SALT PROCESSING AT THE SAVANNAH RIVER SITE: RESULTS OF TECHNOLOGY DOWN-SELECTION AND RESEARCH AND DEVELOPMENT TO SUPPORT NEW SALT WASTE PROCESSING FACILITY

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ABSTRACT

The Department of Energy's (DOE) Savannah River Site (SRS) high-level waste (HLW) program is responsible for storage, treatment, and immobilization of HLW for disposal. The Salt Processing Project (SPP) is the salt waste (water-soluble) treatment portion of this effort. The overall SPP encompasses the selection, design, construction, and operation of technologies to prepare the salt-waste feed material for immobilization at the site's Saltstone Production Facility (SPF) and vitrification facility (Defense Waste Processing Facility [DWPF]). Major constituents that must be removed from the salt waste and sent as feed to DWPF include cesium (Cs), strontium (Sr), and actinides.

In April 2000, the DOE Deputy Secretary for Project Completion (EM-40) established the SRS Salt Processing Project Technical Working Group (TWG) to manage technology development of treatment alternatives for SRS high-level salt wastes. The separation alternatives investigated included three candidate Cs-removal processes selected, as well as actinide and Sr removal that are also required as a part of each process. The candidate Cs-removal processes are:

- Crystalline Silicotitanate Non-Elutable Ion Exchange (CST),
- Caustic Side Solvent Extraction (CSSX), and
- Small Tank Tetraphenylborate Precipitation (STTP).

The Tanks Focus Area was asked to assist DOE by managing the SPP research and development (R&D), revising roadmaps, and developing down-selection criteria.

The down-selection decision process focused its analysis on three levels: (a) identification of goals that the selected technology should achieve, (b) selection criteria that are a measure of performance of the goal, and (c) criteria scoring and weighting for each technology alternative. After identifying the goals and criteria, the TWG analyzed R&D results and engineering data and scored the technology alternatives versus the criteria.

Based their analysis and scoring, the TWG recommended CSSX as the preferred alternative. This recommendation was formalized in July 2001 when DOE published the *Savannah River Site Salt Processing Alternatives Final Supplemental Environmental Impact Statement* (SEIS) and was finalized in the DOE Record of Decision issued in October 2001.

INTRODUCTION

The DOE SRS HLW program is responsible for storage, treatment, and immobilization of HLW for disposal. The SPP is the salt (water-soluble) waste treatment portion of the SRS HLW cleanup effort. The overall SPP encompasses the selection, design, construction, and operation of technologies to prepare the salt waste feed material for immobilization at the site's SPF and vitrification facility (DWPF). Major radionuclides that must be removed from the salt waste and sent as feed to DWPF include actinides, Sr, and Cs.

In April 2000, DOE-Headquarters (DOE-HQ) established the TWG to manage the SPP technology development program at SRS. The TFA was requested to assist DOE by conducting several activities. These activities included review and revision of the technology development roadmaps, development of down-selection criteria, and preparation of a comprehensive R&D program plan for three candidate Cs-removal technologies, as well as the Alpha/Sr removal technologies that are part of the overall SPP. The TFA issued a revised R&D program plan(1) in November 2000 for the three Cs-removal candidate technologies – CST, CSSX, and STTP – and the associated Alpha/Sr removal technologies.

The R&D program focused on resolving high-risk areas for Alpha/Sr removal and each alternative Cs-removal process by mid-fiscal year (FY) 2001 to support a DOE down-selection decision by June 2001. The testing included parametric studies and flowsheet tests with waste simulants and significant work with actual SRS HLW – including both batch and integrated flowsheet tests in shielded cells. The *Salt Processing Project Research and Development Summary Report*(2) issued in May 2001 documented the technology development results for each process. The SPP R&D program is funded jointly by the DOE Offices of Science and Technology (EM-50) and EM-40. Participants in the program include WSRC's Savannah River Technology Center (SRTC), Oak Ridge National Laboratory, Argonne National Laboratory (ANL), Sandia National Laboratories, Pacific Northwest National Laboratory, and various universities and commercial vendors.

Based on the R&D results and subsequent management recommendations(2,3,4) DOE-HQ selected CSSX as the preferred Cs-removal technology. This selection was documented in the SRS SEIS(5) and Notice of Availability published in the Federal Register on July 20, 2001(6).

RADIONUCLIDE REMOVAL PROCESS DESCRIPTIONS FOR SALT PROCESSING PROJECT

The SPP is the salt (soluble) waste treatment portion of the SRS HLW cleanup effort. The salt waste is comprised of highly caustic liquids and salt cake containing sodium nitrate, sodium nitrite, sodium aluminate, and other soluble chemicals(1). The overall SPP encompasses the selection, design, construction and operation of treatment technologies to prepare the salt waste feed material for treatment at the site's SPF and vitrification facility (DWPF). Major radionuclides that must be removed from the salt waste and sent as feed to DWPF include actinides, Sr, and Cs. The radionuclide removal requirements for the SPP are shown in Table I.

Table I. Radionuclide Removal Requirements

COMPONENT	SALTSTONE WASTE ACCEPTANCE CRITERIA (nCi/g)	REQUIRED DECONTAMINATION FACTOR: AVERAGE/BOUNDING
Cesium-137	45	7,700/40,000
Plutonium/Americium	18 (total alpha)	12/55
Uranium	18 (total alpha)	1/1
Neptunium	0.03	1/33
Strontium	40	5/26

Alpha/Sr Removal

For the STTP, Alpha/Sr removal occurs simultaneously with precipitation of Cs. In contrast, the current preconceptual design for both CST using IONSIV® IE-911 and the CSSX process requires removal of Sr and actinides in advance of removing Cs from the solution. In addition to the process complexity added through extra equipment, the latter two options require an additional solid-liquid separation step. Previous studies showed low filtration flux in the absence of the organic tetraphenylborate (TPB) precipitate. The lower fluxes necessitate the use of larger filtration equipment, and storage vessels for waste to maintain the desired waste-processing rate.

CSSX

Prior to treatment by solvent extraction, actinides are removed from the waste by sorption with monosodium titanate (MST). The resulting slurry is then filtered to remove the MST and sludge solids.

The CSSX process utilizes a novel solvent made up of four components: calix[4]arene-bis-(*tert*-octylbenzo-crown-6) known as BOBCalixC6; 1-(2,2,3,3-tetrafluoropropoxy)-3-(4-*sec*-butylphenoxy)-2-propanol known as modifier Cs-7SB; trioctylamine known as TOA; and Isopar® L, as a diluent. The solvent is contacted with the alkaline waste stream in a series of countercurrent centrifugal contactors (the extraction stages). The resulting clean aqueous raffinate is transferred to Salt Waste Processing Facility (SWPF) for disposal. Following Cs extraction, the solvent is scrubbed with dilute acid to remove other soluble salts from the solvent stream (the scrub stages). The scrubbed solvent then passes into the strip stages where it is contacted with a very dilute (0.001 M) acid stream to transfer the Cs to the aqueous phase. The aqueous strip effluent is transferred to the DWPF.

CST

The proposed ion-exchange process employs CST sorbent to remove Cs from the salt solution. In this process, slurry of MST is first added to the waste to sorb Sr, plutonium (Pu), and other actinides. The resulting slurry is then filtered to remove insoluble MST and any entrained sludge in the waste. The insoluble solids are washed and then transferred as aqueous slurry of the solids to the DWPF for incorporation into borosilicate glass. The clarified salt solution (from filtration) flows through a series of CST columns to remove the Cs. Because Cs cannot be easily recovered by elution, Cs-loaded CST will be transferred to the DWPF. There it is combined with the MST/sludge slurry, washed sludge from the Tank Farm, and frit, to produce borosilicate glass. The decontaminated salt solution (DSS) is transferred to the SWPF and processed into a solid low-level waste for on-site disposal.

STTP

In the STTP process, Sr and alpha are sorbed and Cs precipitated in two continuous stirred tank reactors (CSTR) arranged in series. The solids produced, with the radioactive species, are separated from the DSS by cross-flow filtration. The solids accumulate continuously in a concentrator tank, and are then sent in batches to a wash tank. The concentrated slurry is washed to reduce the salt content and the spent wash is used as dilution water in the first reactor.

The washed slurry is sent in two batches to the precipitate reactor feed tank. The precipitate is hydrolyzed with acid, and the organic product, largely benzene, is stored and incinerated. The aqueous product is sent to DWPF to be vitrified along with sludge waste.

The design features of each Cs-removal process are summarized in Table II.

Table II. Design Features of each Cs-Removal Technology

	CST	**CSSX**	**STTP**
Cs Removal	• 5'-diameter, 16'-high ion exchange columns • 4-column configuration • Size-reduction equipment for CST delivery to DWPF	• 25-cm centrifugal contactors in each of the following steps: – extraction (15 stages) – scrub (2 stages) – strip (15 stages) • Extensive cold chemical equipment	• 2 CSTR for precipitation (16,000 gallons) • 1 precipitate concentration tank (10,000 gallons) • Moderate cold chemical equipment • Precipitate hydrolysis vessels and equipment
Alpha/Sr Removal	• Batch reactor large pumps (3x STTP) large cross-flow filters (2x STTP)	• Batch reactor large pumps (3x) large cross-flow filters (2x)	• Concurrent with Cs-removal

SUMMARY OF R&D RESULTS

The following is a summary of the R&D activities managed by the TFA in support of the DOE technology down-selection decision in 2001. This summary focuses primarily on those technology areas within each process that were previously identified as high risk (i.e., those technology risks that were believed to have the potential to increase the cost of the facility, lengthen the timeframe of the production schedule, or, in the worst case, result in a process being unable to achieve its mission). Although considerable progress has been made in reducing or eliminating technology risks, not all technology risks have been eliminated. There are some cases where new technology risks were identified within a given high-risk area in the course of conducting the R&D. Thus, some technology risks still remain for each alternative, and additional optimization studies are needed to support design of the operating plant. These technology needs will be addressed in subsequent R&D. In addition to an assessment of the current status of the previous high-risk areas, several other important R&D activities and results are summarized below.

Alpha/Sr Removal

Two high-risk areas were identified for the Alpha/Sr Removal process: MST Pu Removal Performance and MST/Filtration. R&D activities thus focused on evaluation of alternative alpha/Sr sorbents and alternative solid-liquid separation methods.

MST Pu Removal Performance: During the past several years, SRTC personnel examined the sorption of Pu – and other radionuclides – by MST under prototypical conditions for the three process options. The accumulated data demonstrated successful operation across a variety of waste compositions while meeting process requirements defined for the proposed facility. While the kinetics of Pu sorption limit the nominal processing capacity for all the process options, R&D and waste blending strategies showed that, for all but about 8% of the batches, MST adequately removed Pu with an acceptable efficiency. Based on the results of existing studies, a relatively low probability exists for failure of this process chemistry. Also, an inability to achieve desired decontamination factor (DF) requires reducing the molarity of sodium in the feed, increasing reaction time, or adding more MST, either of which would likely result in a brief delay in operations. Thus, the overall risk is reduced to a low rating.

Alternative Alpha/Sr Sorbents: Completed feasibility tests explored improved Alpha/Sr Removal through the use of alternative sorbents (i.e., inorganic materials other than MST) or treatment strategies (e.g., addition of permanganate with a reducing agent). Testing with the alternative sorbents indicates a potential to reduce processing time, batch reactor size, and filter equipment. More R&D are being pursued on these alternatives as a backup to MST for actinide/Sr removal.

MST/Filtration: The research for the cross-flow filtration technology used as the baseline for treating alpha/Sr in each Cs-removal technology included both pilot-scale demonstrations of the technology using simulated waste and successful experiments using actual HLW samples. For the STTP option, previous work demonstrated acceptable filtrate flow rate using real waste in full-scale equipment; therefore, MST/Filtration for this technology is a low-risk area.

For both the CST and CSSX processes, however, the measured performance showed notably lower processing rates for simulated wastes without the presence of the TPB precipitate. Also, comparative analysis showed reasonably good agreement between engineering-scale tests using simulated waste and laboratory-sized experiments using real waste. The engineering-scale demonstration yielded acceptable filtrate flow rate, but showed relatively poor performance with slurries containing the maximum concentration of solids expected for the facility. These data suggested the equipment would only marginally achieved the target performance and may well require frequent outages for cleaning. Thus, this technology could likely enforce an extension of the operating lifetime for the facility and still represents a moderate technology risk.

Alternative Solid-Liquid Separation Methods: To further reduce the risk associated with filtration, investigation of alternate means of solid-liquid separation continue, including the use of a centrifuge or of a high-shear, rotary cross-flow filter and alternate process configurations that use chemical additives to achieve enhanced sedimentation in advance of the solid-liquid separation step.

CST

Three high-risk areas were identified for CST Non-Elutable Ion Exchange: Sorbent Stability, Sorbent Sampling and Handling, and Gas Generation. Other areas studied included feed homogeneity and CST-glass studies.

Sorbent Stability: Both thermal and chemical factors can affect the stability of the ion exchange sorbent IE-911 (CST and binder) and were taken into consideration in assessing the risk associated with using IE-911. IE-911 has proven to be thermally stable at operating temperatures below 35°C, which is consistent with proposed normal operating temperatures. Chemical factors include the leaching of components from IE-911, formation of precipitates in the solutions, and coating of IE-911 particles with precipitates, all of which can ultimately lead to column plugging or particle agglomeration. Improvements have been made to IE-911 to effectively remove >95% of the leachable components. However, formation of precipitates in solution and coating of particles during processing remain as unresolved issues. The result is that sorbent stability remains a high risk for this process.

Sorbent Handling and Sampling: Sluicing of as-received IE-911 (500 $\pm$ 200 µm diameter), size-reduction of IE-911, and representative sampling of (size-reduced) IE-911/sludge/frit slurry, to simulate DWPF conditions, were considered in this risk area. Results of studies on sluicing of the relatively large IE-911 particles indicated that suspensions could be formed under the appropriate stirring conditions. Size-reduction of IE-911 particles was demonstrated in two brief vendor tests and indicated that particle-size distributions in the desired range could, with a high degree of confidence, be produced by either method. Sampling of the three-compound (size-reduced) IE-911/sludge/frit slurry was tested using a full-scale Hydragard® sampler in a test loop. The results indicated that the presence of IE-911 did not affect the performance of the Hydragard® sampler. The assessment of these three aspects of sorbent handling and sampling indicates that this risk area is low.

Gas Generation: IE-911 loaded with Cs-137 is expected to generate gas in the waste solution due to water radiolysis. Two possible effects of this gas on the performance of the ion-exchange column were investigated. Disengagement of gas bubbles entrained in the liquid between ion-exchange columns was tested to resolve issues related to sorbent blinding and formation of gaseous voids at the top of downstream columns. The results clearly indicated that gas-disengagement equipment (GDE) would be required between columns and that the GDE most likely will be effective.

The effect of radiolytically generated gas on the absorption of Cs by IE-911 was also investigated. Testing identified no discernible effect on Cs absorption by radiolytically generated gas. Thus, gas generation was judged to present a low risk for use of CST.

Feed Homogeneity: Recent tests showed the expected pattern of increasing yield stress and consistency with increasing solids content for the different melter feeds, all of which exceeded the DWPF design basis yield stress. These results suggest that the solids content of the slurry might have to be reduced (by ~4 wt%) if size-reduced IE-911 is used.

Glass Studies: A study was conducted to determine the effect, if any, of differing cooling rates on the Product Consistency Test (PCT) responses of CST glasses. Two bounding cooling profiles – rapidly quenched and canister-centerline – were used in this study. There was essentially no difference between the PCT responses for glasses subjected to the two cooling profiles. The very good durability of glasses containing IE-911 indicated that durability might not be the limiting factor for waste loading in this option.

CSSX

Four high-risk areas were identified for CSSX: Flowsheet Solvent System Proof-of-Concept, Chemical and Thermal Stability, Radiation Stability, and Real Waste Performance. Commercialization of manufacturing of the key solvent components was also investigated.

Flowsheet Solvent System Proof-of-Concept: The flowsheet solvent system was demonstrated in three tests using SRS average simulant solutions spiked with radioactive Cs-137 and 2-cm centrifugal contactors at ANL. Results from testing showed that the requirements for waste and solvent decontamination (DF $\geq$40,000) were met or exceeded. These very successful demonstrations of the flowsheet solvent system make the risk of failure of the flowsheet low.

Chemical and Thermal Stability: As described above, the solvent system for the CSSX process consists of four chemicals: the extractant (BOBCalix6), a modifier (CS-75B), TOA to aid stripping, and the diluent (Isopar® L). The chemical and thermal stability of this four-component solvent had not been tested previously to determine the products of reaction or their effects on processing, which led to an initial assignment of high risk. The overall conclusion of the studies was that chemical and thermal processes slowly degrade solvent, but effects on the solvent were easily corrected by caustic washing and periodic additions of TOA. Thus, the risk that chemical and thermal effects on the solvent will affect plant operation is low.

Radiation Stability: The risk of radiation stability was judged to be high in the earlier assessment because the solvent had not been tested to determine the products of reaction or their effects on processing. The radiation studies show the solvent to be quite stable to radiation with TOA being most sensitive to radiation-induced degradation. As a result of these studies, the risk that radiation effects will cause problems during plant operation is considered to be low.

Real Waste Performance: At the time of earlier risk assessments, very little real-waste testing had been conducted, which increased the risk that the process might not be viable. Efforts in FY 2001 focused on real waste testing with both batch equilibration studies with waste from several different F and H Area tanks, and a 48-hour test of the flowsheet in 2-cm centrifugal contactors similar to those used for the flowsheet proof-of-concept tests. The real waste test proved flowsheet viability, allowing the consequence to be lowered to moderate. The risk is lowered only to moderate because only one contactor test has been conducted and limited results are available of batch equilibration tests with real waste.

Solvent Commercialization: Efforts are underway to improve the processes for manufacture and to find vendors willing to make these chemicals. IBC Advanced Technologies, Inc. has demonstrated scale-up by preparing 1 kg of good purity extractant. An Expression of Interest solicitation for the manufacture of 2 kg of modifier and 50 g of extractant was sent to 29 companies with seven positive responses received.

STTP

Two high-risk areas were identified for STTP: Catalytic Product Decomposition and Reactor/Vessel Foaming. In addition, R&D activities were performed in two additional areas: precipitate hydrolysis testing and glass formulation.

Catalytic Product Decomposition: The risk of catalytic decomposition of TPB, like that experienced in In-Tank Precipitation Tank 48 in 1995, has been reduced by increasing the understanding of catalytic decomposition and through additional demonstration of process performance. Although an increased understanding of the catalytic decomposition process has been achieved, unknowns still exist as to what activates the catalytic decomposition in real waste. Nevertheless, even if decomposition should occur, R&D tests indicate that the STTP process will meet required DFs, reducing the risk of catalytic product decomposition to moderate.

Reactor/Vessel Foaming: During the STTP process, foaming could occur in the precipitate tank, the concentration tank, and the wash tank. The candidate antifoam must not only be effective in controlling foam in these three tanks, but also must not negatively impact downstream processes or waste forms. Illinois Institute of Technology had developed antifoam known as IIT B52. Testing has shown IIT B52 to be an effective antifoam for the STTP process should foaming occur. Therefore, the risk to the STTP process of reactor/vessel foaming is considered to be low.

Precipitate Hydrolysis Testing: Studies were done to determine the impact of IIT B52 antifoam on hydrolysis kinetics. It was concluded that IIT B52 rapidly decomposes in the feed slurry and/or during acid hydrolysis, and no impact on the process is expected.

Glass Formulation: A glass formulation study was conducted to determine the effect, if any, on the PCT responses of Precipitate Hydrolysis Aqueous (PHA) glasses cooled at different rates: rapidly quenched and canister centerline cooling. The results showed that there was no practical difference between the PCT responses for glasses subjected to the two cooling profiles. Therefore, there is a minimal concern for any impacts on vitrification.

MANAGEMENT APPROACH

DOE prepared an Action Plan to assign roles and responsibilities for the activities necessary to support technology evaluation and selection. The TWG was established to steer the overall activities of R&D evaluation and develop a process to make a technology selection. Fig. 1 shows the organization that DOE assembled. The TWG members were Kenneth Lang (EM-40), Kurt Gerdes (EM-50), Kenneth Picha (Office of Integration and Disposition) and William Spader (DOE-SR). Kenneth Lang was designated as the lead for operation of the TWG. DOE also established the Technical Advisory Team (TAT), a group of consultants led by Joel Case of DOE-Idaho, who provided operational experience and subject matter expertise to assure that operations and implementation issues were identified and addressed. The TFA also utilized its own senior consultants (the Technical Advisory Group [TAG]) with expertise in HLW pretreatment. The TFA incorporated the input from these subject matter experts into the R&D Program Plan to obtain resolution of issues on a schedule that supported down-selection among the alternatives by June 2001.

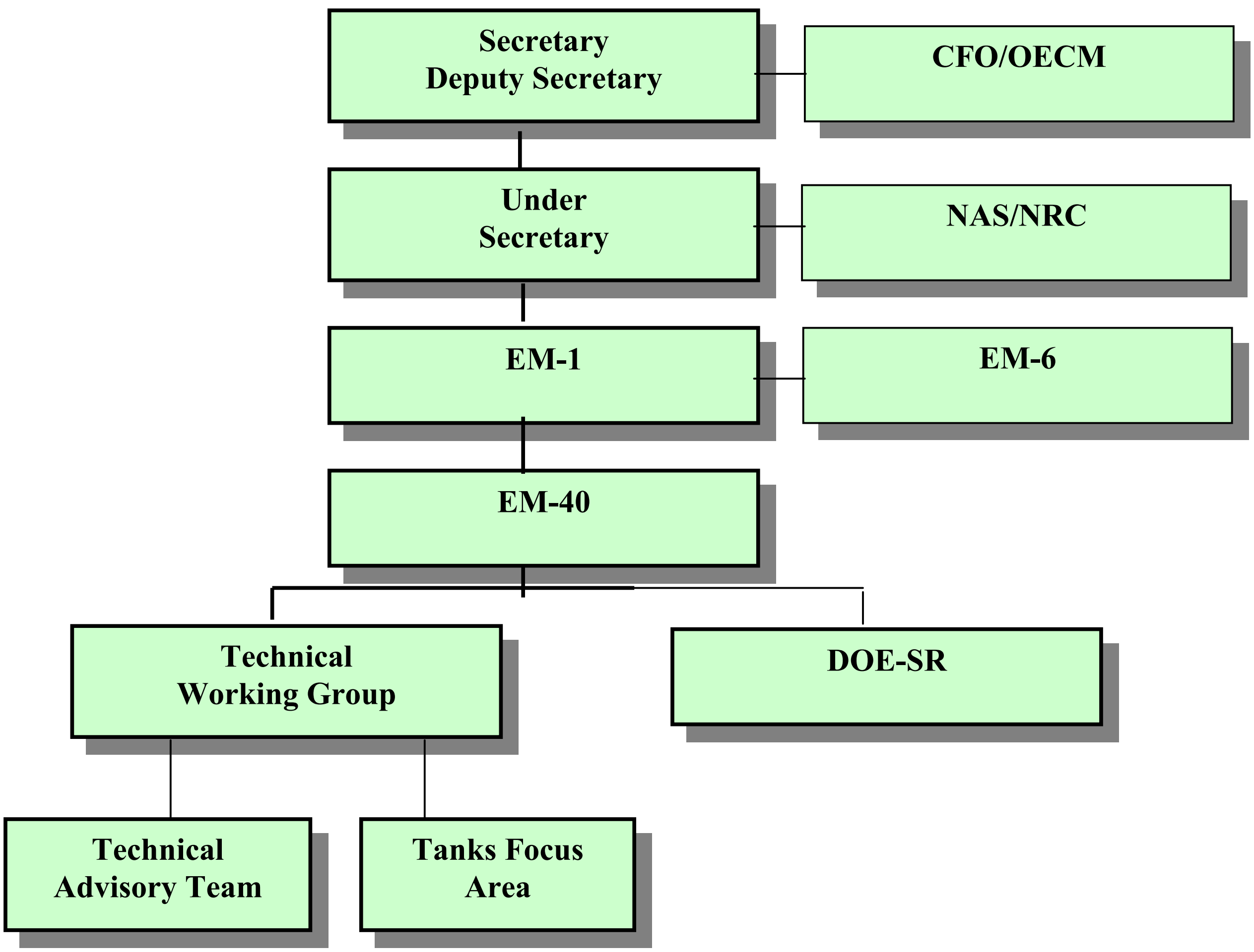


Fig. 1. Management Structure for SRS HLW
SPP Technology Development and Selection

These entities, along with representatives of the SRS SPP, collectively formed the SPP Team.

DOE-HQ and DOE-SR line management had overall responsibilities for oversight and decision making including:

- Approval of criteria
- Re-evaluation of technologies with new and updated data packages
- Formal request for any new studies
- Evaluation of activities to accelerate key R&D activities
- Monitor progress through quarterly updates as R&D programs and engineering data packages mature

The TWG was responsible for managing the technology development of treatment activities through:

- Approval of SRS SPP R&D Program Plan
- Development of technology roadmaps
- Establishing down-selection criteria and weights
- Project integration
- Ensuring project execution and technical oversight
- Briefings to DNFSB and Congressional Staffs
- Facilitating public involvement with open conferences, including a vendor forum
- Reporting to Senior DOE-HQ management on project status
- Making a technology recommendation to Office of the Assistant Secretary (EM-1)

The TFA was responsible for:

- Evaluating technical issues to be resolved
- Revising Technology Roadmaps
- Evaluating R&D of the three alternate Cs-removal processes
- Supporting the identification of criteria to be used for potential down-selection during the R&D phase
- Preparing the new R&D Program Plan
- Endorsing new R&D work scope, and recommending approval to TWG
- Perform R&D activities
- Monitoring progress of the R&D activities
- Serving as a technical resource with specific emphasis on R&D for the TWG
- Convening and facilitating meetings, teleconferences, conferences, workshops, and providing briefings/presentations

The TAT was responsible for:

- Assessing the results of the R&D program and translating the data to impacts on design, construction and operation of production scale facilities
- Providing an engineering maturity baseline for each of the alternatives, which includes a review of the pre-conceptual design as well as the identification of key scale-up issues associated with each alternative
- Assisting the TWG in the development of down-selection criteria, and ensuring that the down-selection criteria address the engineering aspects of the project
- Serving as a technical resource with expertise in implementation of treatment technologies for the TWG
- Project integration

DOWN-SELECTION DECISION PROCESS

Decision Analysis Approach

The SPP decision process(7) focused its analysis on three levels: (a) identification of goals that the selected technology should achieve, (b) selection criteria that are a measure of performance of the goal, and (c) criteria scoring and weighting for each technology alternative. Six goals were identified that appeared to be clear, unique, and inclusive objectives for the project: meet schedule, minimize cost, minimize technical risk, minimize environmental safety and health (ES&H) risk, minimize impact to interfaces, and process flexibility. The technology alternatives were analyzed and criteria were defined that reflected how well each technology achieved the project goals. A series of trial scoring, sensitivity analysis and weighting were conducted using these criteria to confirm their efficacy. The effectiveness of the initial criteria were based on the following factors:

- Differentiation between technology alternatives,
- Relationship to goals or values of DOE and other stakeholders,
- Measurable or estimable,
- Reasonably independent of each other, and
- Well understood by all decision makers.

Table III summarizes the final criteria and definitions that were approved by DOE-HQ in August 2000. In the scoring process, the specific scores assigned varied from 1 to 5 for each criterion, with 1 being the worst, and 5 being the best. The TWG also assigned weights to the goals, which were then allocated among the criteria associated with each goal, to provide a measure of their relative significance and confidence. The scores then multiplied the weights for each criterion, with these products being summed for each technology to obtain a final score for each technology. The TWG also considered other factors, including strengths and weaknesses of each alternative and implementation characteristics of each technology such as reliability, maintainability, inspectability, and recoverability from process upsets.

Criteria Evaluation

The SPP Team proceeded in the technology evaluation in a stepwise process. At each quarterly progress meeting, they tested the data collected to assure its utility for scoring the technology alternatives. These trial scorings also allowed the Team to assess whether the progress of data acquisition was adequate to support technology selection, to establish protocol to normalize the data to utility scores, and to assess the sensitivity of weighting and other factors.

Table IV shows the normalization protocol used to convert data to utility scores. For each of the criteria, the table defines the data needed to convert the "critical measures" for each criterion to a utility score. The table defines whether the relationship between the measures and the score are linear or non linear, what critical measure defines the top and bottom of the (1-5) utility range, and what magnitude of change constitutes a change of one point in utility score. Scoring results were shown in "consumer reports" charts. These charts show, as a color-coded circle, the merit of each criterion for each alternative.

To examine the effects of weighting, the Team prepared a chart for each criterion that showed the overall score for each of the technologies as a function of relative weight. Fig. 2 is a trial weighting sensitivity chart for Criterion 10, "Process Flexibility." If all criteria were equal, each would be weighted 0.091; and the Team generally weighted Criterion 10 somewhat less (0.025 to 0.08). Most significantly, the chart shows that as the relative weight of Criterion 10 increases (and the other criteria decrease proportionally), the score of CST increases and CSSX decreases, and that there is a crossover point. If the weighting is greater than 42%, CST scores higher than CSSX. Similar weighting analyses were conducted for all criteria and they indicated that the weighting would have to be changed by at least 0.15 to affect selection.

Combined, these analyses show that the technology selection is most sensitive to scoring and somewhat less sensitive to weighting. Finally, another sensitivity analysis indicated that the scoring would be affected by rounding. The TWG opted to carry two significant figures in the final scoring because it was supported by the quantitative data used and avoided potential problems due to rounding.

Final Scoring Of Alternatives

In May 21-23, 2001, the TWG met to score the alternatives using the criteria discussed previously and the scoring protocol described in more detail in Reference 7. WSRC provided engineering data packages to support scoring of several criteria. The TWG used the TFA and TAT to advise them during their evaluation. The TWG requested that the TFA and TAT independently score the alternatives based on their discussion of the R&D results, the WSRC data packages, and their personal expertise. The TWG observed these discussions and were provided the results and

Table III. SPP Down-selection Criteria and Definitions

CRITERION	DEFINITION
1. Schedule Risk	Risk to the overall SRS high level radioactive waste program schedule due to high-risk technology issues not being resolved in time to support down-selection by June 2001. This includes programmatic schedule risks.
2. Project Reduction Potential	Potential that cost savings in the total project cost can be identified (generally due to flowsheet or equipment arrangement changes that would allow facility footprint reduction).
3. Life Cycle Costs Through Decontamination & Decommissioning	Total costs to complete all salt processing (including HLW system costs). The focus on life-cycle costs, but the separate components of total project costs and operating costs are examined for key differences.
4. Technical Maturity	The overall maturity of the process flowsheets (including the required strontium and actinide removal steps). EM-50 stages of maturity are applied to each unit operation and the results are averaged.
5. Implementation of Confidence	Amount of relevant process experience (large-scale demonstration or deployment) in the DOE complex and industry for the key equipment used for each cesium-removal process. This criterion includes commercial availability of key components and chemicals.
6. Environmental Impacts	Comparative assessment of environmental impacts from secondary waste streams, airborne emissions, and liquid effluents. This criterion also includes the number of Saltstone vaults for each process.
7. Impacts of the Interfaces at DWPF	Cost of implementing the changes (physical modifications) to the interfacing systems and the loss of canister production caused by outages for equipment installation or transfer-line tie-ins.
8. Process Simplicity of System Interfaces	The simplicity of interfacing the alternative cesium-removal process with other HLW systems. The simplicity is measured by the number of process unit operations needed for the interfaces times a difficulty factor for each interface unit operation.
9. Levels of Safety Control Mitigation	Number and type (e.g., passive, active, administrative, preventive, and mitigative) of controls required to maintain the facility in a safe configuration and to protect the worker, public, and environment.
10. Process Flexibility in Throughput	Capability to operate the process at a higher or lower throughput (turn-up or turn-down) based on the equipment in the current pre-conceptual design.
11. Process Simplicity (Operability)	Simplicity of the process as indicated by the number of pieces of equipment (in both the non-radioactive areas or the remotely operated area) and the number of jumpers (piping connections) required inside the remotely operated area.

brief written summaries of the rationale for the TFA and TAT assigned scores. The TWG then used all the available information and conducted their final scoring for input to down selection, focusing on ensuring factors discovered in the technology development and expert reviews were considered appropriately in the criteria scores.

Fig. 3 provides a "consumer report" type of chart representing a quantitative ranking of the TWG's final evaluation. Based on their scoring results, the TWG recommended CSSX as the preferred Cs-removal alternative.

SELECTION OF CSSX

On May 24, 2001, the SPP Management Review Board (Board) from DOE-HQ and DOE-SR heard from various reviewers, the technology leads, the national laboratory contributors, and the TWG on their evaluations and recommendations for down selection of a primary and backup technology for the SPP. The Board endorsed the TWG recommendation that CSSX be designated the primary Cs-removal technology for SRS high level salt waste. The R&D work done to-date and operating experience in DOE and industry supported a decision to move this technology forward to conceptual design of the an operating facility. The Board believed that additional hot waste testing was essential to confirm system effectiveness in Cs removal, and should be carried out as soon as possible to ensure that design activities are supported.

Table IV. Protocol for Normalizing Data

CRITERIA NAME	POINT WORTH	LINEAR/ NON-LINEAR	SCORE EXPLANATION 5 would be	1 would be
1. Schedule Risk	2 mo. per point	Linear	Early by two mo.	Probably late by 8 mo.
2. Project Reduction Potential	10 VE Savings points per point	Linear	Highest (43 now)	0-3 value points
3. Life Cycle Costs Through D&D	TPC - $200 M per point	Linear	$1000 K	$1800 K
	LCC - $500 M per point	Linear	$2000 K	$4000 K
4. Technical Maturity	MST or Cs Seps. Ops - 1 average stage from maturity chart per point	Linear	5 fully mature	1 concept
5. Implementation of Confidence	Equipment Maturity - 1 average stage from maturity chart per point	Linear	5 fully mature	1 concept
6. Environmental Impacts	Benzene Release – point for some, scale from some to permit limit	Non-linear	No release	Permit level release
	Saltstone Vaults – point per extra vault	Linear	12 vaults	16 vaults
	Secondary Waste (gal.) – some vs. lot is bottom of scale	Non-linear	No organic to treat/ dispose	73 K gallons
9. Levels of Safety Control Mitigation	10 safety controls per point	Linear	20 safety controls	60 safety controls
7. Impacts of Interfaces at DWPF	25 lost canisters per point (1 mo. downtime)	Linear	0 lost	100 lost or 4 mo.
	Extent of Upgrades - 25 M represents 1 point of complexity	Linear	0 upgrades	100 M upgrades
8. Process Simplicity of System Interfaces	2 complexities per point	Linear	0 complexities	8 complexities
10. Process Flexibility in Throughput	Turn Up or Down - 25% turn up capability per point	Linear	100% turn up	0% turn up
11. Process Simplicity (Operability)	50 jumpers per point	Linear	200 jumpers	400 jumpers

Thus, the Board recommended that the Assistant Secretary for Environmental Management accept the TWG recommendation to select the CSSX Cs-removal process as the primary Cs-removal technology for SRS high level salt wastes. This decision was recorded in the Final SEIS(5) and the Notice of Availability was published in the Federal Register on July 20, 2001(6).

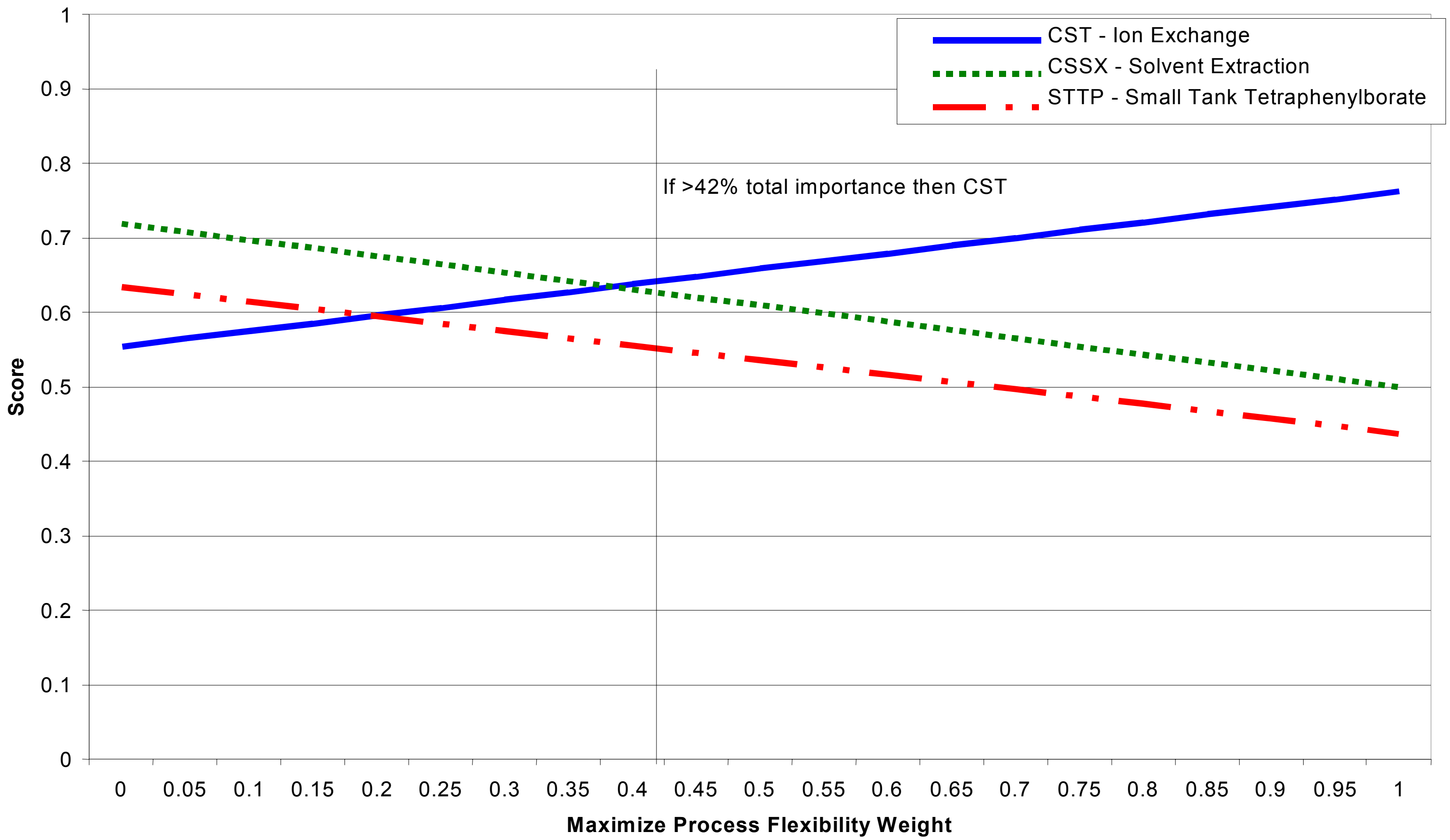
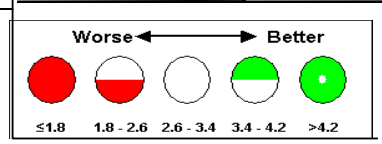


Fig. 2. Process Flexibility Sensitivity Analysis

Project Goal – Confidence Weight	Criteria	CST Overall Score: 30%	CSSX Overall Score: 80%	STTP Overall Score: 59%
Meet Schedule – 9%	1. Schedule Risk	2.0	5.0	5.0
Minimize Cost – 4%	2. Project Reduction Potential	3.0	3.0	2.0
	3. Life Cycle Costs Through D&D	3.7	2.6	3.8
Minimize Technical Risk – 22%	4. Technical Maturity	3.9	3.8	4.4
	5. Implementation Confidence	2.0	4.0	4.0
Minimize ES&H – 26%	6. Environmental Impact	5.0	4.9	3.6
	9. Levels of Safety Control Mitigation	1.0	4.5	2.5
Minimize Impacts to Interfaces – 26%	7. Impacts of Interfaces at DWPF	3.6	3.6	4.6
	8. Process Simplicity of System Interfaces	1.8	4.2	3.4
Maximize Process Flexibility – 13%	10. Process Flexibility in Throughput	5.0	4.2	2.6
	11. Process Simplicity (Operability)	2.0	4.0	2.0



Problem Trying to Solve: Safely and cost effectively process salt from SRS HLW tanks to a final permitted waste form(s).
Scoring Method: 1 to 5 Scale

Fig. 3. TWG’s Final Evaluation

It was also recommended that the Assistant Secretary defer a decision on either CST or STTP as backup technologies to provide additional time for further development. Although it has been shown that there was a reasonable probability that the benzene generation issue associated with STTP could be dealt with through engineering solutions, uncertainties in understanding the chemistry of decomposition of TPB in STTP still exist. Because of this, the unpredictability of the decomposition remains a serious concern. However, an extensive hot waste testing program to determine the bound of the problem may allow an engineering solution and may also provide a better understanding of the mechanism.

As for the CST removal technology, the research program to date had been carried out with the significant constraint of the current large column, fixed bed design. Results from this work indicate that significant redesign and analysis of the proposed large columns was necessary to overcome postulated column channeling, plugging, and heating effects. For these reasons, the Board believed that additional R&D and engineering analysis (without the constraint of the current fixed bed design) would be required before designating CST as the backup technology. Thus, even though the TWG recommended STTP as the backup technology, the Board feels that there was not sufficient information about or differentiation between STTP and CST to make a choice at that point.

PATH FORWARD

On October 4, 2001, DOE issued the Record of Decision(8) on SRS Salt Processing Alternatives. Based on the analyses in the SEIS and the results of laboratory-scale R&D and independent reviews, DOE determined that any of the alternatives evaluated could be implemented with only small and acceptable environmental impacts. DOE decided to implement CSSX for separation of radioactive Cs from SRS salt wastes. Initial implementation of the CSSX technology will consist of designing, constructing, and operating a facility in S-Area. DOE will evaluate the processing capacity needed and may elect to build a facility or facilities to carry out the CSSX process that could accommodate pilot program and production objectives, but would not exceed the size or processing capacity evaluated in the SEIS. In parallel, DOE will evaluate implementation of other salt processing alternatives for specific waste portions for which processing could be accelerated or that could not be processed in the CSSX facility. These evaluations and potential operations would be undertaken to maintain operational capacity and flexibility in the HLW system, and to meet commitments for closure of HLW tanks.

REFERENCE

1. "Savannah River Site Salt Processing Project Research and Development Program Plan", PNNL-13253, Revision 1, November 2000.

2. "Savannah River Site Salt Processing Project Research and Development Summary Report", TFA-0105, Revision 0, May 2001.

3. "Technical Working Group's Final Report on the Salt Processing Project Technology Selection", June 2001.

4. "Salt Processing Project Management Review Board Summary Report", May 24, 2001.

5. "Savannah River Site Salt Processing Alternatives Final Supplemental Environmental Impact Statement", DOE/EIS-0082-S2, June 2001.

6. Federal Register, Vol. 66, No. 140, July 20, 2001.

7. "Savannah River Site Salt Processing Project Down Selection Decision Analysis Summary Report", TFA-0106, Revision 0, June 2001.

8. "Record of Decision: Savannah River Site Salt Processing Alternatives", U.S. Department of Energy, 6450-01-P, October 9, 2001.