

Lessons Learned from V-Tank Waste Remediation Activities at the Idaho National Laboratory

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ABSTRACT

The purpose of this paper is to discuss major activities and lessons learned from remediation of the V-tank waste at Idaho National Laboratory's (INL's) Test Area North (TAN) complex. Remediation activities involved the on-site treatment, solidification and disposal of over 61,000 L (16,000 gal) of radioactively hazardous V-tank waste. In July, 2006, over 98% of the V-tank waste was disposed of at the Idaho CERCLA Disposal Facility (ICDF). Disposal was accomplished using the three 38,000-L (10,000-gal) V-tanks that had stored most of the V-tank waste for over 30 years. Included in V-Tank remediation was the removal of approximately 7,650 m³ (10,000 yd³) of contaminated soil. Plans are to treat the remaining V-tank waste off-site in early 2007, with the treated residual also disposed of at the ICDF.

Disposal of the treated V-tank waste at ICDF marked a major step in completing remediation of the TAN V-tanks, a task begun in 1999 when the original Record of Decision (ROD) was published. Over this time, there have been a number of stops and starts associated with remediating this waste. Although many of these stops and starts were unavoidable, there are a number of lessons learned for the V-tank remediation that could help prevent unnecessary expenses and schedule delays in future remediation activities within the Department of Energy (DOE) complex. This paper identifies major and minor lessons learned from V-tank waste remediation efforts – those that resulted in unnecessary delays/expenses, as well as those areas that accelerated V-tank remediation efforts.

INTRODUCTION

The V-tank system consists of three horizontal underground storage tanks (Tanks V-1, V-2, and V-3) with capacities of 38,000 L (10,000 gal), and a vertical underground storage tank (Tank V-9) with a capacity of 1,500 L (400 gal). Tanks V-1, V-2, and V-3 were designed to collect and store liquid radioactive wastes that were produced at TAN, in preparation for evaporation operations at TAN-616. Tank V-9 was designed to filter out sediments in TAN's radioactive waste discharges, prior to their discharge to V-1, V-2 and V-3. The V-tank system was installed at TAN in 1953 and became operational in 1958.

Tank V-2 was taken out of service in 1968, after a large quantity of oil was discovered in the tank (the residual oil was removed from V-2 in 1981). In addition, evaporation operations at TAN were discontinued in 1970, following failure of the TAN-616 evaporator. Nevertheless, waste discharges to Tanks V-1 and V-3 continued into 1985. Following evaporator failure, the excess wastes in V-1 and V-3 were either pumped to the PM-2A tank system (from 1970-1975), or pumped out of the tanks (through the tank vent pipes) and shipped to the Idaho Chemical Processing Plant for treatment.

In 1985, all low-level radioactive waste discharges at TAN were rerouted through piping modifications, effectively stopping the intentional discharge of radioactive wastes to the V-Tanks. As a result, the residual waste in the V-tanks needed to be removed and treated, in accordance with Environmental guidelines. In support of tank closure operations, a decision was made to treat and dispose of the V-tank waste as part of remediation operations that were being conducted on the V-tank site, in accordance with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

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Although use of the V-tank system was terminated in 1985, there still appeared to be some unintentional discharges of unknown origin to Tank V-3. To eliminate the unintentional volume increases, the V-tank system was completely isolated, by cutting and capping all inlet and outlet lines from TAN into the V-tank system. The resulting final volumes of sediments and wastes within each V-tank were then determined using tank level measurements, and are shown in Table I. As shown in the table, Tanks V-1 and V-2 are less than 20% full, while Tank V-3 is over 80% full. Tank V-3 also contains substantially more supernatant (relative to sludge) than Tanks V-1 or V-2.

Table I. Estimated Sediment and Supernatant Volumes in Each V-Tank.

Tank	Sludge Volume, L (gal)	Supernatant Volume, L (gal)	Total Volume, L (gal)
V-1	1,970 (520)	4,410 (1,160)	6,370 (1,680)
V-2	1,730 (460)	4,310 (1,140)	6,040 (1,600)
V-3	2,470 (650)	29,000 (7,660)	31,500 (8,310)
V-9	950 (250)	260 (70)	1,210 (320)
TOTAL	7,120 (1,880)	38,000 (10,000)	45,100 (11,900)

V-TANK WASTE CHARACTERIZATION

Sediment and supernatant sampling was performed on all four V-tank wastes, to characterize the waste. The sediment and supernatant samples were taken through the manhole on one side of tanks V-1, V-2, and V-3 (with the sampling wand placed at different angles), while samples from Tank V-9 were taken from two depths on the downstream side of the chordal baffle (placed into the tank to assist in sediment filtration). The sediment and supernatant samples were analyzed for volatile organic contaminant (VOC), semi-volatile organic contaminant (SVOC), inorganic contaminant, and radioactive contaminant concentrations. In addition, mechanical properties and Toxic Characteristic Leach Procedure (TCLP) testing was performed. The results from the sediment and supernatant samples were combined, using the volumetric data in Table 1 to define the total concentration of the various contaminants of concern (COCs) within each tank.

Significant results from waste characterization are shown in Table II [1]. Results of V-1, V-2, and V-3 waste characterization found concentrations of tetrachloroethylene (PCE) in excess of the F001 treatment standard for all three horizontal V-tank wastes, based on 90% upper confidence levels (UCLs)^b. In addition, the V-1 waste contained 15 mg/kg of trichloroethylene (TCE), 2.5 times over its F001 treatment standard, while waste in V-2 was found to be characteristically toxic for cadmium. Results from V-9 waste characterization found significant concentrations of TCE PCE, and 1,1,1-trichloroethane (TCA) that needed to be treated to meet F001 treatment standards. The V-9 waste was also characteristically hazardous for cadmium and mercury, with the high mercury concentration causing it to be labeled a “high mercury” waste.

In addition, a number of trace VOCs and SVOCs in the V-tank wastes were reported at detection limits in excess of characteristic toxicity limits. The high detection limits of the trace VOCs were due to high concentrations of certain VOCs in the sludge that forced the VOC samples to be diluted 100-1000 times, before being analyzed, while the high detection levels of the trace SVOCs were due to high organic material concentrations that required significant dilution, prior to SVOC analyses. The dilution levels were sufficient to raise the detection limits for these trace contaminants above their toxicity limits.

As a result of waste characterization, the four V-tank wastes were determined to be both F001-listed and characteristically hazardous. Due to its high mercury concentration, tank V-9 waste also required treatment sufficient to meet RMERC (retorting) or IMERC (incineration) guidelines. The characteristic toxicity designation for each waste also required treatment of underlying hazardous constituents (UHCs) in the waste to their universal treatment standard (UTS) concentrations. The primary UHCs of concern are bis-2-ethyl hexyl phthalate (BEHP) and Aroclor-1260, a poly-chlorinated biphenyl (PCB). These two UHCs are semi-volatile in nature.

^b 90% UCLs are typically used to verify that Environmental Standards have been met.

Table II. Significant Concentrations of Various COCs in Each V-Tank Waste.^a

Contaminant	Conc. Limit	V-1 Conc.	V-2 Conc.	V-3 Conc.	V-9 Conc.
F001 Contaminants					
TCE	6 mg/kg	15 mg/kg^b	0.6 mg/kg	0.3 mg/kg	26,000 mg/kg
PCE	6 mg/kg	830 mg/kg	160 mg/kg	41 mg/kg	550 mg/kg
TCA	6 mg/kg	(1.6 mg/kg) ^c	(0.5 mg/kg)	(0.1 mg/kg)	2500 mg/kg
TCLP Contaminants					
Hg	0.2 mg/L	(0.0001 mg/L)	0.0002 mg/L	0.003 mg/L	0.32 mg/L
Hg Conc.	260 mg/kg	NA ^d	NA	NA	2000 mg/kg
Cd	1 mg/L	0.4 mg/L	1.3 mg/L	0.3 mg/L	1.03 mg/L
Trace VOCs	0.2-6 mg/L	(0.5 mg/L)	(0.5 mg/L)	(0.5 mg/L)	(13 mg/L)
Trace SVOCs	0.1-7.5 mg/L	(12 mg/L)	(11 mg/L)	(12 mg/L)	(8.5 mg/L)
Underlying Hazardous Constituents					
BEHP	28 mg/kg	1300 mg/kg	1000 mg/kg	390 mg/kg	500 mg/kg
PCBs	10 mg/kg	47 mg/kg	30 mg/kg	13 mg/kg	140 mg/kg

a - based on 90% UCLs

b - bolded values are in excess of contaminant concentration limits (F001 treatment standards, TCLP limits, or UTSSs)

c - values in parentheses are purely based on detection limits

d - not applicable, since TCLP-Hg values were below 0.2 mg/L

INITIAL RECORD OF DECISION REMEDY FOR V-TANK WASTE REMEDIATION

The next step of V-tank remediation effort involved identifying potential technologies for successful V-tank waste remediation. The potential technologies had to remove or destroy both VOCs and SVOCs in the waste. In addition, the technology selected for V-9 waste remediation had to remove mercury from the waste. The resultant waste form had to meet TCLP, while also treating F001-listed contaminants and UHCs to below their treatment standard concentrations, to meet LDR treatment requirements.

Treatability studies performed in support of this effort included chemical oxidation using Fenton's reagent, and subsurface planar in situ vitrification (SP-ISV). Chemical oxidation or SP-ISV could be used to treat the V-1, V-2, and V-3 wastes, but only SP-ISV could be used to treat V-9 waste. The SP-ISV treatability study was a full-scale test performed on a simulated horizontal tank filled with water, sediments, and trace contaminants, while the chemical oxidation treatability study was performed on a lab-scale basis using actual V-tank wastes (only wastes from V-1, V-2, and V-3). Both treatability studies achieved the objectives that had been identified for them—objectives that had been identified based on pre-test input from project personnel.

Following successful treatability study completion [2,3], concerns arose over issues that weren't identified prior to testing. Issues of SVOC migration/deposition in surrounding soils and the leachability of stainless steel eliminated SP-ISV from further consideration, while the inability to treat V-9 waste with chemical oxidation eliminated it from further consideration. Instead, a decision was made to look at potential off-site treatments for both removing mercury from V-9 waste and also removing or destroying the volatile and semi-volatile organic F001-listed contaminants, TCLP constituents and UHCs. Looking for an off-site solution was assumed to be more cost effective than continuing to support an on-site treatment option.

Following a vendor search, a single off-site treatment facility was identified capable of processing the V-tank waste in a manner that both removes mercury and removes or destroys volatile and semi-volatile COCs in the waste. The

company selected (Allied Technology Group, Limited [ATG], located in Richland, WA) had the potential for treating the V-tank wastes using a carbon electrode-based plasma vitrification unit, though an off-gas permit for the plasma unit was not yet in place. As a result, the initial Record of Decision (ROD) remedy for V-tank waste remediation was developed specifying waste removal and off-site treatment [4]. After the ROD was issued a subcontractor was hired to design and implement the remedy.

Initial problems with the off-site treatment approach became apparent when it was determined that the V-tank waste met Class B radioactive guidelines, as specified by the Nuclear Regulatory Commission (NRC). The Class B nature of the waste generated shipping limitations that limited the transport of V-tank liquid waste to values identified in 10 CFR 20, Appendix B (Table II, Column 2). When applied to V-tank wastes, this resulted in maximum shipment volumes of 190 L (50 gal) at a time. The additional remediation steps and added cost associated with this finding was substantial, and had not been considered in the ROD. In addition, the original subcontracted design for removing waste from the V-tanks generated concerns with personal safety (particularly radiation exposure issues).

As a result, an Explanation of Significant Differences (ESD) was drafted to address the required additional remediation steps. During this time, however, ATG filed for bankruptcy, eliminating the capability for treating V-tank waste off-site and invalidating the initial ROD. Because of the bankruptcy, a decision was made to terminate implementation for the original remedy and move towards amending the ROD.

Lessons learned from the initial ROD activities on V-tank remediation were as follows:

- Adequate time needs to be spent understanding potential treatment technologies that are being considered for remediating a waste, and identifying objectives for a treatability study that addresses all issues that may be of concern. Had issues of semi-volatile contaminant migration/deposition and stainless steel leachability been addressed beforehand, resolution of these issues could have been performed as part of the SP-ISV treatability study.
- When making a decision to proceed with off-site treatment, one needs to understand and include costs associated with waste removal and off-site transport, prior to the ROD determination. One also needs to consider the difference between what is promised by the vendor, vs. what can actually be performed. In the case of ATG, plasma vitrification was promised, though an off-gas permit was not yet in place.
- When considering off-site treatment, one should attempt to identify multiple vendors for implementation of the treatment solution to achieve best value for the project and to minimize technical risk. If alternative vendors are not available, consideration must be given to the complexity of the selected technology, documented successes the vendor has with implementation of the technology, and the vendor's readiness to perform the operations. Questionable feed-back on any of these items may require reconsideration of the "off-site" decision.
- Project personnel must interface closely with off-site vendors, as they develop designs for and/or prepare to process the waste. The vendor must demonstrate compliance with all applicable Regulatory, Environmental, and Safety and Health guidelines prior to shipment of waste material. Depending on the vendor, and their demonstrated level of experience, this may mean nothing more than communication of the technical and functional requirements, supported by routine communication and reviews to make certain the end product will satisfy these requirements. The cost of this interface function must be considered, when making decisions to proceed with off-site treatments.

ROD AMENDMENT/NEW TECHNOLOGY SELECTION FOR V-TANK REMEDIATION

The technology evaluation performed in support of the ROD amendment process still focused on an evaluation of on-site and off-site treatment technologies, but with much heavier emphasis on on-site treatment options. Technologies considered as part of the ROD amendment process included on-site SP-ISV, on-site ex situ vitrification, on-site thermal desorption, off-site thermal desorption, on-site thermal desorption with off-site secondary waste treatment, on-site in-situ chemical oxidation/stabilization, and on-site ex-situ chemical oxidation/stabilization.

Of the seven technology alternatives under evaluation, only SP-ISV and ex situ vitrification were capable of processing the waste in a manner that met IMERC or RMERC. However, the need for IMERC or RMERC treatment of the V-tank waste had been based on earlier assumptions that the V-tank waste streams were separate waste streams, rather than a combined waste stream. As part of the ROD amendment process, a decision was made

to treat the V-tank waste as a combined waste stream, since the entire V-tank system was part of a single process at Test Area North. The decision to consider the V-tank waste as a combined waste stream was agreed to by the Agencies as part of the Technology Evaluation Report for the amended ROD [5].

In support of the combined waste stream decision, a new characterization evaluation of the waste was made. The combined waste characterization effort used previous sample analyses combined with estimated sludge and supernatant volumes shown in Table I, but combined the waste streams together to arrive at estimated total and leachate concentrations for the combined V-tank waste. Significant results for the combined waste stream characterization effort are shown in Table III [3]. As shown in the table, F001-listed contaminants and trace organic contaminants are still present and above their treatment standards. However, leachate concerns over mercury and cadmium had been eliminated. As a result of the combined waste stream analysis, issues over the need for treatment meeting the guidelines of IMERC (incineration) or RMERC (mercury retorting) were eliminated, thereby allowing thermal desorption and chemical oxidation technologies to be considered for the entire V-tank waste stream. The combined V- tank waste still needed to be treated for F001-listed VOCs and semi-volatile UHCs such as BEHP and PCBs, however, based on the results of the “calculated” waste characterization evaluation.

Table III. Significant COC Concentrations for the Combined V-Tank Waste Stream.^a

Contaminant	Conc. Limit	Combined V-Tank Waste Conc.
F001 Contaminants		
TCE	6 mg/kg	1100 mg/kg^b
PCE	6 mg/kg	240 mg/kg
TCA	6 mg/kg	120 mg/kg
TCLP Contaminants		
Hg	0.2 mg/L	.058 mg/L
Cd	1 mg/L	0.42 mg/L
Trace VOCs	0.2-6 mg/L	(2.1-2.3 mg/L)^c
Trace SVOCs	0.1-7.5 mg/L	(6.4 mg/L)
Underlying Hazardous Constituents		
BEHP	28 mg/kg	550 mg/kg
PCBs	10 mg/kg	21 mg/kg

a - based on 90% UCLs

b - bolded values are in excess of contaminant concentration limits (F001 treatment standards, TCLP limits, or UTSs)

c - values in parentheses are purely based on detection limits.

To assist in the technology evaluation, a decision analysis model was used. The decision analysis model that was used was originally developed by the United States Air Force to help quantify decisions made as part of a CERCLA technology evaluation, and had been adapted to support the remediation technology evaluation for the INL's Subsurface Disposal Area [6]. The decision analysis model uses technology evaluation criteria and sub-criteria that were developed based on EPA CERCLA guidance. The criteria and sub-criteria were then assigned individual weighting factors, based on overall importance as determined by the Agencies. Performance ratings were then assigned to the evaluation criteria/sub-criteria for each technology under evaluation. The performance rankings of each criterion, multiplied by their respective weighting factors, were then added up to provide a total value rating for each technology under consideration. Results of the technology evaluation identified ex situ chemical oxidation/stabilization as the preferred technology for remediating the combined V-tank waste stream [5]. Following review and approval by the Agencies, a decision was made to proceed with the identification of chemical oxidation/stabilization as the preferred technology for remediating the combined V-tank waste stream in the amended ROD [7].

The technical evaluation performed as part of the amended ROD process was more technically justifiable than the original ROD evaluation, due to use of the decision analysis model to assist in quantifying the technology selection. The decision to identify the waste as a combined waste stream also expanded the potential treatment technologies available for remediating V-tank waste. However, there were still a number of areas where improvements could have been made to the technology selection process had more time been spent in increased understanding of both the hazardous nature of the combined V-tank waste and the overall technologies that were being considered.

A problem with the chemical oxidation evaluation was that it used inaccurate information for a chemical oxidant (sodium persulfate) not fully understood at the time. Sodium persulfate oxidation was eventually eliminated from consideration during initial conceptual design, due to concerns over the limited solubility of sodium persulfate, and the amount required to complete chemical oxidation of the V-tank waste. Nevertheless, the performance values that were used in evaluating chemical oxidation as a potential treatment technology for V-tank waste were partially based on assumptions relative to the use of sodium persulfate that sometimes weren't applicable. .

With regards to the characteristic evaluation on the combined V-tank waste stream, limited understanding of reportable detection limits (RDLs) vs. method detection limits (MDLs), led to a requirement that all technologies under consideration would either have to remove or destroy semi-volatile UHCs such as BEHP and Aroclor-1260, as part of the treatment. This was a major issue for the thermal desorption technologies under consideration, due to contamination control concerns over airborne particulates that would develop as the waste was dried, before semi-volatile UHCs could be removed (since the boiling point for water was much lower than the boiling point for these contaminants). However, the actual detection limits for the VOC and SVOC analyses were substantially lower than the RDLs that were reported. Using MDLs instead of RDLs to evaluate the combined V-tank waste stream's characteristic toxicity would have eliminated characteristic toxicity concerns over many of the trace VOCs and SVOCs that had been previously-identified. In combination with historical process knowledge, the assumption of characteristic toxicity for the combined V-tank waste stream could have been eliminated.

Eliminating the characteristic toxicity designation would reduce treatment requirements to only having to destroy or remove F001-listed contaminants, not UHCs. Since the F001-listed contaminants are all volatile, there would be no need to dry the waste as part of thermal desorption. Rather, the waste could remain in slurry form and simply be sparged with air to drive off the VOCs, eliminating the major contamination control issue with thermal desorption. The increased value of thermal desorption technologies resulting from such a change in assumptions would probably have resulted in thermal desorption being selected as the preferred remediation technology for the combined V-tank waste.

In pursuit of this logic a detailed evaluation of the existing data was performed to eliminate the characteristic toxicity designation for V-tank waste [8]. This allowed for treatment to evolve from the ROD-stated chemical oxidation approach to a less costly and less risky air-sparging approach. This change in technology was agreed to by the Agencies without ROD amendment, since air-sparging had been identified as a pre-treatment step for chemical oxidation. However, the Agencies also specified that post-treatment analysis was needed to verify the assumed non-characteristic nature of the waste.^c

Lessons learned while amending the ROD for V-tank remediation were as follows:

- One should verify the correctness of the assumptions made regarding the waste that is to be remediated. If not correct, these assumptions may result in unnecessary remediation requirements that could unnecessarily drive up the cost of the remediation. For V-tank remediation, classifying the wastes as a combined waste stream eliminated concerns over having to retort or incinerate the V-9 portion of the combined waste stream. However, a more thorough review of the characteristic toxicity assumption could have led to selection of an inexpensive air-sparging process without the schedule delays and costs that were required to retrofit the remediation approach, once this was learned.
- The technology evaluation process should use tools (such as decision analysis modeling) to quantify the decision as much as possible and to facilitate input from all responsible parties relative to the decision criteria.

^c Post treatment characterization analysis was necessary due to high concentrations of F001 contaminants that interfered with the characteristic toxicity determination for trace organics in the waste.

However, such a quantification process requires equal understanding of each technology being evaluated to provide better documentation of the technology inputs. In the V-tank remediation evaluation, the projected value of chemically oxidizing the waste was somewhat overstated for certain criteria, since it was based on a chemical oxidant (sodium persulfate) that later proved to be non-implementable. It is suggested that a more detailed pre-conceptual design be performed on each prospective technology, prior to making the final technology selection.

- In identifying the preferred remediation technology, the ROD should be written somewhat generally, rather than specifically. This is particularly important if the treatment is 'innovative' in nature. Identifying the selected technology without exactness allows for small changes to be made as the technology design is conceptualized and developed, without having to amend the ROD. For instance, the V-tank ROD amendment specified chemical oxidation, followed by stabilization. But it did not specify in situ or ex situ chemical oxidation, or the type of chemical oxidant that was to be used. This allowed for the project to move to a consideration of Fenton's reagent instead of sodium persulfate, without ROD amendment, and also allowed us to consider in situ vs. ex situ approaches to air-sparging, once the need for chemical oxidation was eliminated. It also helped allow for the transition from chemical oxidation to air sparging, without ROD amendment.

DESIGN/FABRICATION OF THE PROPOSED TREATMENT FOR V-TANK REMEDIATION

Following completion of the ROD amendment process, and the focused evaluation of the Chemical oxidation process which eliminated sodium persulfate from further consideration, lab-scale testing was initiated to evaluate other chemical oxidants. Tests conducted by MSE Technology Applications, Inc. focused on the evaluation of chemical oxidation (and solidification) of simulated V-tank waste, using Fenton's reagent as the chemical oxidant. Fenton's reagent was selected based on previous treatability studies with V-tank waste [4] and the fact that a Fenton's reagent process, manufactured by AEA Technology Engineering Services was potentially available for use, once work at Oak Ridge National Laboratory (ORNL) had been completed. Results of the laboratory study demonstrated the effectiveness of chemically oxidizing simulated V-tank waste slurry using Fenton's reagent [9]. Work was therefore initiated on designing a process for utilizing AEA's chemical oxidation system hardware.

In the summer of 2004 a decision was made to accelerate remediation of the TAN V-tanks. The accelerated schedule for V-tank remediation eliminated the option of using AEA's chemical oxidation system, since it was still being used at ORNL. It was around this time, however, that the combined V-tank waste was determined to be non-characteristically hazardous. With the new non-characteristic determination, an evaluation of potential air-sparging techniques that could also be classified as chemical oxidation was investigated. A potential technique identified from the evaluation involved sparging the waste with ozone. Though the total amount of ozone required to completely oxidize the organic content would be large, the presence of ozone, coupled with air sparging, could be used to remove the hazardous VOCs (e.g., TCE, PCE, and TCA) to below F001 treatment standards, even if chemical oxidation was minimal. Approval to use ozonation as a potential remediation technology was tentatively agreed to by the Agencies provided the post-sparged waste was non-characteristically hazardous. Sonication was added as an additional technique to enhance the treatment.

The original procurement strategy that was established involved a subcontractor that performed engineering work for the INL under a mentoring program to design and fabricate the ozonation/sonication/air-sparging system. Included in these subcontracted work was the preparation of CERCLA documentation supporting the design (i.e., Remedial Design/Remedial Action Work Plan, Health & Safety Plan, Sampling Analysis Plan, etc.). This strategy was abandoned just before contract award, however, when the project was directed to issue a Request for Proposal (RFP) from industry to perform the site remediation utilizing some form of chemical oxidation, per ROD guidelines. Conditions of the RFP included vendor assumption of remedial risk, and compliance with schedule and cost constraints. Two final bids were considered from the RFP process. Both bids were judged to be non-responsive; based on excessive costs, schedule delays, incomplete addressing of all aspects of the requested scope, and non-requested scope additions, such as a proposed sequence of treatability studies. The unsuccessful competitive bid approach delayed initiation of the internal design effort approximately six months.

AEA's chemical oxidation equipment became available within a week of the non-responsive bid determination, however, due to work cancellations at ORNL. As a result, the AEA equipment was transferred to the INL, to be used in conjunction with air sparging, should the post-sparged waste turn out to be characteristically toxic. In support of this, the design team focused on building a system for transferring and consolidating the V-tank in three 30,000-L (8000-gal) consolidation tanks.

Initial requirements for treatment assumed that chemical oxidation would have to occur outside, rather than inside the horizontal V-tanks. This was due to concerns over existing shell thicknesses, and whether chemical oxidation would corrode the tank shell sufficient to cause leaking (either during treatment or post-solidification tank removal). Once air-sparging became a viable option, however, these issues generally went away. As a result, some consideration was given to sparging and solidifying the waste in the V-Tanks in situ, to minimize fabrication costs and eliminate the complexity associated with waste removal and transfer operations. However, company performance goals previously established for the V-Tanks Remediation Project had focused primarily on tank/contaminant source removal and surrounding soil cleanup, rather than treatment. In addition, a minor potential still existed that the post-sparged waste would fail TCLP testing, thereby still requiring chemical oxidation for UHCs. Rather than reconsider the performance goals, the project was directed to proceed with development of, what was considered to be a relatively straight forward, waste removal and transfer system and ex-situ treatment facility.

Predictably, the assumed simplicity of the systems was not correct. In hindsight, it appeared that in situ treatment of the waste would have been much easier to perform than the combined waste removal and ex situ air-sparging operation. A similar in situ air-sparging and solidification approach, performed on the INL V-14 tank, after its residual tank waste was fluidized (to resemble V-tank waste slurry), was completed approximately nine months faster than V-tank waste remediation. With in situ treatment, there would have been no need to fabricate a complicated consolidation tank system with numerous recirculation lines, pumping systems, valves, mechanical stirrers, spill protection and sparge rings. Rather, as with the V-14 tank, one only needed to fabricate sparge wands that could rotate in the bottom of the tank, while sparging the tank with sufficient air to both remove VOCs from the waste and keep the sediments suspended, particularly during solidification. Figure 1 shows the complexity of the recirculation and transfer lines going into and coming out of the horizontal V-tanks and ultimately to the consolidation tank system. Completion of the design, testing, installation, and personnel training extended the project schedule approximately five-months. As a result, the established company performance goals were ultimately missed.

Lessons learned from this phase of the remediation project are as follows:

- When implementing innovative, one-of-a-kind treatment techniques, resist allowing performance incentives to be established for the project that may adversely influence technology decisions. The incentives should be renegotiated, if possible, to allow for new approaches and their respective effects on the schedule.
- One should thoroughly evaluate the expected cost savings of subcontracting on-site remedial operations. Eliminating direct in-put from on-site technical expertise vs. dollar savings may be different than anticipated. In the case of the V-Tanks project, requiring an off-site vendor(s) to assume remediation risk under an accelerated waste treatment schedule, combined with complications associated with conducting work on the DOE site, drove prospective bidders to either not bid, or bid with significant cost increases, to insure that their financial risk was covered.

V-TANK WASTE REMOVAL OPERATIONS

Prior to waste consolidation operations, a mockup test was conducted to determine the best means for removing sludge and supernatant from the four V-tanks, while training the operations team on use of the equipment that was eventually selected. Based on the results of these tests and input from operations personnel, it was decided that a high volume recirculation pump system was necessary to mix the waste within the horizontal V-tanks (V-1, V-2, and V-3) and keep the sludge sediments suspended in the supernatant, during its transfer to the consolidation tanks. For

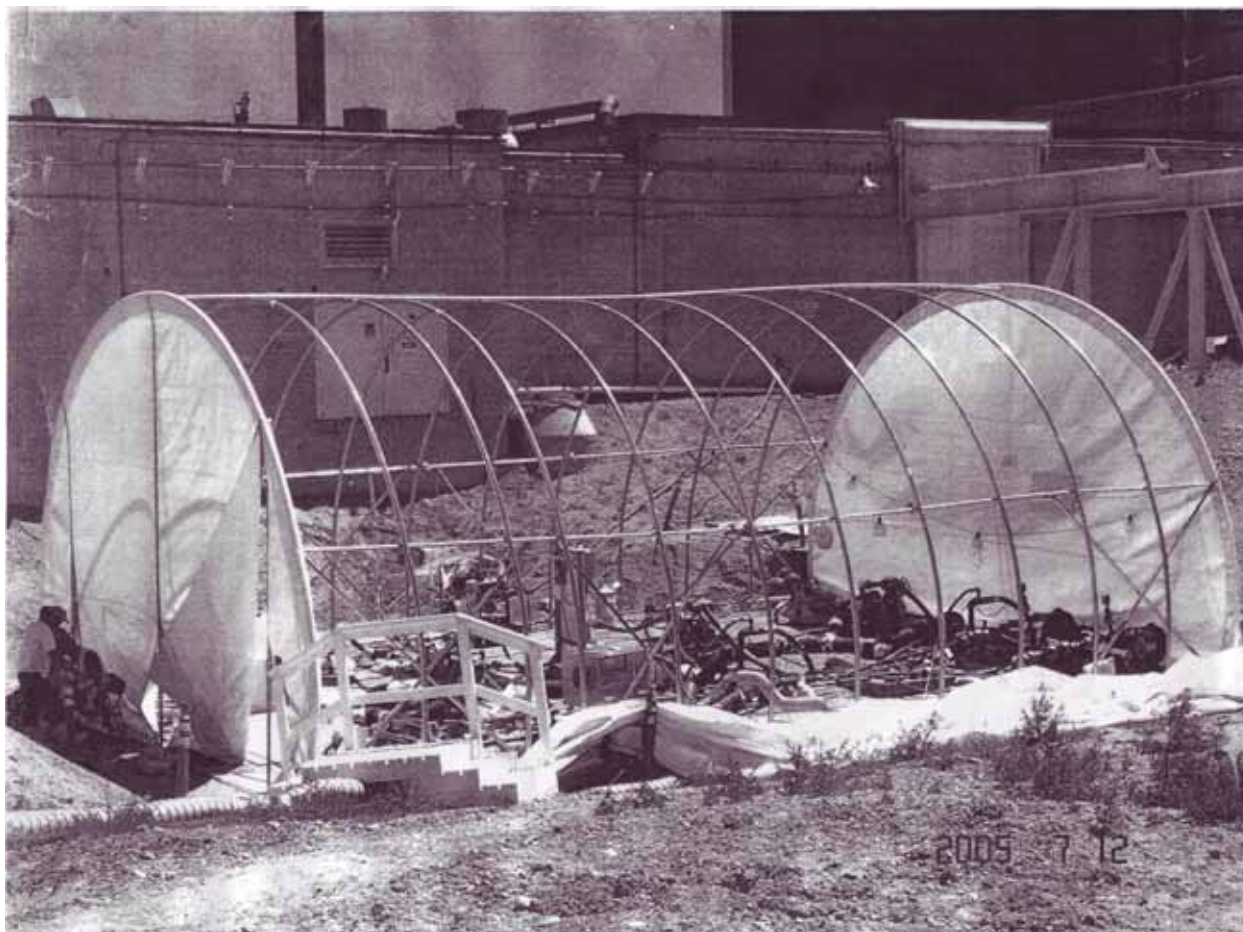


Fig. 1. Photograph of recirculation and transfer lines coming out of the horizontal V-Tanks.

V-9 waste removal, a combination of high pressure and heated water fluidized the solidified sludge stimulant sufficiently to remove it from the tank, using the same sludge pump used on the horizontal V-tanks. Results from these mockup tests significantly modified retrieval system design.

Following system design, fabrication, and installation, the system was ready to initiate System Operations (SO) testing, while continuing to train Operations personnel on how to use the equipment. SO Testing began in March 2005, in support of a Management Readiness Assessment that was completed in June 2005. Actual operations began in July 2005. At this point in the project, a “turn-over” was required of the project team, a departure from the original project plan. Due to the short duration of the job and the complexity of the systems involved it was intended that the project production coordinator, system engineer, and key personnel from the design team would direct Operations personnel in performance of the scope. Instead, it was decided that system operations would be turned over to the TAN facility to conduct the work, with cursory involvement from the original team members. As a result, the Operations team faced numerous mechanical issues/problems that developed in the initial stages of tank transfer and air sparging (e.g., pump leaks, failed gaskets, plugged lines plugged level instrumentation, etc.) without support from a knowledgeable system engineer. Although the project team was eventually consulted to help rectify these issues, the initial decision to not use them during V-tank remediation operations resulted in key engineering support being reassigned to other projects. Consequently, recovery from many of these problems took more time to implement, since Engineering was not readily available to observe and solve the problems directly. Although the Engineering teams were eventually re-assembled, they had to be staffed with a Project Engineer and System Engineer that was not part of the original team that possessed intimate knowledge of the system.

Waste removal operations commenced in July 2005, with the transfer of 21,000 L (5500 gal) of supernatant from Tank V-3 to one of the consolidation tanks. This was done using a peristaltic pump and a hose-line that pumped out the top of the supernatant layer in V-9, in a manner that minimized re-suspension of the sludge layer at the bottom of

the tank. Following removal of V-3 supernatant, removal of sludge and supernatant material from all four V-tanks was initiated using the recirculation and transfer system. Initial slurry transfer operations focused on the residual sludge and slurry in V-3. Following plugging of the transfer line, however, a decision was made to begin sludge and supernatant transfer from tanks V-2, V-1 and V-9, before returning to V-3. Although occasional transfer line plugs delayed completion of the waste removal operation, the horizontal V-tank tank recirculation and sludge removal system was able to successfully remove essentially all of the waste from V-1, V-2, and V-3 by late August 2005. With water addition, total consolidated waste volume came to 60,000 L (15,800 gal).

Sludge and supernatant waste removal operations on tank V-9 were not as successful, however. Initial V-9 waste removal operations were able to remove all but approximately 75 L (20 gal) of combined sludge and supernatant from the downstream side of the V-9 tank. The remaining portion had sufficient debris material in it to continually plug the transfer line, however, with each removal attempt. Repeated attempts to remove the waste with water addition were unsuccessful. Rather than continue, a decision was made to stop waste transfer operations, and proceed with in situ treatment of the residual V-9 waste, using air-sparging.

AIR SPARGING OPERATIONS

Air-sparging of the consolidated V-tank waste was initiated as soon as sufficient waste was present in the consolidation tanks to cover the sparge rings. Sparging of the consolidated waste continued throughout the remainder of the sludge transfer operation, with internal recirculation of each consolidation tank, while allowing for occasional transfers of recirculating and air-sparged sludge between tanks. Each consolidation tank was sparged at a rate of 140-230 L/min (5-8 scfm).

To collect air-sparged VOC emissions, the V-tank off-gas system included Granular Activated Carbon (GAC) beds downstream of the High Efficiency Particulate Air (HEPA) filter. The GAC material was also sulfur impregnated to collect any mercury vapors that were released during sparging. Monitoring of specific VOC concentrations in the off-gas stream was performed using a Fourier Transform Infra-Red (FTIR) analyzer (when available) and off-gas “sniffer” tubes (when the FTIR was not available for use).

Air-sparging continued uneventfully until late August 2005, when it was initiated on the residual waste within tank V-9. Initial sparging of the V-9 waste was conducted at 1270 L/min (45 ft³/min). Within one hour of initiating V-9 waste sparging, one of the two GAC beds caught on fire, shutting down operation. Damage to the treatment system was confined to the single GAC unit.

The resulting investigation and work stoppage lasted for approximately five months. A management and technical review found that the root cause of the fire was extremely high concentrations of VOCs (over 54,000 ppmv) being fed to the GAC beds, which raised temperatures significantly enough (due to the exothermic heat generated from VOC adsorption on the carbon) to cause the GAC material to ignite. The concentration of VOCs in the off-gas was substantially greater than the anticipated off-gas design guidelines of 10,000 ppmv. Although pre- and post-GAC analysis of VOC concentrations in the off-gas stream was a part of operations, the intermittent nature of the data collection did not allow the high off-gas concentrations to be determined in a timely manner.

The decision to air-sparge residual V-9 waste was made based on a brief evaluation considering the anticipated VOCs left in the 75 L (20 gal) of waste that was suspected to still be present in V-9. Based on this evaluation, it was anticipated that organic concentrations in the off-gas would remain within routine operating parameters. In retrospect, this decision presented a greater risk than what was realized. Integration of the resultant emissions data indicated that there were substantially more VOCs in the untreated V-tanks waste than originally anticipated. The total revised estimate of VOCs in V-9 waste (353 kg, or 778 lbs) was over six times greater than original data estimates of 56 kg (124 lbs).

The investigation found that the off-gas system did not have a fire suppression system, even though such a system had been recommended as part of system design. Although recommended, the project made a decision, based on the lower anticipated off-gas concentrations, to not include fire detection and suppression systems in the off-gas train. . Although VOC concentrations below 10,000 ppmv were expected and evaluated for sparging the consolidated tank waste, sparging of a more concentrated V-9 waste residue had not been considered during system design. Therefore, the decision to proceed with air-sparging of V-9 waste residue was outside of the operational envelope of the system.

The resultant GAC fire pointed out the need to sometimes install redundant safety systems, even if the design does not show an unsafe condition under normal operations. One needs to remember that sometimes, an operating system may be pushed beyond its normal operating conditions. With redundant safety systems in place, the potential problems associated with operating outside of the operational envelope could have been avoided, or at least minimized. Hard adherence to the standard operational envelope should also be mandatory, when decisions to eliminate “redundant” safety systems are made.

Air sparging of the consolidated V-tank waste and the residual sludge in V-9 was resumed in late January 2006, following a decision to air-sparge without the use of GAC beds in the off-gas stream. To do this, it was necessary to minimize VOC emission rates to less than 1.4 kg/hr (3 lb/hr). A photo-ionization detector was added to the off-gas system to provide more continuous monitoring of off-gas VOC emissions. Air-sparging continued until early April 2006, with sparge rates maintained at up to 510 L/min (18 scfm) in each consolidation tank, and 280 L/min (10 scfm) in Tank V-9.

Air sparging to the consolidation tanks was discontinued after conformational sampling indicated that remediation goals (i.e., F001 treatment standards) had been met. Post-sparging TCLP analysis also confirmed that the waste was not characteristically hazardous, eliminating the need to continue waste remediation, using chemical oxidation. In preparation for confirmation sampling, the waste contents within each of the three consolidation tanks were cross-circulated between tanks, to achieve a consistent waste profile within the three consolidation tanks.

CONSOLIDATED WASTE SOLIDIFICATION OPERATIONS

Plans for solidifying the consolidated V-tank waste, following treatment, were to mix the treated waste with a water-absorbent solidification material, as it was pumped into the recently unearthed, horizontal V-tanks that most of the waste (other than V-9) had previously been stored in. The solidified V-tank waste material and horizontal V-tanks would then be disposed of at the ICDF, with the residual voids in each tank filled with grout prior to burial.

Based on a technical review of potential absorbents for water-based slurries, a decision was made to use WaterWorks SP-400 Crystals™ as the solidification material for the consolidated V-tank waste. WaterWorks SP-400 Crystals™ is an acrylic acrylate copolymer that is capable of absorbing up to 50 times its weight in water, producing a polymeric solidified waste form that meets the requirements for disposal of previously-liquid wastes at the ICDF. In preparation for solidification, a series of mockup tests were performed to determine the best means for mixing WaterWorks SP-400 Crystals™ with a liquid waste simulant having similar properties to that of the consolidated V-tank waste. Results of the mockup tests found that the preferred method of waste/solidification product mixing was to add WaterWorks™ crystals to the treated V-tank waste, as it was pumped into the horizontal V-tanks. A vortex mixer was used to mix the treated waste with WaterWorks™ crystals as it was pumped into the V-tanks. Addition of solidification product to the mixer was controlled using an auger system with a variable-speed drive to continuously keep the rate of solidification product added to the waste at 7-13 wt% of the treated waste addition rate. A picture showing the consolidated waste system in operation is shown in Figure 2.

Solidification of the consolidated V-tank waste material was performed in June 2006. The solidification operations resulted in each of the three horizontal V-tanks being filled between one-half and two-thirds full. Although some debris was still present in each tank, the debris was encapsulated by the solidified V-tank waste material, as it was pumped into the tanks. Figure 3 shows some of the solidified waste form, as it encapsulates debris in Tank V-2. The WaterWorks™ and treated V-tank waste material mixture produces a dark spongy gelatinous waste form, absent of free liquid. Following solidification, the horizontal V-tanks were shipped to ICDF for final disposal, void filling (with grout) and burial.

In general, the consolidated waste solidification operation operated smoothly, without the operational problems seen during waste removal and air-sparging operations. The smoothness of the solidification operation was due to the decision to use mockups to define the process, prior to initiating design efforts.



Fig. 2. Solidification system used for the consolidated V-Tank waste.



Fig. 3. Resultant solidified waste form in Tank V-2.

RESIDUAL V-9 WASTE SOLIDIFICATION AND TREATMENT

The revised approach for V-9 residual waste treatment was to continue to air-sparge the residual waste in situ, followed by in situ solidification of the waste. The tank would then be removed and disposed of at the ICDF complex, without removing the solidified waste-form from the tank. Air-sparging operations for the residual waste in tank V-9 were plagued by low VOC emissions rates that continued long after air-sparging was anticipated to have been completed, however. To accelerate VOC removal, submersible heaters were inserted into V-9 to increase residual sludge temperatures. Although low VOC emissions continued (following periodic surges), confirmatory sampling verified that the “treated V-9 waste” met F001 treatment standards. Following sample confirmation, the residual V-9 sludge was solidified within tank V-9 using 75 kg (165 lb) of Stockosorb C™, a cross-linked acrylamide/potassium acrylate copolymer similar to WaterWorks™ crystals. The projected ratio of Stockosorb C™ to residual V-9 waste was estimated at 1:8.2, sufficient to produce a very dry solid.

Following solidification, the tank was readied for final excavation and disposal. During this time, beads of metallic mercury were observed in the attached inlet pipe, as it was removed. The presence of mercury in the inlet pipe led to speculation that the original V-9 characterization data, taken from waste on the outlet side of the tank baffle, did not provide represent the total residual waste profile in V-9. As a result, residual sludge material in V-9 was re-sampled in May 2006 at three locations on the outlet side of the V-9 baffle and one sampling location on the inlet side of the V-9 baffle. In performing the sampling activity it was observed that there appeared to be untreated waste remaining on the inlet side of the baffle that had not been dislodged through mixing and transfer operations. This observation was verified when analytical results indicated that the remaining material contained both unacceptable concentrations (up to 7 wt%) of various F001 contaminants as well as high concentrations (up to 1.6 wt%) mercury. Analytical results also indicated that 75 L (20 gal) of partially-treated sludge containing unacceptable F001 contaminant concentrations was present on the outlet side of the tank. The presence of this untreated waste explained why low VOC emissions would continue to emanate from V-9, long after sparging was anticipated to have been completed. Since V-9 had become decoupled from the rest of the V-tank waste due to the stand-alone in-situ treatment, the inclusion of the high-mercury subcategory treatment standard was now applied to this waste.

Because of the relatively viscous nature of the residual untreated V-9 sludge, a decision was made to pursue off-site treatment of this waste, rather than removing and treating the untreated and partially-treated waste on-site. After reviewing potential vendors, a decision was made ship the waste for off-site treatment at Pacific EcoSolutions, located in Richland, Washington. Efforts to complete treatment of the residual waste are still underway. Plans are to treat the waste in a manner that removes or destroys the F001 contaminants (to below treatment standards), while stabilizing the waste sufficiently to keep mercury leachability under characteristic toxicity limits.^d

The inability to identify residual untreated waste on the inlet side of the V-9 baffle before waste solidification and tank removal was due to a lack of visual access on the inlet side of the V-9 baffle, during waste transfer operations. The only access to V-9 waste was through a 15-cm (6-in) penetration in the tank lid that entered the tank on the outlet side of the baffle. No access ports existed on the inlet side of the baffle. Although a suggestion was made to drill a hole through the top of V-9 to provide access, the suggestion was rejected due primarily to personnel radiation exposure concerns.

The radiation exposure goals set for V-tank waste remediation improperly drove the decision to remove waste from V-9 without visual access to the inlet side of the baffle. However, personnel exposure goals are only that—goals. Since actual exposure limits were not going to be exceeded, the request for providing visual access on the inlet side of tank V-9, during waste removal operations, should have been granted. Had visual access been granted, project personnel would have become aware of the large volume of untreated waste that still existed in V-9, and taken steps to fluidize this waste to allow for its removal, using the same access ports that were used to provide visual access.

^d Although high concentrations of mercury in waste generally requires treatment by either incineration (IMERC) or retorting (RMERC), both treatments were designed to promote the recycling of mercury, something not desirable when dealing with radioactive wastes (due to contamination control concerns). As a result, agreements were made with the Agencies to proceed with treatment and stabilization of the residual untreated V-9 waste, without the need to remove mercury from the waste, in accordance with RMERC or IMERC.

Another reason for not being aware of the large volume of residual untreated waste in V-9, following waste removal operations, was due to results of V-9 mockup testing. Mockup testing had suggested that sludge on the inlet side of the V-9 baffle would slough into the bottom of the tank during waste removal operations (allowing it to also be removed), if heated water injection was used. Based on these tests, the need to access the inlet side of V-9 was not expected to be necessary. However, the simulated waste used in the mockup test was prepared based only on a qualitative visual evaluation of V-9 sludge, not actual V-9 sludge properties. Apparently, the mechanical properties of the simulated V-9 waste were not representative of actual V-9 waste, in terms of ability to flow into and be pumped out of the bottom of V-9, with heated water addition.

LESSONS LEARNED DURING V-TANK OPERATIONS

Primary lessons learned during V-tank waste remediation operations were as follows:

- Personnel involved in the remediation system design should continue to support the project during remediation operations. This includes design team members staying on the project after design is and having project team members in charge of actual remediation operations. Remediation of environmental waste sites within DOE complexes should not exclusively rely on facility operations, with sets of Operating teams taking direction from an Operations Manager. Rather, Operations should provide operations manpower and oversight support to the project team to perform the treatment operations. This is because Project team members have a better knowledge/experience base regarding the waste being treated, and the system being used to treat it. Project teams should also stay fully functional throughout the waste remediation activity, with particular emphasis on maintaining Project Engineers and System Engineers that “own” the project, from inception to closure. If personnel changes occur, there needs to be a smooth transfer of knowledge base for these positions, to assure that their replacements continue to “own” the process.
- In making decisions over what to include in a system design, one needs to be aware of the potential for using the system outside of the operational envelope that it was designed for. For this reason, one should err on the side of caution, when deciding whether or not to include safety systems in the overall system design. Even if existing evaluations show that unsafe conditions would not occur, one should be aware of the assumptions behind that evaluation, how correct they are, and whether or not all potential operating conditions have been evaluated. As a minimum, strict operation guidelines need to be enforced, if redundant safety controls are eliminated.
- Mockup testing appears to be effective in defining how to perform certain complex remediation activities (such as waste removal or solidification), while serving as a platform for personnel training. However, one needs to be aware of the inherent limitations of mockup testing. For instance, the results may depart from actual waste remediation operations, when simulants are prepared without a full understanding of the actual waste being simulated.
- While important, pre-set personnel exposure goals for waste remediation operations are just that—goals! They should not be used to drive operational decisions that increase the risk of operational failure. Only if actual administrative exposure limits or safety concerns are impacted, should decisions be made that could increase the potential for incomplete waste remediation.
- A major support to accelerating waste remediation operations is to maintain good communication channels with the Agencies, as new approaches are identified to solve the processing problems that arise during waste remediation operations. During V-tank waste remediation efforts the decision to move to a less costly air-sparging approach, as well as allowing off-site treatment of the untreated V-9 waste residue, without ROD amendment, was crucial in completing V-tank remediation operations without unnecessary schedule delay..

CONCLUSIONS

Although the purpose of this paper is to identify lessons learned from the V-tank remediation, it is not meant to distract from the significant accomplishment of remediating V-tank waste. As of January 2007, over 99% of the V-tank waste has been treated, and over 97% has been disposed. Remediation of the V-tank wastes at INL has been attempted without success for over 30 years. Completion of V-tank waste remediation is a major achievement for the Idaho Cleanup Project. Remediation and disposal of the remaining V-tank waste is expected to be completed in early 2007, ahead of the original schedule and at a lower cost than projected when the ROD amendment was issued

in February 2004. It was expected that the accelerated remediation effort would result in numerous problems, as remediation activities were planned, designed for and initiated. Looking at the lessons learned, however, may avoid some of the pitfalls that otherwise might be experienced in future remediation efforts.

A summary of the key lessons learned are as follows:

- Keep the project team in charge of remediation, from initial technology identification to final waste closure operations. This includes being responsible for actual remediation operations, with no operational turnover. Representatives of the design team should also be part of the project team during operations, to assure successful operation of the designed system. Fully functioning Project Engineers and System Engineers should also be present throughout the project.
- Consideration should be given to the true cost of off-site treatment, when deciding between off-site and on-site treatment. A complete determination needs to be made of the full cost of off-site treatment, including on-site treatment activities to preparing the waste for shipment, and the estimated cost of shipping the waste.
- Quantifying the decision as to how to remediate a particular waste is effective in helping to justify final technology selection. However, care needs to be taken to make sure that all assumptions regarding the quantified decision are correct. This includes assumptions on the conditions of the waste site being remediated and information on specifics related to the technologies being evaluated.
- Decisions regarding what to include in a particular system design must consider what is needed, as well as potential ways that the equipment could be used, once it is in place. Consideration should be given to including redundant safety systems in the system design, if there is a potential for the operational envelope to be exceeded, either due to inaccurate assumptions about the waste, or the potential to operate the system outside a less robust operating envelope.
- Other than what is prescribed in the ROD, initial performance goals should not drive technical decisions regarding how to best treat the waste. Although personnel safety goals should be considered in controlling work, they should not provide an obstruction to completing the work unless actual administrative safety controls would be exceeded.
- Good communication with Regulatory Agencies is essential through waste remediation operations. This includes periodic meetings where Agency representatives are kept advised on all aspects of the remediation, including when possible impacts to the ROD may result. Good communication on issues related to the selected remedy was very effective in expediting Agency agreements on remedy changes and Agency reviews of the remedial design.

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