INITIAL SELECTION OF SUPPLEMENTAL TREATMENT TECHNOLOGIES FOR HANFORD'S LOW-ACTIVITY TANK WASTE

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ABSTRACT

In 2002, the U.S. Department of Energy (DOE) documented a plan for accelerating cleanup of the Hanford Site, located in southeastern Washington State, by at least 35 years. A key element of the plan was acceleration of the tank waste program and completion of "tank waste treatment by 2028 by increasing the capacity of the planned Waste Treatment Plant (WTP) and using supplemental technologies for waste treatment and immobilization." The plan identified specific technologies to be evaluated for supplemental treatment of as much as 70% of the low-activity waste (LAW). In concert with this acceleration plan, DOE, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology proposed to accelerate -- from 2014 to 2006 -- the Hanford Federal Facility Agreement and Consent Order milestone (M-62-11) associated with a final decision on the balance of tank waste that is beyond the capacity of the WTP.

The DOE Office of River Protection tank farm contractor, CH2M HILL Hanford Group, Inc. (CH2M HILL), was tasked with testing and evaluating selected supplemental technologies to support final decisions on tank waste treatment. Three technologies and corresponding vendors were selected to support an initial technology selection in 2003. The three technologies were containerized grout called cast stone (Fluor Federal Services); bulk vitrification (AMEC Earth and Environmental, Inc.); and steam reforming (THOR Treatment Technologies, LLC.). The cast stone process applies an effective grout waste formulation to the LAW and places the cement-based product in a large container for solidification and disposal. Unlike the WTP LAW treatment, which applies vitrification within continuous-fed joule-heated ceramic melters, bulk vitrification produces a glass waste form using batch melting within the disposal container. Steam reforming produces a granular denitrified mineral waste form using a high-temperature fluidized bed process.

An initial supplemental technology selection was completed in December 2003, enabling DOE and CH2M HILL to focus investments in 2004 on the testing and production-scale demonstrations needed to support the 2006 milestone.

INTRODUCTION

The Hanford Site's radioactive tank waste resulted from 40+ years of nuclear materials production operations. Baseline plans for disposition of these wastes include the separation of low-activity and high-level fractions of the waste, followed by vitrification of both fractions to produce immobilized high-level waste (HLW) and low-activity waste (LAW) forms. The immobilized HLW will be disposed in a deep geologic repository, while the immobilized LAW will be disposed in a shallow burial facility at Hanford. Separation and vitrification operations will be performed in the Waste Treatment Plant (WTP) that is currently under construction. The WTP contract and initial operations were intended to treat approximately 10% of the tank waste mass and 25% of the tank waste radioactivity by 2018. Additional treatment capacity was to be brought online by 2018 to support full production and completion of the tank waste treatment mission by 2048. However, this schedule did not support the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement [TPA]) milestone to complete tank waste treatment by 2028.[a]

In 2002, the U.S. Department of Energy (DOE), Washington State Department of Ecology (Ecology), and the U.S. Environmental Protection Agency (EPA) agreed to cooperatively develop approaches to accelerate Hanford Site cleanup, including evaluating methods to accelerate tank waste treatment. Enhanced WTP capacity for both HLW and LAW vitrification could be achieved by 2010. However, WTP capacity enhancements alone would still not provide adequate schedule acceleration to meet the TPA milestone. Additional LAW treatment capacity, supplemental to the WTP, would be required (Fig. 1). Supplemental treatment could be applied to tank wastes that have been pretreated through the WTP or to tank wastes that have undergone sufficient alternate pretreatment. To accelerate the treatment mission, reduce costs, and meet the TPA commitment of 2028, a mission acceleration initiative (MAI) and an acceleration plan were developed that included both WTP enhancements and evaluation of supplemental treatment [1].

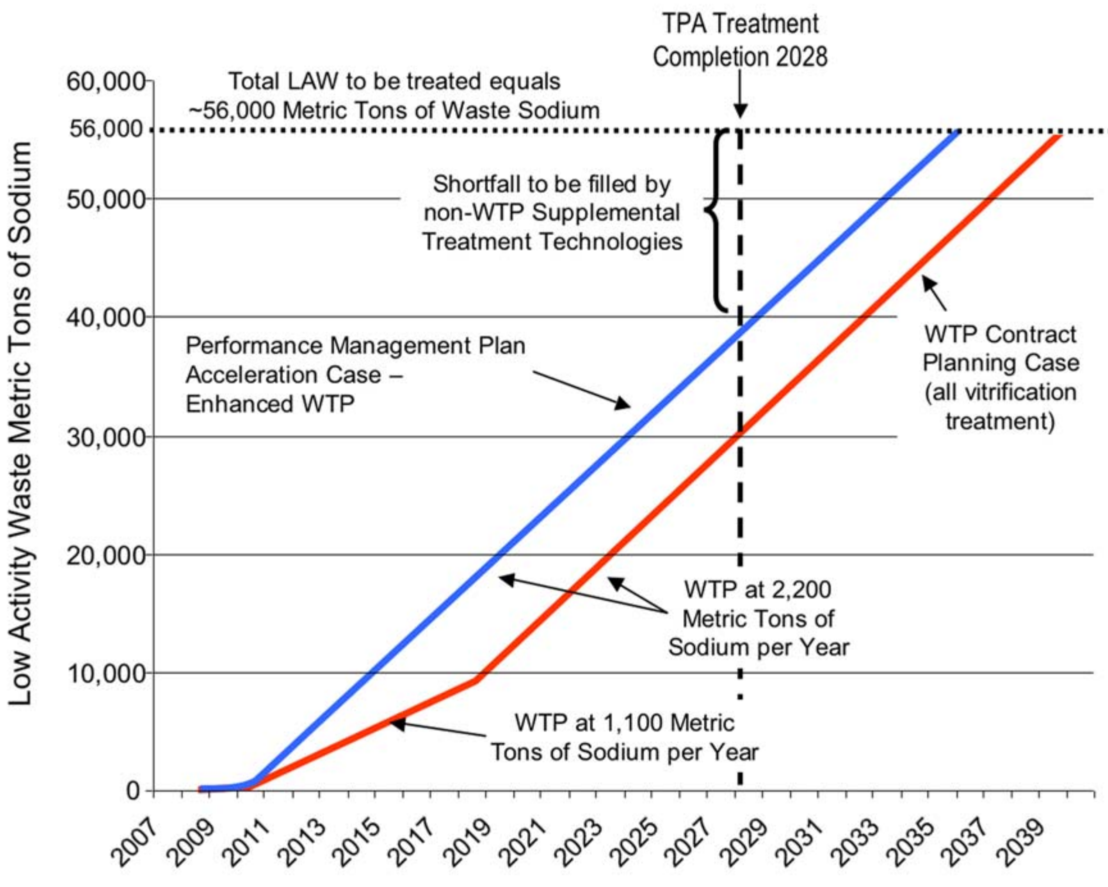

Fig. 1. Comparison of Waste Treatment Plant (WTP) contract and Performance Management Plan acceleration cases for treating Hanford low-activity waste (LAW). The combination of accelerated LAW treatment in the WTP and supplemental technologies provides a pathway to complete waste treatment by 2028.

In a series of workshops in 2002, an MAI team consisting of DOE, Ecology, EPA, DOE contractors, and external experts evaluated dozens of technologies for supplemental treatment and recommended three LAW immobilization approaches for further evaluation[b]: 1) containerized grout, 2) bulk vitrification, and 3) steam reforming [1,4].

The containerized grout technology mixes LAW with cementitious materials (such as Portland cement, fly ash, clays, and blast furnace slag) which are poured into mild steel containers and allowed to solidify. Unlike previous Hanford plans for grouting tank waste that involved the pouring and solidification of the cementitious waste form in large monolithic vaults [6], the containerized grout waste package could be readily retrieved, if necessary, after disposal. In addition, some of the earlier grout formulation constraints -- needed to ensure pumpability -- could be removed because the containerized grout mixture is cast directly into the steel container.

Bulk vitrification combines LAW and glass-forming chemicals within a large disposal container and melts the contents using electrical resistance heating. Bulk vitrification employs a disposable melter where the waste form and melter (i.e., container) are disposed in a LAW burial ground after the vitrified waste form has cooled. Because the bulk vitrification melter is used only once, some of the processing constraints of the baseline joule-heated, continually fed ceramic melters can be avoided.

Steam reforming is a moderate temperature (650-800°C) fluidized bed process that produces a solidified mineral waste form. The process operates by reacting LAW with carbon and iron-based reductants to convert nitrates and nitrites directly to nitrogen gas. Radionuclides, alkali metals, sulfate, chloride, fluoride, and non- volatile heavy metals in the waste stream are reacted with clay (kaolinite) or other inorganic materials to produce a polycrystalline mineral product. Some constituents of LAW that limit waste loadings in the baseline vitrification process, such as sulfate, can be readily processed by steam reforming.

The objective of the MAI in 2003 was to test and further evaluate these three supplemental treatment options to support an initial technology selection. In concert with DOE's acceleration plan for tank waste treatment, Ecology, EPA, and DOE proposed TPA milestone changes (Table I) to accelerate the joint agency decisions and schedule the establishment of requirements for completing tank waste treatment [2]. A final regulatory decision on tank waste treatment was accelerated from 2014 to 2006. Therefore, the goal was to make an initial selection in 2003 and focus fiscal year (FY) 2004 and 2005 resources on the selected technology(s) to support the TPA M-62-08 and -11 negotiations and decision.

The overall goal of the MAI is to select and bring online the appropriate combination of WTP and supplemental treatment capacity to ensure completion of tank waste treatment by 2028.

DOE's Hanford tank farm contractor, CH2M HILL Hanford Group, Inc. (CH2M HILL), was tasked with performing the required testing and evaluation of the three supplemental technologies to support the initial technology selection decision in 2003. The approach to technology selection included criteria definition, process testing and analysis, process evaluation, and process recommendation. Each of these elements of the approach was conducted collaboratively with DOE, Ecology, and EPA to ensure that the initial technology selection would be acceptable and supportive of the TPA.

SELECTION CRITERIA DEVELOPMENT

In July 2002, shortly after the MAI team recommendation to further evaluate three supplemental treatment technologies [4], an effort was initiated to define the criteria by which an initial technology selection could be made. The acceleration plan established a 13-month schedule for technology testing,

Table I. TPA Milestones and Changes Associated with Supplemental Treatment

TPA Milestone	TPA Milestone Title/Description	Due Date	Major Changes Proposed June 24, 2003
M-62-08	Submittal of Hanford Tank Waste Supplemental Treatment Technologies Report, Draft Hanford Tank Waste Treatment Baseline, and Draft Negotiations Agreement in Principle	1/30/2005	Accelerates technology report from 7/31/05, eliminates need for 2-year updates of report through 2014. Accelerates Agreement in Principle from 1/31/2014.
M-62-11	Submit a Final Hanford Tank Waste Treatment Baseline	1/30/2006	Accelerates completion of negotiations on final tank waste treatment from 2014.

evaluation, and an initial technology selection decision. The MAI process in 2002 had demonstrated the value of involvement of the three agencies responsible for the ultimate TPA decisions, the tank farm contractor, and supporting technical staff in the evaluation and selection process. In addition, a similar technology selection process recently completed for DOE's Savannah River Site Salt Waste Processing Facility provided lessons learned that could benefit the supplemental treatment selection decision [5]. A key lesson learned from the Savannah River Site decision was involving the DOE decision makers and technical experts early in defining the selection criteria and process and continuing their involvement throughout the process as data supporting the evaluation became available. Extended workshops with decision makers and experts were extremely valuable to the Savannah River Site Salt Waste Processing Facility selection in defining criteria, evaluating data, and reaching consensus on information and recommendations. However, unlike the Savannah River Site selection, Hanford's supplemental treatment decision process involved direct input from external Hanford regulators: EPA and Ecology.

A selection criteria workshop was held in late July 2002 to define the supplemental treatment goals, criteria, and measures by which the criteria could be judged. The all-day workshop involved DOE, Ecology, EPA, and contractor management and technical staff, and resulted in clearly defined goals and criteria, and a draft set of measures. A series of follow-up meetings were held to refine the measures and produce a consensus set of criteria and measures. Table II lists the 6 supplemental treatment goals, 10 selection criteria, and 14 measures that were developed with the MAI team to guide the technology evaluation and selection process.

Initial criteria development efforts emphasized identification of quantitative and objective measures to minimize subjectivity in the selection process. However, as the criteria development process evolved, both quantitative and qualitative, and both objective and subjective measures were selected for use in evaluating each criterion. Several important lessons learned and notable expectations were identified through the selection criteria development process.

- Both quantitative and qualitative measures were acceptable. Quantitative measures were originally identified for several criteria such as *achieve inherently safe system* and *operability risk*. However, the measures were changed to allow more qualitative and subjective expert assessments. For these criterion, it was difficult to identify quantitative measures that a) were limited in number and for which data could be obtained without significant expenditure of resources, b) represented a direct relationship to the criterion and goal rather than an indirect indicator, and c) could be communicated externally and readily understood by stakeholders and the public. Expert assessments allowed for subject area experts to use their collective technical judgment to evaluate each technology option against the criterion

Table II Supplemental treatment technology selection decision goals, criteria, and measures

Goal	Criterion	Measures
Ensure worker and public safety	Achieve inherently safe system	Independent safety expert assessment
Provide environmental protection comparable to current vitrified waste disposal plan[1]	Waste form performance	Flux at points of undisturbed soil and bottom of the waste packages
	Disposal space required	Acres of land for disposal site
	Secondary wastes produced	Potential to emit (PTE) constituents; solid waste volume; liquid waste volume
Maximize schedule acceleration	Confidence in meeting 2028 date[2]	50% probability date for achieving 10 GPM throughput
	Process robustness	Metric tons of sodium (Na) processed by 2028
Maximize cost effectiveness	Life cycle cost [2]	Life cycle cost (LCC)
	Peak year cost	Peak year cost
Maximize operability	Operability risk	Independent expert assessment to include: Number of unit operations; equipment count, etc.
Minimize overall system interface impacts	System interface impacts	Liquid effluent greater than Effluent Treatment Facility (ETF) capacity
		Dose of waste package (impacting handling within disposal system)
		Volume returned to double-shell tanks (DSTs) (impacting stored waste volume)

[1] Achieve comparable level of environmental performance to vitrification considering the nature of waste, pretreatment, and performance of the immobilized waste form and/or disposal units.

[2] Schedule and cost goals include consideration of the difficulty of obtaining facility permits, Waste Incidental to Reprocessing (WIR) determination, additional infrastructure required, increased disposal costs based on waste volume differences, etc.

- Waste form performance is a particularly important criterion. A quantitative measure was selected to calculate the flux of key contaminants out of each waste form package and into the undisturbed soil below the disposal facility as a function of time. This measure represents a key output of performance assessment calculations and was selected because it allows for direct comparison of each waste form to the baseline WTP immobilized LAW glass product. Because the TPA currently requires vitrification of all tank wastes, Ecology communicated their expectation that the selected supplemental treatment waste form must be as good as the baseline immobilized LAW glass in terms of waste form performance. This value was incorporated into the selection process.
- Criteria weighting and scoring were not applied. Instead, quantitative and qualitative evaluation of the technologies against each criterion was deemed appropriate to provide decision makers with the information necessary to support a decision. Decision processes frequently use quantitative methods with scoring of each option against the criterion and weighting of each criterion. These methods allow for summation of individual criterion scores to produce an overall ranking of the options. While such weighting and scoring were options that the evaluation team could have employed, it was not necessary to achieve a consensus evaluation.

Concurrent with the selection criteria development, several Requests for Information were issued to identify prospective vendors for the supplemental treatment technologies. Technology testing recommendations [7], Statements of Work, and Requests for Proposals (RFPs) were also being developed. Results of the selection criteria development efforts were used as input to the testing recommendations and the Statement of Work development and helped ensure that data needed to support the eventual selection decision would be available from the vendors' FY 2003 project activities.

PROCESS TESTING AND ANALYSIS

Two competitive procurements and one sole-source procurement resulted in the selection of three vendors to conduct testing and/or engineering design and analysis in FY 2003 to support the selection decision process. Contracts were awarded for containerized grout (Fluor Federal Services), bulk vitrification (AMEC Earth and Environmental, Inc.), and steam reforming (THOR Treatment Technologies, LLC). Each of the vendors was contracted to develop a preliminary engineering design and cost estimate for a facility capable of processing 10 gallons per minute of low-activity saltcake waste with a nominal 5 Molar sodium concentration. Fluor Federal Services proposed a containerized cementitious waste form referred to as cast stone. AMEC Earth and Environmental, Inc. proposed a proprietary in-container vitrification technology that uses soil as the primary glass former additive. Both Fluor Federal Services and AMEC Earth and Environmental, Inc. work activities included significant development and testing of their respective waste forms with both Hanford tank waste simulant and small quantities of cesium-decontaminated tank waste to produce data needed for the selection decision process. THOR proposed a proprietary steam reforming technology that had been previously demonstrated on a Hanford tank waste simulant. This demonstration was performed for Bechtel National, Inc., to support an initial evaluation of the technology's potential for enhancement to the WTP. A single pilot-scale test was performed in 2002 with a waste simulant and produced a non-radioactive waste form for subsequent testing and analysis [8, 9]. Samples of both bulk vitrification and steam reforming waste forms underwent several additional tests at the Pacific Northwest National Laboratory to produce specific data needed to support waste form performance calculations. Cast stone samples were tested at the Hanford 222-S Laboratory.

Results of testing, engineering design, and analysis were documented for each of the technologies. All three vendors produced detailed preliminary engineering reports that described their preliminary design, flow sheet, material balance, and estimated cost for the design, construction, and operation of facilities for nominal treatment of 40,000 metric tons of sodium (as LAW) at a throughput of 10 gallons per minute. Each vendor also provided development and testing reports documenting results of both process and waste form testing conducted during the supplemental treatment contract period or prior projects. Additional testing and analysis performed by Pacific Northwest National Laboratory to support performance calculations for bulk vitrification and steam reforming were also documented [10, 11].

PROCESS EVALUATION

The process for evaluating each supplemental treatment technology against the 10 selection decision criteria and their corresponding 14 measures followed the phased approach described in this section.

Data Mapping and Trial Calculations

This first phase involved an effort to map the product or output for each measure back to the required data inputs to ensure that a) all necessary data were being obtained on schedule to support each measure's analysis, and b) the analyses were technically sound, unbiased, and achievable with the resources available. Each measure was assigned to an appropriate CH2M HILL technical staff member responsible for leading the evaluation process (i.e., measure leads). Each measure lead identified any additional technical support needed to implement the analysis process. This phase also involved additional definition of the process and products for the two expert assessment measures and selection of internal and external experts to support these assessments.

Review of Trial Analyses with the MAI Team

This second phase ensured that the products for each measure were consistent with the MAI team's needs to support the selection decision. The process, preliminary, or trial input data, and preliminary measure products were reviewed to ensure that the MAI team concurred with the specific plans for each measure's data evaluation and analysis. The process and products planned for each of the 14 measures were reviewed during weekly meetings extending over approximately 1 month.

Draft Qualification and Quantification of the Selection Decision Measures

During the third phase of evaluation, the measure leads and additional technical support staff reviewed the vendor documentation, interviewed the vendors, and conducted extended review and assessment meetings to ensure that the input data used in the measure process were being interpreted correctly. Analyses and calculations were performed to translate input data from the preliminary engineering reports and testing data into the qualitative and quantitative measure products. These products were then reviewed with each of the respective vendors as an additional quality check. Any vendor disagreement with the process, assumptions, or products was noted for consideration by the MAI team. Any errors that were acknowledged by the measure leads were corrected.

MAI Team Review and Consensus Evaluation Workshops

Two workshops were conducted by the MAI team during this fourth phase of the evaluation to review the draft selection decision measure products and to prepare consensus statements for each measure. The measure leads presented the results of their analyses, addressed questions from the MAI team, and proposed draft consensus statements for consideration. The MAI team developed statements documenting a consensus position on each technology's evaluation against each measure. Seven of the 10 criteria and their corresponding measures were addressed in the first workshop held in August 2003. The final 3 criteria – waste form performance, life cycle cost (LCC), and peak year cost -- were addressed in a second workshop held in early September 2003. The vendors provided an overview of their testing and engineering activities and proposed facilities at the beginning of the first workshop. However, attendance during the evaluation portion of the MAI workshops was limited to the MAI team, measure leads, and supporting technical staff.

Initial Supplemental Technology Selection - Recommendation and Decision

The final phase of the evaluation process involved formal communication of the consensus evaluation and completion of an initial technology selection. CH2M HILL communicated the results of the evaluation and status of the initial technology selection to DOE's Office of River Protection Manager following the consensus evaluation of the MAI team. Regulators and stakeholders had the opportunity to provide additional input directly to the Office of River Protection Manager. The initial selection procurement decision was the responsibility of CH2M HILL.

RESULTS AND DISCUSSION

The phased evaluation process provided several opportunities to evaluate the appropriateness and relevance of the selection criteria and measures before the final evaluation. This process also helped identify additional data or analysis requirements early enough to enable incorporation of the information into the schedule. For example, the flux of contaminants measure for the waste form performance criterion was intended to compare the release of contaminants from the three primary supplemental waste forms. During the first phase of the evaluation process, the measure lead identified the need to evaluate the impact of secondary liquid wastes generated by each process in addition to the primary waste forms.

As is planned for the WTP, secondary liquid wastes are to be processed into a residual solids waste stream through an existing Effluent Treatment Facility, and ultimately disposed adjacent to the primary waste forms in an Integrated Disposal Facility at Hanford. Rather than only compare the flux of contaminants from the primary waste forms, the measure lead chose to perform and document a preliminary risk assessment as the primary product to support the waste form performance criterion. This risk assessment produced the data necessary to calculate the required flux of contaminants measure, while also producing information important for the MAI team's consideration of total system impact on groundwater and long-term risk. In the final consensus statements for this criterion, the measure was restated to include groundwater impact as well as flux of contaminants.

Later phases of the evaluation process also resulted in refinement of the criteria and measures. Additional data were included in the consensus statements for several of the measures, and one additional criterion and measure was added to the environmental protection goal. Specifically, the regulators on the MAI team requested an additional criterion to evaluate each technology's potential to meet Polychlorinated Biphenyl Framework Agreement criteria, and specifically meet the required Toxic Substances Control Act disposal requirements and demonstrate effective destruction or removal. Although specific testing data were not collected to support this measure, the MAI team provided a qualitative assessment of the likelihood of the measure to be met.

The MAI team's resulting selection criteria consensus statements and comparison information for each of the supplemental technologies is shown in Table III. The consensus statements are denoted by the shaded sections of the table. Several of the criteria and measures did not indicate any significant difference or provide discrimination between the three technologies. For example, the criterion for *Disposal space required* was originally viewed as a significant discriminator, especially for the cast stone technology. One of the issues with the previous Hanford grout program had been the significant disposal space of approximately 160 acres that was required. However, due to differences in waste loading, density, and waste package fill efficiency between the three technologies, any of the supplemental waste forms could be accommodated within the designed capacity of the Integrated Disposal Facility. Other criteria that provided very little discrimination were *process capacity* and *confidence in meeting 2028 dates*. Each of the technologies was designed to meet the required processing capacity, and there was no indication that any of the options could not meet the 2011 interim deadline for hot startup. However, additional vendor information would be required to confirm the ability to support the 2005 TPA M-62-08 milestone.

Although most of the criteria did not provide significant discrimination between the technologies, differences were identified for the following criteria and were noted in the selection evaluation consensus comments: *achieve safe system*, *process/operability risk*, *system interface impacts* (dose of waste package measure only), *LCC*, and *waste form performance*. The basis for the consensus statements for each of these criteria are discussed in more detail below.

Achieve Safe System

While all three supplemental treatment technologies were judged to be capable of safe operations with the appropriate safety controls, the three technologies varied in terms of availability of energetics and need for safety significant controls. The cast stone technology provided the lowest energetics availability and lowest need for safety structures, systems, and components. Steam reforming was judged to have the highest energetics availability, primarily due to the use of oxygen and carbon fuel sources.

Process/Operability Risk

Similar to the safety criterion, all three technologies were judged to be capable of meeting the operability requirements necessary to support a 2028 TPA milestone for completion of tank waste treatment.

Table III Supplemental treatment selection comparison information

Identified Goals, Criteria, and Measures			Approach and Basis for Evaluation		
GOAL	CRITERION	MEASURES	Bulk Vitrification (BV)	Cast Stone (CS)	Steam Reforming (SR)
Ensure worker and public safety	Achieve safe system	Independent safety experts' assessment	Based on qualitative HAZOPs and Preliminary Hazard Analyses: ▪ Each of the 3 technologies can be operated within nuclear safety guidelines with the appropriate safety controls. ▪ There are no significant radiological consequences to the onsite worker or offsite public for any of the 3 technologies. ▪ There are no toxicological consequences to the offsite public for any of the 3 technologies. ▪ There are potential toxicological consequences to the onsite worker for bulk vitrification and steam reforming which can be mitigated by appropriate safety controls.		
			Due to NOx generation, the bulk vitrification thermal treatment process will require safety SSCs and mitigative controls for the offgas system. Moderate energetics available for hazard scenarios and dispersing material: ▪ High temperature (1500°C) ▪ Electrical (9MVA) ▪ Similar processes have been authorized in DOE Complex.	No NOx generation; no safety SSCs or mitigative controls required. Low energetics available for hazard scenarios and dispersing material: ▪ Similar processes have been authorized in DOE Complex.	The steam reforming process produces minimal NOx offgas but will require NOx safety SSCs and mitigative controls. High energetics available for hazard scenarios and dispersing material: ▪ High temperature (1100°C) ▪ Oxygen and carbon fuel source in explosion-resistant reformers ▪ Similar processes have not been authorized in DOE Complex.

ALARA = as low as reasonably achievable; CoC = contaminant of concern; DET = determination of equivalent treatment; DOE = U.S. Department of Energy; DST = double-shell tank; EDE = effective dose equivalent; ERDF = Environmental Restoration Disposal Facility; ETF = Effluent Treatment Facility; GPM = gallons per minute; GW = groundwater; HAZOPS = Hazards and Operability; HLVIT = Vitrification of High Level Mixed Radioactive Wastes; IDF = Integrated Disposal Facility; LAW = low-activity waste; LCC = life cycle cost; LDR = land disposal restriction; MCL = maximum contaminant level; MT = metric tons; PCB = polychlorinated biphenyls; PTE = potential to emit; RCRA = Resource Conversation and Recovery Act; SSC = structures, systems, and components; TOE = total operating efficiency; TPA = Hanford Federal Facility Agreement and Consent Order; TSCA = Toxic Substances Control Act

Table III Supplemental treatment selection comparison information (continued)

Identified Goals, Criteria, and Measures			Approach and Basis for Evaluation		
GOAL	CRITERION	MEASURES	Bulk Vitrification (BV)	Cast Stone (CS)	Steam Reforming (SR)
Maximize schedule acceleration	Confidence in meeting 2028 dates **	Can technology achieve 10 GPM in time to meet 2028?	▪ Ability to meet the 2005 TPA M-62-08 milestone date is subject to further information from the vendors. ▪ Each of the 3 technologies could meet a 2011 date. ▪ Using vendor-supplied information, there is no indication that any of the 3 supplemental technologies cannot meet the 2011 hot start date and ultimately the 2028 date. However, uncertainties surrounding their ability to meet construction and production requirements need to be evaluated to increase assurance of meeting dates.		
	Process capacity	Metric tons of sodium (Na) processed by 2028	Each of the 3 technologies exceed average rate of 10 GPM and achieve processing of the necessary amount of Na by 2028.		
		MT immobilized waste product per day	59.2 MT/d	139.5 MT/d	55.4 MT/d
		%TOE	75%	85%	80%
		Na2O Loading (wt%)	20%	7.6%	19.8%
		MT Na by 7/2028	42,100 MT Na (~100,000 m^3)(1)	42,800 MT Na (350,000 m^3)(1)	41,700 MT Na (250,000 m^3)(1)

(1) Corresponds to the total volume of immobilized waste for 40,000 MT of Na.

** Schedule and cost goals include consideration of the difficulty of obtaining facility permits, waste classification, additional infrastructure required, increased disposal costs based on waste volume differences, etc.

Table III Supplemental treatment selection comparison information (continued)

Identified Goals, Criteria, and Measures			**Approach and Basis for Evaluation**		
GOAL	**CRITERION**	**MEASURES**	**Bulk Vitrification (BV)**	**Cast Stone (CS)**	**Steam Reforming (SR)**
Maximize operability	Process/ operability risk	Independent expert assessment	Each of the 3 technologies meets the operability requirements to meet the 2028 date.		
			Facility configuration consists of 6 lines operating in parallel. Thermal process with moderate process complexity, high demand on feed material handling.	Facility configuration consists of 2 lines operating in parallel. Non thermal process with low process complexity, high demand on waste package handling.	Facility configuration consists of 2 lines operating in parallel. Thermal process with highest process complexity, lower demand on feed material handling and waste package handling.
			Technology used commercially on hazardous and low-level waste, with prototypic demonstration on simulated Hanford tank waste. Uncertainty on the mixer-dryer experience for transitioning from commercial to nuclear environment.	Technology used on waste that is similar to Hanford tank waste. Least uncertainty about the operability of the process.	Technology used on commercial nuclear waste, but not demonstrated (at production scale) on waste that is similar to Hanford tank waste. Integrated process test needed to validate operating characteristics.
			Number of immobilized waste packages is ~4,600 to 9,300. (Variation due to package fill efficiency)	Number of immobilized waste packages is ~8,100 to 33,000. (Variation due to package size)	Number of immobilized waste packages is ~5,800 to 7,500. (Variation due to product density)
Minimize overall system interface impacts	System interface impacts	Liquid effluent compared to ETF capacity	ETF capacity (~65 GPM) is sufficient to meet requirements of any of the technologies.		
			3.6 GPM (1)	5.2 GPM (1)	0 GPM (1)
		Dose of waste package	Each of the 3 technologies complies with contact-handled dose rate requirements. (200 mR/hr is maximum allowable contact-handled package dose rate and 500 mR/hr is maximum IDF dose rate for disposal)		
			5.4 mR/hr (2,4)	80 mR/hr (2,3)	110 mR/hr (2,3)
		Volume returned to DSTs	0	0	0

(1) Vendor supplied information. Expert opinion indicates that worst case is 14 gallons per minute.
(2) Vendor supplied information based on 8.7×10^{-5} Ci/l Cs137.
(3) Higher concentration feeds would require additional shielding for cast stone and steam reforming.
(4) Bulk vitrification can accommodate waste feed up to 0.01 Ci/l without additional shielding.

Table III Supplemental treatment selection comparison information (continued)

Identified Goals, Criteria, and Measures			Approach and Basis for Evaluation		
GOAL	CRITERION	MEASURES	Bulk Vitrification (BV)	Cast Stone (CS)	Steam Reforming (SR)
Maximize cost effectiveness	Life cycle cost**	Life cycle cost (LCC)	▪ Ability to meet the 2005 TPA M-62-08 milestone and need date at a competitive cost is subject to further information from the vendors. ▪ Because ALARA was not consistently applied in the design for all technologies, it was normalized through the package shielded design in cast stone and steam reforming. ▪ Container configuration greatly affects LCC estimates ▪ Pre-conceptual engineering information was used to develop these LCC estimates. With further engineering development and operational planning, the LCCs are subject to increase. Therefore, these costs were not discriminating factors in the selection process. ▪ Cast stone and steam reforming life-cycle costs do not include potential cost increases due to schedule delays (due to more difficult permitting) of up to 2 years.		
			▪ Lowest container surface dose ▪ Range for all cases examined is \$1.2B to \$1.3B ▪ This meets the ALARA case	▪ Has the lowest facility and operating costs ▪ Has the highest container and disposal costs ▪ Range for all cases examined is \$1.0B to \$1.5B ▪ Upper-end of range reflects initial estimates of ALARA improvements	▪ Has the lowest LCC for non-ALARA cases ▪ Range for all cases examined is \$0.9B to \$1.3B ▪ Upper-end of range reflects initial estimates of ALARA improvements ▪ If a monolith is required due to intruder scenario performance objectives, considerable increase in cost could occur
	Peak year cost	Peak year cost	Peak year cost: \$142M	Peak year cost: \$ 67M	Peak year cost: \$ 97M
			Note: Peak year costs assume 3 years for design and construction.		

Table III Supplemental treatment selection comparison information (continued)

Identified Goals, Criteria, and Measures			**Approach and Basis for Evaluation**		
GOAL	**CRITERION**	**MEASURES**	**Bulk Vitrification (BV)**	**Cast Stone (CS)**	**Steam Reforming (SR)**
Provide environmental protection comparable to current vitrified waste disposal plan*	Disposal system performance	The current plan is to use the IDF and therefore the disposal system will be the same for all technologies and not a discriminating factor.			
	Disposal space required	Acres of land for Integrated Disposal Facility 40,000 MT Na Basis	LAW PRODUCED BY EACH SUPPLEMENTAL TECHNOLOGY CAN BE ACCOMMODATED BY THE CAPACITY OF THE IDF. *Note: IDF = ~53 Acres [ERDF = ~230 Acres] [Original plan of 230 Grout Vaults that covered all Tanks = ~160 Acres]*		
			10-21 acres	15 acres	9-11 acres
	Secondary wastes produced	Each of the 3 technologies is permitable pursuant to the Clean Air Act requirements. Site disposal resources are adequate for secondary solid waste generated. (Equals less than 1% of ILAW product treated waste)			
		Potential to emit (PTE) air emission.	Bulk vitrification requires abatement practices to meet air permit requirements. RCRA air emission requirements for thermal treatment processes have not been evaluated.	Cast stone is less reliant on abatement practices to meet air permit requirements.	Steam reforming requires abatement practices to meet air permit requirements. RCRA air emission requirements for thermal treatment processes have not been evaluated.
		Liquid waste volume	3.6 GPM (1) liquid waste volume	5.2 GPM (1) liquid waste volume	0 GPM (1) liquid waste volume
		Solid waste volume	28 m^3/yr solid waste volume	110 m^3/yr solid waste volume	23 m^3/yr solid waste volume
	Waste form performance	Flux at point of undisturbed soil and bottom of waste package, and GW impact	Given the assumptions of the study and the limited data points; ▪ Total groundwater impacts should include the immobilized waste and secondary wastes. Analysis is based on Hanford current burial-ground practices and shows significant impact from secondary wastes from thermal processes. ▪ Iodine is a key driver in the risk assessment and the inventory of iodine is uncertain for tank waste and secondary waste. In order for thermal processes, including WTP, to be permitted, the issue of iodine in secondary waste will be resolved. ▪ All but cast stone meet the 4 mR/yr drinking water dose rate standard and the 900 pCi/l MCL for Tc. ▪ For all the waste forms, the groundwater impacts from the non-radioactive chemical constituents analyzed (chromium, nitrate, nitrite, uranium) will meet minimum standards. Numbers given below assume that 25% of total LAW goes into each treatment process. It is assumed that ~70% of the LAW will be treated by supplemental technologies.		

1. Vendor supplied information. Expert opinion indicates that worst case is 14 gallons per minute.

* Achieve comparable level of environmental performance to vitrification considering the nature of waste, pretreatment, and performance of the immobilized waste form and/or disposal units.

Table III Supplemental treatment selection comparison information (continued)

Identified Goals, Criteria, and Measures			Approach and Basis for Evaluation		
GOAL	**CRITERION**	**MEASURES**	**Bulk Vitrification (BV)**	**Cast Stone (CS)**	**Steam Reforming (SR)**
Provide environmental protection comparable to current vitrified waste disposal plan*	Waste form performance	Flux at point of undisturbed soil and bottom of waste package, and GW impact	BV flux results in short term (600-3000 years), high GW impact due to Tc salt outside vitrified immobilized waste (peak = 0.10 mR-EDE/yr drinking water dose, 128 pCi/l at 1650 years). *Note: Vendor believes an engineered solution is feasible.* Given the uncertainties, long-term performance is indistinguishable from WTP glass and SR.	CS flux results in the highest GW impacts, which are beyond the drinking water standards (peak = 2.64 mR-EDE/yr drinking water dose from Tc and I, [1300 pCi/l Tc and <11 pCi/l iodine at 1850 years]). *Note: The iodine number is an upper limit, based on a detection limit from a laboratory test. Vendor believes optimization is feasible.*	SR flux results in the lowest calculated GW impact (1.5×10^{-5} mR-EDE/yr, 0.02 pCi/l Tc), but given uncertainties, SR is indistinguishable from WTP glass and to BV in the long term.
			GW impact from BV secondary waste (0.63 mR-EDE/yr drinking water dose, 4.2 pCi/l iodine) is higher than from immobilized waste.	CS has minimal secondary waste, therefore, GW impacts due to secondary waste are minimal.	GW impact from SR secondary waste (0.63 mR-EDE/yr, 1.4 pCi/l Tc and 4.2 pCi/l iodine) is much higher than for the immobilized waste.
			BV performance results are sensitive to 1) Tc salt not incorporated into the glass matrix and 2) the iodine inventories in the secondary waste.	CS performance results are sensitive to 1) the use of a physical release model without direct consideration of chemical processes, and 2) an upper-bound diffusion coefficient for iodine calculated from analytical detection limit.	SR performance results are sensitive to 1) the assumption that one SR sample that was produced is representative, 2) the assumption that the nosean mineral captures the CoC, 3) the calculated nosean solubility constant, and 4) the assumption of inventory in the secondary waste. *Note: There is significantly less understanding of the degradation of nosean mineral compared to similar understanding of other waste forms.*

* Achieve comparable level of environmental performance to vitrification considering the nature of waste, pretreatment, and performance of the immobilized waste form and/or disposal units.

Table III Supplemental treatment selection comparison information (continued)

Identified Goals, Criteria, and Measures			Approach and Basis for Evaluation		
GOAL	CRITERION	MEASURES	Bulk Vitrification (BV)	Cast Stone (CS)	Steam Reforming (SR)
Provide environmental protection comparable to current vitrified waste disposal plan*	Waste form performance	Flux at point of undisturbed soil and bottom of waste package, and GW impact.	BV does not pose a significant intruder risk.	CS does not pose a significant intruder risk.	SR has the highest intruder risk, based on the waste form analyzed. SR may need to be incorporated into a monolith.
			BV does not meet the definition of HLVIT, but is a similar process and is likely candidate to meet determination of equivalent treatment (DET) and is likely to meet organic LDR requirements. However, confirmatory investigation into volatile contaminants in disposal package needs to be conducted.	Cs does not meet the definition of HLVIT. As a stabilization technology, CS is a less likely candidate for a determination of equivalent treatment (DET), and is generally not an acceptable treatment technology for organics.	SR does not meet the definition of HLVIT. Although not a glass waste form, it is a likely candidate to meet determination of equivalent treatment (DET) and is likely to meet organic LDR requirements.
			If the Tc salt problem in BV is resolved, then the BV glass appears to be equivalent to WTP glass.	CS performance is not equivalent to WTP glass.	Based on very preliminary data, SR performance appears to be equivalent to WTP glass.
	Meet PCB Framework Agreement Criteria	For DST waste, meet TSCA disposal requirements and demonstrate effective destruction/ removal following dilution associated with necessary treatment.	BV is likely candidate to meet required TSCA demonstrations.	▪ CS is not likely candidate to meet required TSCA demonstrations. ▪ With respect to TSCA, may be appropriate for select secondary waste.	SR is likely candidate to meet required TSCA demonstrations.

* Achieve comparable level of environmental performance to vitrification considering the nature of waste, pretreatment, and performance of the immobilized waste form and/or disposal units.

However, significant differences were identified. Cast stone was judged to have the lowest process complexity, but the highest demand on waste package handling operations due to the higher number of packages produced. Bulk vitrification was assessed to have a moderate process complexity, but with the highest demand on feed material handling. Steam reforming was judged to have the highest process complexity, with lower demand on both feed and waste package handling. Both bulk vitrification and steam reforming were judged to have processing uncertainties that required additional process demonstrations.

System Interface Impacts (Dose of Waste Package)

While the measures for both liquid effluent and volume returned to double-shell tanks met requirements or were equivalent, significant differences in the dose of the waste packages drove additional analysis for the LCC criterion. While all three technologies would meet the contact-handled dose rate requirement, the design of the bulk vitrification disposal package provides significant shielding and much lower dose rates than either of the other technologies.

Life Cycle Cost

Cost details provided by the vendors varied significantly due to different assumptions in areas such as facility requirements, labor, and other unit costs. Because of the wide disparity in assumptions, a direct cost comparison of vendor data was not possible. Therefore, a cost normalizing effort was performed to enable more direct comparison of the technologies. The normalizing effort established a common set of cost elements across the three technologies and normalized assumptions for the technology-independent elements of the proposed facilities and operations. For example, analytical laboratory facility requirements and costs were applied equally to each technology option. Only one of the three vendors had included an analytical facility to support process control and operations in their design.

Waste form container design was another significant difference between the three technologies, significantly affecting the package dose rate, the number of containers, and the total LCC. To normalize the impact of container design, a common container size was assumed for all three technologies. In addition, a second case was developed to address the difference in package dose rate. An as low as reasonably achievable (ALARA) case was developed. The ALARA case involved applying a package shielded design to cast stone and steam reforming to produce a comparable dose rate to bulk vitrification. The LCC for all options and all cases ranged from $0.9B to $1.5B. Steam reforming had the lowest LCC with the non-ALARA case. With the ALARA case, LCC ranged from $1.2B to $1.5B with bulk vitrification having the lowest cost.

Waste Form Performance

The waste form flux and risk assessment calculations were conducted to assess the likely long-term contaminant release rates and groundwater impacts from each of the supplemental technology options. To ensure defensibility of these calculations, testing and modeling techniques were selected that had been previously applied and approved for radiological performance assessments at Hanford and other DOE sites. In addition, risk assessment methods [10] and results [12] were externally reviewed by technical experts. The evaluation results for this criterion provided significant discrimination between the non-thermal cast stone technology and the two thermal treatment technologies. Fig. 2 provides the estimate of groundwater concentrations downgradient of the disposal facility for one of the key contaminants of concern, technetium, as a function of time for each of the three supplemental technologies and the baseline WTP immobilized LAW glass. Cast stone contaminant release resulted in the highest groundwater impact. Cast stone was judged to not perform equivalent to WTP immobilized LAW glass.

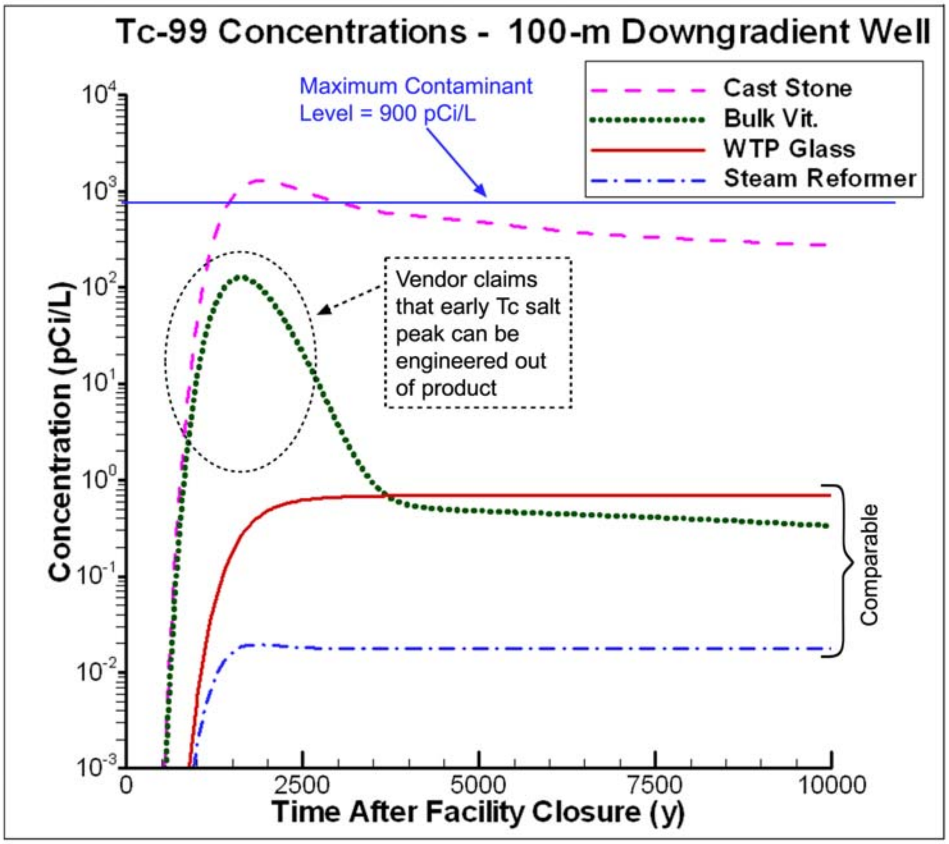

Fig. 2 Estimate of groundwater impacts downgradient of the Integrated Disposal Facility for the supplemental treatment waste forms and Waste Treatment Plant immobilized low-activity waste glass. Impacts are based on 25% of technetium-99 tank waste inventory in each waste form.

Both bulk vitrification and steam reforming were judged to be indistinguishable from each other and WTP immobilized LAW glass over long time periods.

A short-term, high groundwater impact was predicted for the bulk vitrification system tested in 2003 due to the presence of a small quantity of soluble technetium salt that was found in the waste package but outside of the glass waste form. The vendor believes that an engineering solution is feasible to prevent a volatile technetium fraction from depositing outside of the bulk waste form. Resolving the soluble technetium salt deposits will be critical to achieving equivalency in waste form performance between the bulk vitrification system and WTP immobilized LAW glass.

Steam reforming results in the lowest calculated short- and long-term groundwater impact. However, the performance results are sensitive to several key assumptions regarding representatives of the single sample tested, where technetium is captured within the mineral waste form, and the degradation of the mineral waste form. In addition, the granular steam reforming product may need to be incorporated into a monolith to meet intruder risk performance assessment goals.

In addition to the comparison of the primary waste forms, the groundwater impacts from secondary wastes were also estimated. Iodine is a key driver in the risk assessment, especially for the secondary wastes from the thermal processes, including WTP immobilized LAW vitrification. The impacts are sensitive to the uncertainty in iodine inventory.

Initial Supplemental Treatment Selection Recommendation

Results of the MAI team workshops provided consensus evaluation information to support a selection recommendation. In summary, the team's consensus agreement in September 2003 is as follows:

- Safety, schedule, cost, operability, and system impacts are not discriminators for a selection at this time.
- Secondary waste is an issue that must be resolved for all thermal waste forms, including WTP.
- The current formulation of grout (cast stone) does not meet environmental standards if it is used to treat more than 30% of the LAW. As a result, the grout waste form performance is not comparable to WTP immobilized LAW glass.
- Bulk vitrification and steam reforming are potentially comparable in performance to WTP immobilized LAW glass.
  - Steam reforming must resolve
    - Intruder performance
    - Questions resulting from limited test data.
  - Bulk vitrification must resolve the issue of technetium salt.

CH2M HILL management communicated the following project status and recommendation to the DOE - Office of River Protection Manager in mid-September 2003.

1) For the primary waste form for supplemental treatment, further evaluation including pilot-scale demonstration on actual tank waste should be performed on one of the two thermal technologies (bulk vitrification or steam reforming), depending on the evaluation of proposals resulting from a pending RFP for pilot-scale demonstration. This approach is consistent with recent Hanford Advisory Board advice requesting that additional time be allowed to enable their input prior to the final investment decision.

2) For secondary waste, cast stone should be evaluated as a solution for the secondary waste issue for all thermal processes. Containerized cast stone should not be eliminated from consideration for specific low-level waste, LAW, or transuranic waste streams not requiring thermal treatment.

CH2M HILL management reviewed the results of the evaluation, including uncertainties, and determined that additional information was needed from the two thermal treatment vendors to complete an initial selection decision. RFPs were issued to the bulk vitrification and steam reforming vendors. The RFPs requested cost and technical proposals on design, construction, and operation of a pilot-scale demonstration facility to further test and evaluate their respective treatment processes on actual Hanford dissolved saltcake tank waste. The demonstration facility was to operate in 2004 through 2006 to support the TPA M-62-08 and -11 milestones and provide data to support waste form qualification, performance assessment, and future Resource Conservation and Recovery Act permitting, pending the M-62-11 joint agency decision on completion of tank waste treatment. Additional information from vendor proposals was needed to a) determine the cost to design, build, and operate a pilot-scale demonstration facility, b) define the magnitude of intellectual property costs for a production facility, and c) update vendor information used in the supplemental treatment selection comparison (Table III).

Vendor proposals in response to the RFPs were received in December 2003, and a panel of experts was convened to evaluate the information. The results of the proposal evaluation were generally consistent with those of the MAI team evaluation in September 2003. Specifically,

- Both thermal technologies can be operated safely
- The costs for each of the thermal treatment pilot-scale facilities were similar
- Bulk vitrification was assessed to have a moderate process complexity, whereas steam reforming was judged to have the highest process complexity
- Both bulk vitrification and steam reforming were judged to have processing uncertainties that require additional process demonstrations.

The only significant evaluation difference between the MAI team's results (see Table III) and the proposal evaluation team's results involved progress on resolving the bulk vitrification technetium salt issue. Results of bulk vitrification engineering-scale tests conducted since the MAI team's evaluation in September 2003 indicated that several engineering changes that might address the technetium salt deposits during bulk vitrification processing could be implemented effectively.

As a consequence of this evaluation, CH2M HILL judged that the bulk vitrification proposal showed the most promise for meeting mission needs safely with a reduced cost to the taxpayers. Therefore, a decision was made to enter into contract negotiations with AMEC Earth and Environmental, Inc. for a pilot supplemental treatment test and demonstration facility.

CONCLUSIONS

In the summer of 2002, DOE documented a proposed plan for accelerating the cleanup of Hanford tank waste and meeting TPA schedule commitments. A primary element of that plan requires implementation of LAW treatment capability supplemental to the WTP. In cooperation with EPA, Ecology, and CH2M HILL, three technologies were selected for evaluation. To meet the accelerated clean-up schedule within limited budgets, an aggressive testing, design, analysis, and evaluation schedule was required.

In September 2003, less than 14 months after the selection of three technologies for further evaluation, initial process and waste form testing were completed. Also, preliminary engineering designs and LCCs were made, and an initial risk assessment was complete. Culmination of this information enabled the MAI team to establish a consensus evaluation and support an initial investment decision in December 2003.

Key factors that contributed to the successful decision process included:

- Clearly defined and communicated goals and objectives. From the initial MAI selection of technologies in 2002 through the final consensus evaluation in 2003, there were commonly understood and communicated goals (including schedule) among project staff, DOE, and the regulators. Common goals and objectives helped maintain the project direction and progress. Although the need arose several times to revisit and clarify specific elements and objectives, the consistency of the overarching goals and objectives provided the foundation for continued progress. The common goals also ensured a personal commitment to the very aggressive schedule, including the commitment from the technical project staff and vendors, who had the overwhelming burden of supporting the project schedule.
- An effective participatory decision process from project inception to completion. The MAI team -- involving contractors, DOE, and regulators -- defined the evaluation criteria and process at project inception. Early definition of the evaluation criteria ensured the adequacy of testing and analysis plans. Throughout the project duration, this evaluation team met regularly to review progress and address any needed changes. As data became available, the team convened to

review and evaluate the information. This active involvement of the MAI team throughout the process helped ensure a timely evaluation, which met the group’s consensus, and an acceptable investment decision.
- Credible and rigorous technical underpinnings for key evaluation criteria. The waste form performance criterion was critical to the investment decision. Therefore, a technically sound and objective testing and analysis process was required to ensure that the waste form performance evaluation was fair and credible. A rigorous testing and analysis approach was selected that remained consistent with the methods used for prior performance assessments of the baseline waste forms. This approach, and the corresponding risk assessment product from the analysis, received a technical peer review. In addition, uncertainties in the analysis were well documented and communicated to the MAI team. Confidence in the credibility of the waste form performance information was important to achieving an evaluation that garnered MAI team consensus.

An investment decision in December 2003 enabled CH2M HILL to pursue a pilot-scale test and demonstration facility for bulk vitrification treatment of selected Hanford LAW. Results of testing in 2004 and 2005 will enable completion of TPA milestone M-62-08 and support a joint agency decision on the baseline for completion of tank waste treatment by 2028.

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FOOTNOTES

[a] The current TPA requirement is for vitrification of all tank wastes by 2028.

[b] A fourth technology, sulfate removal, was also recommended as a pretreatment option to enhance the processing capacity of the baseline vitrification technology. An investment decision on sulfate removal was deferred pending the results of the supplemental treatment evaluation and initial selection decision.