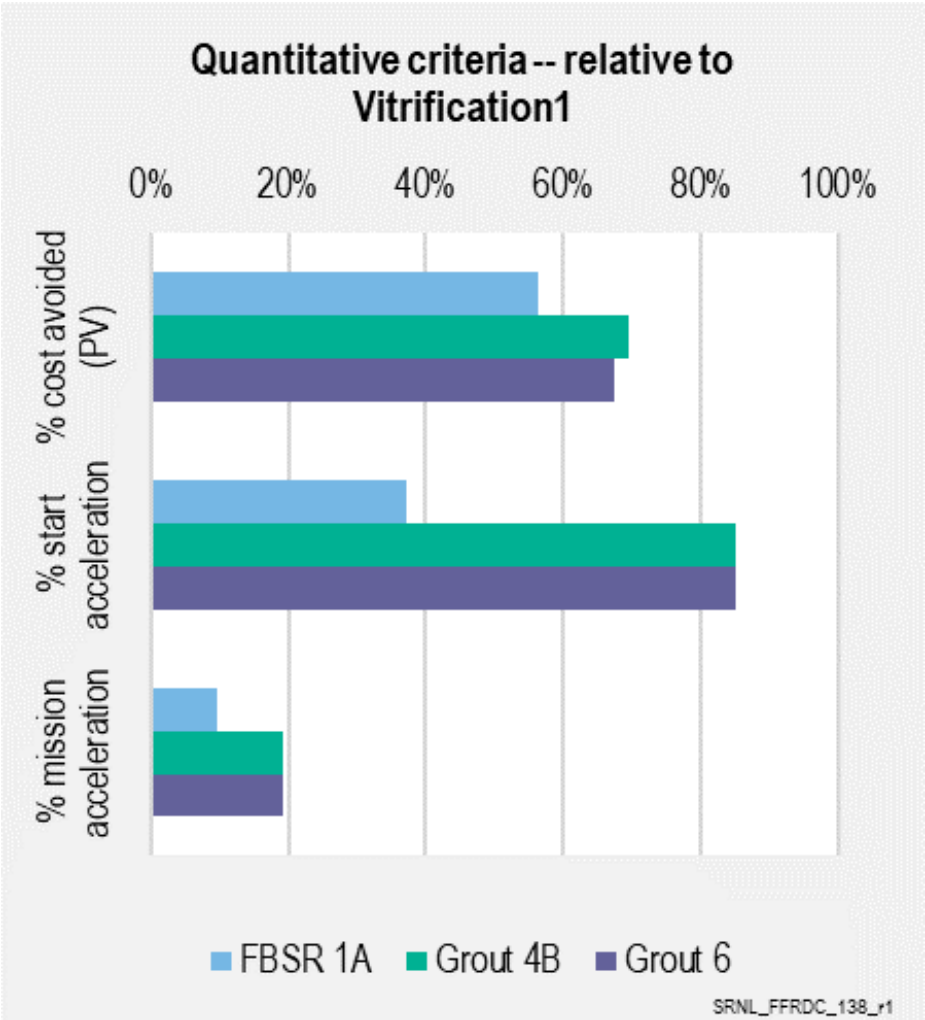
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Vitrification 1	7,608	5,092	12,700

FBSR = fluidized bed steam reforming.



Comparisons of Quantitative Criteria Relative to Alternative Vitrification 1





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Wrap Up — Summary & Conclusions

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FFRDC Team Lead

2021 NDAA-3125 Meeting #4

January 31-February 1, 2023



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Comparative Analysis of Four Selected Alternatives

Vitrification 1: Disposal onsite at Hanford	FBSR 1A: Solid monolith product disposal onsite at Hanford	Grout 4B: Off-site grouting/disposal	Grout 6: Phased Approach Off-site grouting/disposal, then on-site grouting/disposal
Criterion 1: Long-term effectiveness (environmental and safety risk after disposal)			
Highly effective for primary waste; moderately effective for secondary waste. Medium confidence in the assessment.	Effective. Medium confidence in the assessment, due to technology immaturity.	Highly effective. High confidence in the assessment.	Highly effective. Good to high confidence in the assessment.
Criterion 2: Implementation schedule and risk (environmental and safety risks prior to mission completion, including risks driven by waste tank storage duration)			
High risk due to significant cost-based startup delays and operations limits. Moderate technical implementation risk. Construction finishes and treatment starts in 2047, mission does not complete without significant additional annual budget.	High risk due to construction time required and technical execution risk. Construction finishes and treatment starts in 2039; mission completes 2070.	Low risk due to earliest potential start of treatment in 2027, minimal construction, low-temperature process, likely capacity, and modest transportation and operations costs. Limited facilities (e.g., evaporator and load-out station) needed; mission completes 2066.	Very low risk due to earliest potential start of treatment in 2027, flexible timing of conversion to on-site low-temperature process, and inexpensive operations. Grout plant construction finishes 2039; mission completes 2066.
Criterion 3: Likelihood of successful mission completion (including technical, engineering, and resource-related risks)			
Very low probability of successful completion due to resource intensity.	Low probability of successful completion due to technical risk.	Very high likelihood of successful completion.	High likelihood of successful completion.
Criterion 4: Lifecycle cost (discounted lifecycle costs)			
\$7.6B construction; \$5.1B operations (total operations costs exceed benchmark budget by \$1.2B)	\$3.4B construction; \$2.2B operations	\$0.4B construction; \$3.4B operations	\$1.4B construction; \$2.7B operations

Conclusions

- **Only Grout-Based Alternatives Allow Near-Term LAW Disposition & Achieve Fastest Risk Reduction**
- **Processing Flexibility is an Important Consideration**
- **Grout Alternatives Have the Highest Likelihood of Completion at Benchmark Funding Levels**
- **Vitrification & Grout Waste Forms can Provide Long-Term Protectiveness**
- **FBSR is Considered “First-of-a-Kind” for Hanford LAW**
- **Off-Site Disposal Removes Tc and I from Hanford**
- **Most of this LAW Would Be Class A/B**
- **The State of WA is Granted Broad Discretion over Regulatory Flexibility**
- **A Decision is Needed as Soon as Possible to Ensure Readiness to Support HLW Processing**
- **The Decision Framework can be used by Decision-Makers**

Recommendation

- ***DOE should expeditiously secure and implement multiple pathways for off-site grout solidification/immobilization and disposal of LAW in parallel with the DFLAW vitrification process.***
 - **Rapid Risk Reduction** – DST Space, Accelerate Waste Retrievals, Waste Stabilized
 - **Environmental Protection** – Reduce On-Site Disposal Inventory, Offsite Disposal with No Credible Pathway to Potable Water
 - **Flexibility** – Can Route LAW Treatment and Disposal Selectively
 - **Mitigates Risk** – Having Multiple Licensed Off-Site Treatment and Disposal Facilities with Selection Based on Sampling
 - **Time to Enable Transition(s)** – If On-Site Treatment and/or Disposal are Pursued, Benefits from Operating Experience
 - **Reduction or Elimination of Need for Future Capabilities**
 - **Minimized Financial Demands** – Closest to Current Funding Levels
 - **High Likelihood of Successful Implementation and Mission Completion**