

SYSTEMS ENGINEERING APPROACH TO THE ALTERNATIVE SELECTION FOR THE RESOLUTION OF THE BENZENE GENERATION PROBLEM ASSOCIATED WITH THE IN-TANK PRECIPITATION (ITP) FACILITY AT SRS

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ABSTRACT

The High Level Waste (HLW) Salt Disposition Systems Engineering Team (Team) was formed on March 15, 1998, under the sponsorship of the Westinghouse Savannah River Company (WSRC) High Level Waste Division Vice President and General Manager. The Team was chartered to identify options, evaluate alternatives, and recommend a preferred alternative(s) for processing HLW salt to a permitted waste form. This requirement arose because the existing In-Tank Precipitation (ITP) process, as currently configured, cannot simultaneously meet the HLW production and DOE approved Authorization Basis safety requirements.

The Team was comprised of experts from WSRC and its partners, with outside consultant support from academia, National Laboratories, and the Department of Energy (DOE) complex. Team membership and position attributes were identified in a "Team Charter" (Ref. 1).

The charter identifies three phases in the achievement of the Team's mission:

- Phase I: Problem definition, idea generation, and coarse screening to create an "Initial List of Alternatives"
- Phase II: Preliminary risk analysis and engineering flow-sheet evaluation to down-select to a "Short List of Alternatives"
- Phase III: Detailed evaluation and analysis of the Short List including preparation of life cycle cost estimates to down-select to a preferred alternative

This paper describes the process adopted and the results obtained from the above Phases.

INTRODUCTION

The In-Tank Precipitation (ITP) Facility initiated radioactive operation in September 1995. During operation of the slurry pumps within the 1.3MM gallon tank in December 1995, benzene evolved from the tank at higher rates than expected though the operational safety limit was never approached. Subsequently, it was determined by chemistry studies of the reaction mechanisms and kinetics associated with the ITP process that the benzene was generated as a byproduct of the process from the catalytic decomposition of sodium tetraphenylborate (NaTPB).

In August 1996, the Defense Nuclear Facilities Safety Board (DNFSB) issued Recommendation 96-1 (Ref. 2) in which the DNFSB recommended that operations and testing in the ITP Facility not proceed without an improved understanding of the mechanisms of benzene generation, retention, and release. WSRC embarked upon an extensive chemistry study program to respond to the issues raised in the 96-1 recommendation. The results of the studies indicated that

production goals and safety requirements for processing of HLW could not be accomplished in the ITP Facility as currently configured. The results led to a WSRC recommendation to DOE in January 1998 to conduct a systems evaluation of salt disposition options and to recommend the preferred alternative.

In March 1998, the Team was selected to perform a structured Systems Engineering analysis of options for salt disposition at Savannah River. Guidance for the Team was documented in the charter and the Systems Engineering Management Plan (SEMP) (Ref. 3). The task of salt disposition evaluation was broad based in technical scope and was not limited to any single process. Precipitation methods, ion exchange processes, other chemical or mechanical separation techniques, direct vitrification/grout options, or combinations of these options were considered.

The process that was ultimately selected for HLW salt disposition had to have minimal impact on the other HLW facilities e.g., Defense Waste Processing Facility. Additionally, the selected alternative must interface safely and efficiently with the remainder of the processing facilities outside of the High Level Waste Division. Timeliness of the selection was key to support the tank farm space/water inventory management program and the Federal Facility Agreement (FFA) for tank closure.

SYSTEMS ENGINEERING PROCESS

A number of different approaches were used to identify alternative processes to meet the production and safety requirements for salt disposition. Tapping the Savannah River Technology Center (SRTC) technologies and the operations/engineering expertise throughout the Savannah River Site (SRS) via “Pro-Forma” sheets along with formal brainstorming with internal/external stakeholders and selected technical experts throughout the DOE complex ensured the capture of all technologies for evaluation. This process was supplemented by historical reviews and literature surveys. Facilities within the DOE complex and other companies with chemical processing experience, (e.g., Corps of Engineers, National Laboratories, and British Nuclear Fuels) were accessed for ideas as well. All ideas were documented on Pro-Forma sheets for consistency in the evaluation process (Ref. 4).

The resulting list of approximately 130 submittals was evaluated against a set of minimum screening criteria that included scientific maturity, engineering maturity, implementation feasibility, safety, licensability, and feasibility of permitting the final waste form. Alternatives were either accepted as- written, modified by combination or addition, or dismissed (Ref. 5).

The Phase I ranking was performed within technology categories in order to focus on the alternatives with the highest potential for success. The result of the exercise was an Initial List of 18 alternatives selected for further evaluation which were grouped in the following categories: Crystallization, Electrochemical Separation, Elutable Ion Exchange, Non-elutable Ion Exchange, Organic Precipitation/Modify ITP, Organic Precipitation/New Facility, Solvent Extraction, Vitrification, and Miscellaneous.

One of the building blocks in the System Engineering process to facilitate selection of the Short List of alternatives in Phase II was the application of a preliminary risk assessment of the Initial List. Approximately 400 risks of varying significance were identified during the assessment. In order to validate the identified risks for the candidate alternatives, field confirmation trips were taken to sites representing the identified technologies. The site visits provided valuable technical information and broadly confirmed the applied assessment process and the preliminary risk assessment. Following the preliminary risk assessment, a review was performed to ensure consistent identification of risk. For those risks categorized as “high”, a strategy was determined to handle the risk and the corresponding risk value was revised to reflect this change (Ref.6).

To provide a technical basis for the selection process, flow-sheets were developed for each initial list alternative. The alternative processes were modeled to provide anticipated material balances, waste processing rates, emission levels, chemical adjustment, canister production in the Defense Waste Processing Facility (DWPF), and saltstone production (Ref. 7 and 8).

To assist the Team in establishing the Short List of Alternatives, weighted evaluation criteria and supporting utility functions were developed (Ref. 9). The Team used information from the preliminary risk assessment, off-site trips, preliminary life cycle cost estimates, and flow-sheet analysis to score each alternative against the following weighted evaluation criteria:

- Technology
- Current Mission Interfaces
- Future Mission Interfaces
- Regulatory/ISMS/Environmental
- Engineering (Design)
- Cost/Schedule

A structured process (Multi-Attribute Utility Analysis and Analytical Hierarchy Process) was utilized by the Team to perform the evaluation. The weighting factors selected for Phase II ensured that Science, Engineering, and Safety attributes were most important at this step. The Team felt that all alternatives selected for the Short List could be implemented in the field. The Team evaluation resulted in the following Short List (Ref. 10):

- Direct Disposal of HLW as Grout
- Small Tank ITP
- Non-elutable Ion Exchange (glass/ceramic waste form)
- Caustic Side Solvent Extraction

Direct Disposal as Grout was chosen for continued evaluation due to the simplicity of the process, high throughput capability, and extensive operational experience while understanding that the Regulatory impact due to permanent disposal of the Class C waste as grout at Savannah River may be substantial. Small Tank ITP was chosen due to the level of knowledge of the precipitation technology based on the recent chemistry studies, its simple unit operations, and compatibility with existing infrastructure. Several of the non-elutable ion exchange options ranked well due to the stability of the separation media, high levels of pilot and production nuclear experience, and compatibility with the SRS salt waste streams. Caustic side solvent

extraction also ranked well as compared to the other Initial List alternatives due to significant positive operating experience using solvent extraction on and off-site, no impact on glass formulation, and high level of the engineering maturity of the extraction unit operations.

The purpose of Phase III was to select the preferred alternative(s) for implementation at SRS for HLW salt disposition. In this phase, the emphasis was on analyzing the comparative merits and weaknesses of technologies and their associated engineering which are known to have a high probability of successful deployment in this application, particularly with regard to cost, schedule, and ease of implementation. All decisions in this phase were structured to make the best use of available and developed information to make a final selection.

The Phase III scoring process differed from Phase II in its emphasis. Phase II process was used to establish the candidates that had the best chance of success from a technology, design, safety, or interface point of view. Since all of the surviving candidates are acceptable in these categories, cost and schedule performance now becomes a major discriminator. The weighting system used in Phase III reflected this change. Additionally, the work underway in this phase provided the more detailed data needed to provide differentiating scores for the candidates in those areas where data was unavailable in earlier phases.

The Phase III selection process encompassed a more detailed Life Cycle Cost Analysis and Programmatic Risk Evaluation. Flowsheet finalization for preconceptual design, limited scope research and development to support the use of go/no-go criteria, initiation of further scoped research and development activities necessary to support prototype or detailed design and a detailed schedule evaluation. Flowsheets already developed were enhanced to include:

- Equipment sizing
- Energy Balance
- Physical properties and kinetics
- Facility/Equipment planning drawings

Cost and schedule considerations received enhanced weighting in Phase III compared to that of Phase I and II due to the additional information developed in this phase.

FINAL SELECTION

The process for selecting the preferred alternative emphasized the use of cost and schedule as discriminating attributes. These two parameters had been given low weighting in the Investigation Phase because the level of definition of the Initial List alternatives at that stage was insufficient to give a high degree of confidence in the assigned values. Cost and schedule were the focus of attention in the Selection Phase and other attributes which might influence the decision were treated as uncertainties which manifested themselves as a cost and/or schedule impact. The following paragraphs summarize the flowsheet data for the four Short List alternatives:

Caustic Side Solvent Extraction (Figure 1)

The basic principle of solvent extraction is to use an insoluble diluent material that carries an extractant that will complex with the cesium-137 ions in the caustic solution. The clean aqueous stream (raffinate) is sent to saltstone for disposal. The cesium-137 contained in the organic phase (solvent) can be stripped back into an aqueous phase ready for transfer to vitrification in DWPF. The solvent is then recycled.

Initially, the alkaline salt waste is treated with monosodium titanate (MST) to sorb the actinides followed by filtration to remove the MST and sludge solids. The clarified salt solution flows to the Salt Solution Holding Tank. The solvent is contacted with the alkaline waste stream in a series of countercurrent centrifugal contactors (extraction stage). The resulting clean aqueous raffinate is transferred to Saltstone for disposal. Following cesium extraction, the solvent is scrubbed with dilute nitric acid to remove other soluble salts from the solvent stream (scrub stage). The solvent is then contacted with a very dilute nitric acid stream containing a small quantity of cold cesium to transfer the cesium to the acid stream (strip stage). The strip effluent is transferred to vitrification in DWPF.

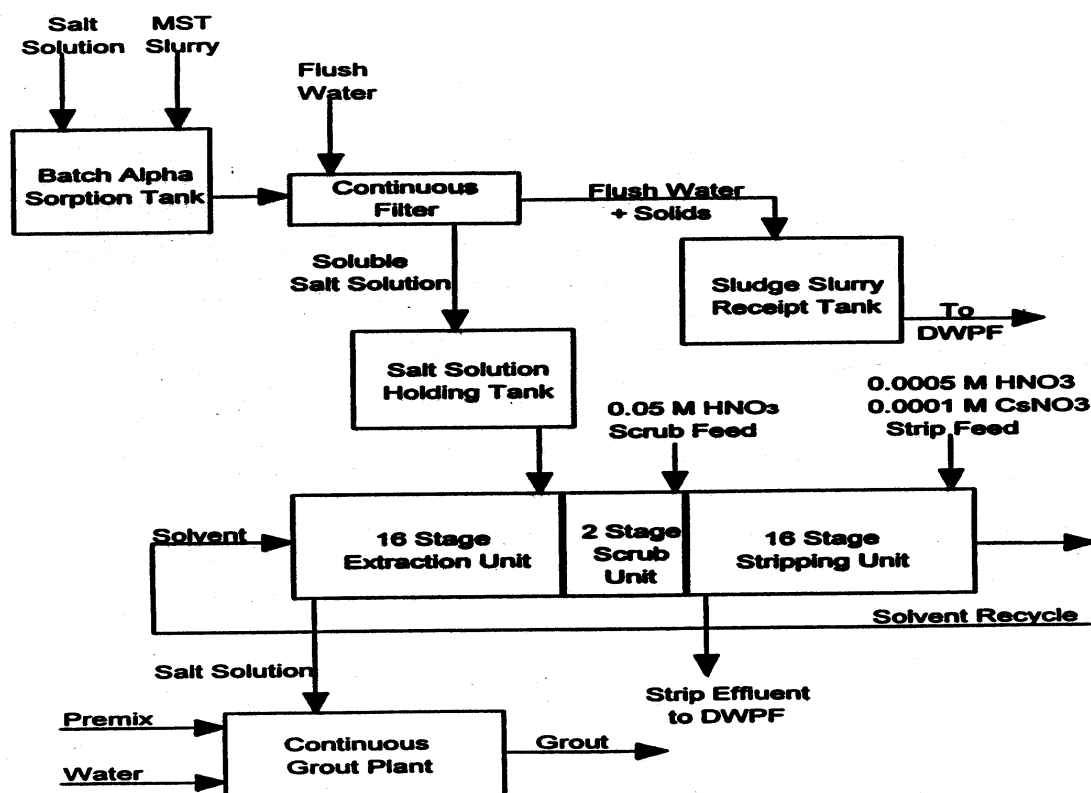


Figure 1: Caustic Side Solvent Extraction

Crystalline Silicotitanate CST Non-Elutable Ion Exchange (Figure 2)

The proposed alternative would employ CST resin to remove cesium-137 from the salt solution. Initially, the alkaline salt waste is treated with monosodium titanate (MST) to sorb the actinides followed by filtration to remove the MST and sludge solids to prevent IX column plugging and to meet the Class A grout specification. The loaded resin is transferred to the vitrification plant (DWPF) to be combined with sludge and frit to produce borosilicate glass. The decontaminated salt solution goes to Saltstone to be made into grout.

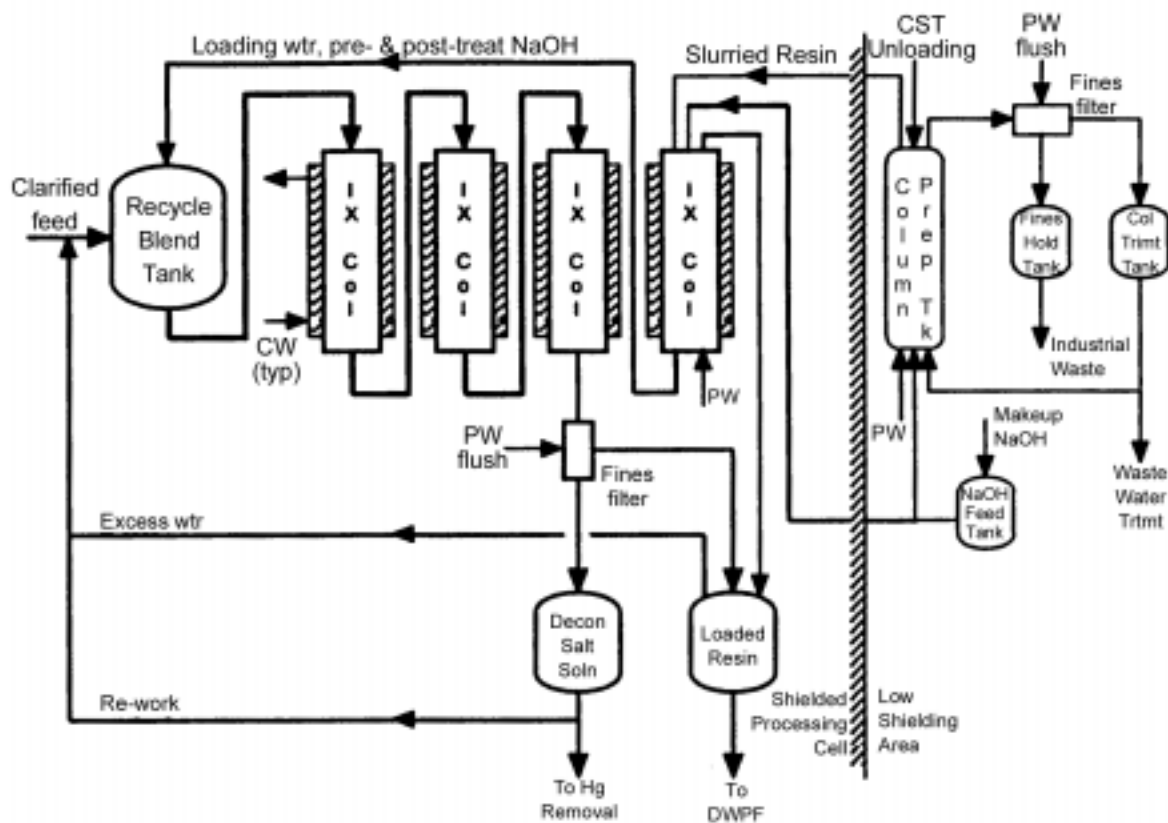


Figure 2: Crystalline Silicotitanate CST Non-Elutable Ion Exchange

Direct Disposal in Grout (Figure 3)

In this proposed alternative, cesium-137 is not separated from the salt waste or concentrated supernate. All soluble waste is sent to a new shielded grout facility. The saltstone wasteform generated from dissolved saltcake solution must meet NRC Class C Low Level Waste disposal requirements for near-surface disposal. The vaults presently used at SRS meet current regulations for NRC Class C disposal, although, the current permit restricts the average curie content in a disposal cell to be within NRC Class A limits. Treatment of salt solution is required to remove entrained sludge and actinides so that soluble alpha activity meets the disposal criteria. If mercury is present, it also must be removed to meet the disposal criteria.

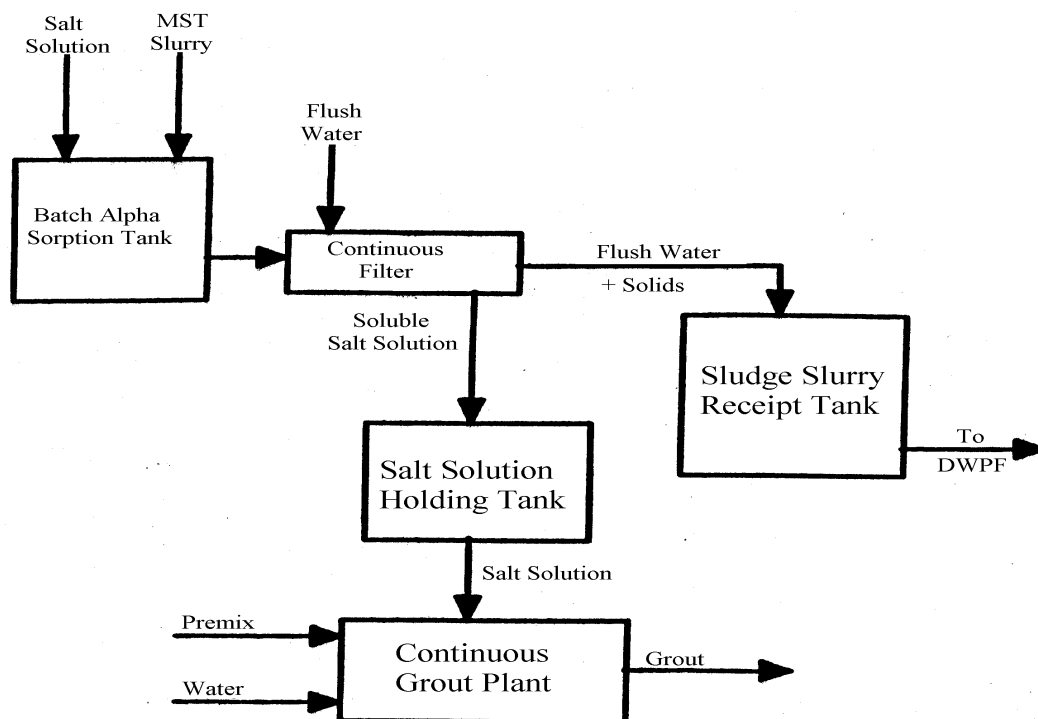


Figure 3: Direct Disposal in Grout

Small Tank Tetraphenylborate (TPB) Precipitation (Figure 4)

In the TPB process, cesium-137 is precipitated with sodium TPB and the actinides are removed with MST. The resulting precipitate (containing most of the radionuclides) is filtered to concentrate the solids. The precipitate is sent to vitrification in DWPF. The decontaminated salt solution is transferred to saltstone for grout disposal.

The attributes selected for the final Team evaluation were Total Project Cost (TPC), Life Cycle Cost (LCC), Safety, Science/Technical Maturity, and Mission Impact. In addition, the following areas were evaluated based on the Team expertise obtained over the preceding months:

- Likelihood of success – the Team’s judgement of successfully deploying the technology and meeting the key schedule requirements.
- Applied engineering – a measure of the difficulty of translating each technology into a functional radioactive facility.
- Management of uncertainty – the characterization of the difficulty in managing the range of uncertainties associated with each technology, with emphasis on the risk of waterlogging the Tank Farm.

- Scope for optimization – the Team's view of relative opportunity for throughput improvement or cost reduction as a result of further R&D or engineering studies.
- Fallback options – the characterization of the ability of the alternative to recover from a failure of the chosen separation media by use of a fallback chemical in the same equipment.

The Team discussed each area in turn and ranked the alternatives. Direct Disposal in Grout has the most schedule uncertainty. This raised the issue that delayed radioactive operations would result in waterlogging the Tank Farm at SRS. Even with an aggressive management approach to shortening the time for public consultation, regulatory approval and litigation, selection of the alternative would result in exceeding the 2010 Tank Farm space limit. Therefore, this alternative was excluded from final consideration.

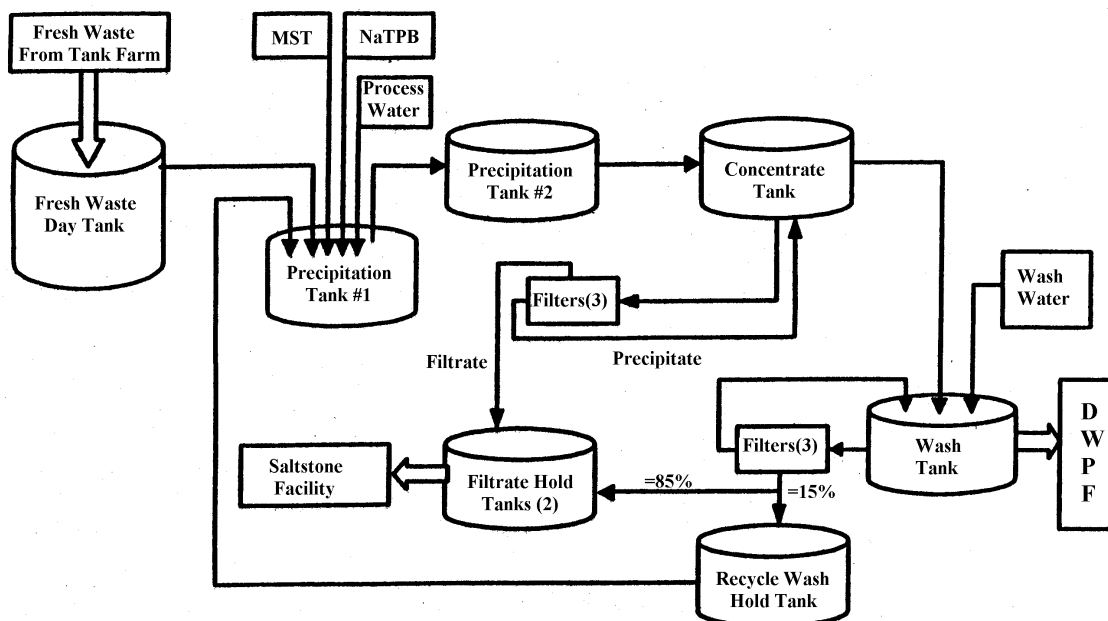


Figure 4: Small Tank Tetraphenylborate (TPB) Precipitation

CONCLUSION

Considering the information reviewed during the selection process, the Team reached a consensus that Small Tank TPB Precipitation should be recommended as the preferred alternative (Ref. 11). The principal reasons being:

- Best likelihood of success
 - Simple safety strategy
 - R&D scope is small and defined
 - Skill mix of personnel is available

- Most “discovery” issues likely to be mechanically rather than chemically solved
- Even with uncertainties fully applied, schedule implementation does not challenge Tank Farm space
- Most manageable risks
 - Safety strategy implementable
 - Cash flow requirements lowest of viable alternatives
 - Risks are operational failures more than technology failures
- Most technically mature
 - Known chemical reaction expression
 - Extensive R&D program experience
 - Large empirical data set
- Best pessimistic life cycle cost
- Lowest project cost

None of the alternatives were clearly superior to the others and each required further R&D. In order to reduce overall program risk, the Team decided it was prudent to select a backup alternative. The technical maturity and likelihood of success for CST Non-Elutable Ion Exchange was selected as the backup alternative for the following reasons:

- Relatively simple chemical process
 - Separation media commercially available
 - Once through process
 - Reduced rotating equipment
- Risks more manageable
 - More margin the Solvent Extraction for Tank Farm space
 - More technically mature than Solvent Extraction
 - Applied engineering solutions for known technology issues
- Technically mature
 - Large scale pilot demonstration
 - Multiple National Lab research effort
- Better fallback options
 - DWPF campaigning
 - Optional lower performing resin
 - CST only glass formulation possible

REFERENCES

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4. HLW-SDT-980014, "Position Paper on Dispositioning of Pro-Formas Received During Phase II"
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