RPP-20110
Revision 2

STAGE I RETRIEVAL DATA REPORT FOR SINGLE-SHELL TANK 241-C-106

T. L. Sams
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Date Published
June 2004

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Hanford Group, Inc.

Post Office Box 1500
Richland, Washington

Prepared for the U.S. Department of Energy
Office of River Protection

Contract No. DE-AC27-99RL14047

This report concerns retrieval actions only performed at SST 241-C-106. The report does not address closure actions or residual waste classification and does not constitute a decision on closure, disposal, or waste classification, including but not limited to, "waste incidental to reprocessing" (WIR) determinations under DOE Order 435.1. Portions of DOE Order 435.1 which would have permitted WIR determinations have been challenged, held invalid, and are currently under appeal. (*Natural Resources Defense Council, et al., v. Abraham, et al.*, 271 F. Supp. 3d 1260 (D. Id. 2003). DOE has appealed this decision to the 9th Circuit Court of Appeals under case number 03-35711.

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EXECUTIVE SUMMARY

This document was prepared to comply with the *Hanford Federal Facility Agreement and Consent Order* (HFFACO) (Ecology et al. 1989) Milestone M-45-05H and M-45-05M-T01. This document provides a summary of the single-shell tank 241-C-106 retrieval campaign and post-retrieval waste volume determination including uncertainty calculations. The performance of the modified sluicing and acid dissolution technologies used to retrieve the waste remaining in single-shell tank C-106 is presented. Data to support completing retrieval operations is included. The post-retrieval waste volume calculation provided a verification and comparison of the volume measurements obtained during the retrieval campaign. At completion of retrieval operations, 2,770 gallons or 370 cubic feet of residual waste remained in the tank which included approximately 11 cubic feet of liquid and 359 cubic feet of solid waste.

The majority of the waste contained in single-shell tank 241-C-106 was removed during the 1998 and 1999 sluicing campaign. Approximately 62,000 gallons of waste, including an estimated 5,200 gallons of solids remained in single-shell tank 241-C-106 following the 1999 sluicing campaign. From 1999 through March 2003, approximately 26,000 gallons of water evaporated from single-shell tank 241-C-106 leaving 36,000 gallons of waste. Subsequently, in preparation for the 2003 retrieval campaign, an additional 18,000 gallons of supernatant was transferred from single-shell tank 241-C-106 to double-shell tank 241-AY-102 in April 1, 2003, leaving approximately 18,000 gallons of waste in single-shell tank 241-C-106.

Removal of the residual 18,000 gallons of waste in single-shell tank 241-C-106 was conducted from August 2003 through December 2003 using a combination of oxalic acid dissolution and modified sluicing retrieval methods. Six separate oxalic acid batches were added to single-shell tank 241-C-106 to dissolve and reduce the particle size of the residual solids. Four modified sluicing waste retrieval operations were conducted intermittently with the oxalic acid dissolution steps to remove waste from single-shell tank 241-C-106. The last modified sluicing waste retrieval operation was conducted after the last oxalic acid dissolution step.

The solids content of the waste slurry removed from single-shell tank 241-C-106 decreased following each of the six oxalic acid dissolutions. The waste slurry transferred to double-shell tank 241-AN-106 contained 3% volume solids following the last acid dissolution step. Similar diminishing performance was experienced with the modified sluicing operations. The first modified sluicing operation conducted in single-shell tank 241-C-106 initially resulted in the retrieval waste slurry containing 8% volume waste and ended in the last batch with the retrieval waste slurry containing 0.3% volume waste. The combined decrease in the volume percent solids content of the waste slurry removed from single-shell tank 241-C-106 by both the oxalic acid and modified sluicing operations did not justify continued waste retrieval operations.

For the purpose of tracking waste during retrieval operations and to provide an indication of waste retrieval efficiency, the waste volume determination was obtained by two methods; material balance calculations using a flow totalizer and material balance calculations using

Enraf[1] level detection. The in-process material balance calculations at the end of retrieval operation using the flow totalizers indicated 2,584 gallons of waste (approximately 345 cubic feet), and indicated 2,722 gallons of waste (approximately 364 cubic feet) using the Enraf level detection (see Table ES-1). The final waste volume determination by topographical modeling used the video camera/CAD Modeling System to confirm waste volume estimates. The video camera/CAD Modeling System as selected in the data quality objectives provided the final waste volume calculation of 370 cubic feet remaining in the tank. The final volume was calculated at a 95% confidence level and resulted in uncertainty of plus or minus 26%, respectively (see Table ES-2).

The Stage II Retrieval Data Report for single-shell tank 241-C-106 includes information regarding residual tank waste characterization and the Waste Management Area C post-retrieval risk assessment. Available waste retrieval technologies with associated detailed cost estimates, actions to refine and develop tank waste retrieval technologies, and recommendations for further action are provided in the Stage II Retrieval Data Report.

Table ES-1. Single-Shell Tank 241-C-106 Waste Volume Summary.

Volume measurement technologies	Waste volume remaining in tank	
	gal	ft^3
Waste immersion (Enraf[a] level)[b]	2,722[d]	364
Material balance (flow totalizer)[b]	2,584[d]	345
Video camera/CAD Modeling System[c]	2,770[d]	370.33

Notes:

[a] Enraf is a trademark of Enraf-Nonius, N.V. Verenigde Instrumentenfabrieken, Enraf-Nonius Corporation Netherlands, Rontegenweg 1, Delft, Netherlands.

[b] This waste volume was not included in the waste measurements of either material balance using double-shell tank 241-AN-106 Enraf measurements or material balance using the flow totalizer during waste transfers to double-shell tank 241-AN-106. The waste volume on the stiffener rings included approximately 17.3 ft^3 of the total volume of waste remaining in the tank and was not included in either waste immersion volume calculation.

[c] Calculation of uncertainty using 95% upper confidence level for tank waste adds + 26% or 97.12 ft^3 for a total waste volume of 370.33 + 97.12 = 467.45 ft^3. See uncertainty calculation summary in Table ES-2.

[d] The conversion factor used for converting cubic feet to gallons is 7.481.

[1] Enraf is a trademark of Enraf-Nonius, N.V. Verenigde Instrumentenfabrieken, Enraf-Nonius Corporation Netherlands, Rontegenweg 1, Delft, Netherlands.

Table ES-2. Volume Uncertainty Calculation using 95 Percent Confidence Level for Waste at the Bottom of Single-Shell Tank 241-C-106.

Waste location	Waste volume (ft^3)	Estimated uncertainty (%)		Estimated uncertainty (ft^3)	
		+	-	+	-
Bottom of tank	336.89	27%	27%	90.96	90.96
Equipment in tank	4.84	0%	25%	0.00	1.21
Stiffener rings	17.30	18%	0%	3.11	0.00
Liquid waste	11.30	27%	27%	3.05	3.05
Total	370.33 (nominal)[1]	26%	26%	97.12	95.22
Total waste ± uncertainty				467.45	275.11

Note:

[1] Post-retrieval waste volume calculations include 11.3 ft^3 of liquid waste, i.e. 370.33 - 11.3 = 359.03 ft^3 solid waste.

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ATG	Advanced Technology Gauge
CAD	computer-aided design
CCMS	video camera/CAD Modeling System
DQO	data quality objective
DST	double-shell tank
gpm	gallons per minute
HFFACO	*Hanford Federal Facility Agreement and Consent Order*
SST	single-shell tank

1.0 INTRODUCTION

This document was prepared to comply with the *Hanford Federal Facility Agreement and Consent Order* (HFFACO) (Ecology et al. 1989) Milestone M-45-05H and M-45-05M-T01. This document provides a summary of the single-shell tank (SST) 241-C-106 (SST C-106) retrieval campaign and post-retrieval waste volume determination including uncertainty calculations. The performance of the modified sluicing and acid dissolution technologies used to retrieve the waste remaining in SST C-106 is presented, and includes data to support completion of retrieval operations. The post-retrieval waste volume calculations provided the final verification and comparison of the volume measurements obtained during the retrieval campaign. At completion of retrieval operations in December 2003, 15,000 gal of waste had been removed leaving 2,770 gal or 370 ft^3 of residual waste remaining in the tank which included approximately 11 ft^3 of liquid and 359 ft^3 of solid waste.

The engineering data of the two retrieval technologies deployed in this retrieval campaign provided an estimate of the waste volume remaining in SST C-106 and included the basis for concluding that the technical limits of a modified sluicing/acid dissolution process had been met resulting in termination of retrieval operations. This was indicated during retrieval operations by the following:

- Waste recoveries of less than 3% by volume per acid batch processed, less than 0.3% by volume of entrained waste by sluicing
- The presence of unreacted acid in the last oxalic acid bath addition indicating that the remaining waste was not reacting with the acid
- An increasing cost to retrieve along with a declining trend of waste removal efficiency for each technology.

The waste volume measurements used during retrieval operations included material balance calculations using double-shell tank (DST) AN-106 Enraf[1] level detection measurements and material balance calculations using flow totalizers. Upon termination of retrieval operations, the final waste volume determination used topographical modeling in the video camera/computer-aided design (CAD) Modeling System (CCMS) to confirm volume estimates. The CCMS was developed (and qualified by testing) to establish a final volume of waste remaining in the tank at the completion of retrieval (RPP-17663, *Test Plan for the Video Camera/CAD Modeling System*).

The CCMS utilizes a three-dimensional volume measurement technique prescribed by the *Tank 241-C-106 Component Closure Action Data Quality Objectives* (DQO) (RPP-13889) and was selected as the final approved method used to determine the post-retrieval waste volume. The accuracy and precision of the three techniques used to determine waste volumes were

[1] Enraf is a trademark of Enraf-Nonius, N.V. Verenigde Instrumentenfabrieken, Enraf-Nonius Corporation Netherlands, Rontegenweg 1, Delft, Netherlands.

quantifiable and are discussed in this report. The material balance process calculations were used primarily to track operational efficiencies of waste removal and to account for potential leakage of waste during transfer operations. Waste transfer system configuration and equipment accuracy was adequate to track waste slurry flow rates and in-tank waste level measurements as required by administrative procedures, but was not used for final calculations of waste volumes. The waste volume measurement uncertainties introduced by the transfer dynamics, varying waste forms, and waste/tank geometries did not support the requirements for final waste volume accuracy. These uncertainties are discussed in Section 2.3.1.

1.1 PURPOSE

The SST C-106 waste retrieval campaign goal was to remove existing residual tank waste remaining after past retrieval campaigns to allow for interim closure of the tank. To achieve this goal, retrieval operations deployed retrieval technologies to meet the criteria of the HFFACO Milestone M-45-00 series. This criteria described an end state for interim tank closure that required the selected retrieval technology to remove as much waste from the tank as is technically possible and to leave no more than a mean value of 360 ft^3 of residual waste in the tank. The 2003 retrieval campaign did not meet the volume of residual waste criteria, but did meet the limit of technology criteria for the two technologies deployed.

1.2 PRE-RETRIEVAL CONDITIONS

SST C-106 is a 530,000-gal single-shell tank that has been used to store mixed radioactive waste since the tanks were placed into service in 1947. To address a high-heat safety issue, the majority of waste stored in SST C-106 was successfully retrieved and transferred to DST AY-102 in 1998 and 1999 (Project W-320). However, approximately 62,000 gal of solid and liquid waste remained in the tank after this retrieval (RPP-12547, *Tank 241-C-106 Residual Liquids and Solids Volume Calculation*). From 1999 through March 2003, approximately 26,000 gal of water evaporated from SST C-106. Therefore, in April 2003 to prepare for this retrieval, 18,000 gal of liquid was pumped from SST C-106 to DST AY-102. The final retrieval campaign was initiated on August 7, 2003, with the addition of the first batch of oxalic acid, to retrieve the remaining solid waste to the criteria established in the HFFACO Milestone M-45-00 series.

2.0 RETRIEVAL/VOLUME MEASUREMENT TECHNOLOGIES

2.1 RETRIEVAL TECHNOLOGIES

The sluicing campaigns of 1998 and 1999 removed most of the waste sludge from SST C-106, but did not remove all of the solid material in the tank, which was characterized as a cobble-like, stable agglomeration with varying dimensions up to 6 in. in size (RPP-13707, *Process Control Plan for Tank 241-C-106 Closure*). The standard sluicing techniques deployed in past retrieval campaigns would not dissolve the hard heal of waste remaining in the tank. This insoluble heal required an additional method to dissolve the waste sufficiently for removal. The combination of the acid dissolution and modified sluicing technologies were selected to dissolve and break down the waste for removal. Acid dissolution reflects the use of oxalic acid to dissolve solids, and had historically been used at the Hanford Site and other U.S. Department of Energy sites to decontaminate tanks and equipment. The phrase "modified sluicing" is used to reflect various performance-enhancing sluicing improvements that have been instituted since the 1999 retrieval effort and included the use of varying combinations of sluice head designs to shape and control the fluid stream. The combination of the two methods was designed to maximize removal of the present waste by chemically and mechanically breaking down the waste to a smaller size that would be more readily entrained in the waste slurry and pumped out of the tank. The acid also leached constituents from the increased surface of waste resulting in a remaining waste form that could result in a reduced concentration of radioactivity by volume.

Through experience gained operating Savannah River Site facilities, such as the Defense Waste Processing Facility and tank farm evaporators, the effectiveness of oxalic acid to remove contamination on waste processing equipment was well known (WSRC-TR-2003-00401, *Waste Tank Heel Chemical Cleaning Summary*). As a result of studies performed at the Savannah River Site, the addition of oxalic acid was proposed to enhance the removal of the remaining waste in SST C-106. The Savannah River studies also referenced a variety of tests that were conducted using oxalic acid and determined that up to 70% volume of sludge could be dissolved with the oxalic acid process. In that study, oxalic acid generally dissolved a larger percentage of sludge than other chemical agents or combinations of reactants. The Savannah River study also revealed that longer contact time, in addition to higher solution-to-sludge volume ratios, did not result in significant gains in waste dissolution. This indicated that those constituents that would dissolve did so in a finite amount of time despite the existence of additional acid available to dissolve waste. As was corroborated in laboratory testing at the Hanford Site, the Savannah River testing of oxalic acid dissolution resulted in identification of hematite and boehmite remaining in the insoluble sludge residue at the completion of the acid reaction. The oxalic acid process was subsequently tested and its performance to dissolve waste was validated in laboratory testing at the Hanford Site (RPP-16462, *Process Control Plan for Tank 241-C-106 Acid Dissolution*).

Laboratory-scale testing of acid-dissolution at the Hanford Site (using a sample of the SST C-106 waste) was performed to determine the effectiveness for dissolving the waste. This laboratory testing demonstrated that nearly 70% of the waste solids dissolved in oxalic acid (RPP-17158, *Laboratory Testing of Oxalic Acid Dissolution of Tank 241-C-106 Sludge*). To validate this technology, laboratory tests were conducted in two phases. The first phase examined whether significant sludge dissolution was feasible. The second phase optimized the amount of oxalic acid required and examined operating impacts such as the amount and type of gas generated and the impact on the double-shell receiver tank.

The first phase of testing showed that 50% to 70% of the sludge by weight could be dissolved in oxalic acid or in a mixture of oxalic acid and nitric acid. The mixture of both oxalic and nitric acids was only slightly more effective in dissolving the sludge than oxalic acid alone; however, nitric acid would cause measurable oxidation of tank surfaces and was not considered suitable for tank waste retrieval.

In the second phase of testing, sludge was dissolved over a period of 18 days with the result that the reaction time to dissolve waste mass per day was effectively equivalent each day for the duration of the test. During the test, 68% of the water-washed sludge dissolved and the amount of sludge dissolved were nearly equivalent regardless of whether the volume of acid was added in a single batch or in three smaller batches. The acid dissolution reaction also produced primarily carbon dioxide gas, and further testing indicated that mixing of the acid leachate with simulated DST AN-106 supernatant liquid produced large volumes of easily-compacted smaller solid material. The solids precipitating in DST AN-106 after mixing with the supernatant are predominately sodium oxalate and sodium phosphate.

2.2 RETRIEVAL OPERATIONS

Several modes of operation were used for the retrieval operation of SST C-106 (RPP-19919, *Campaign Report for the Retrieval of Waste Heel from Tank 241-C-106*):

- Oxalic acid was added in discrete and accurately measured batches to SST C-106 through the mixer-eductor or the pump drop-leg.
- Acid was recirculated with the mixer eductor to assure a more complete reaction with the waste, followed by removal of the acid using the retrieval pump.
- Water was continuously added to SST C-106 (between 85 and 350 gpm) through one of the two sluicers to mobilize and redistribute the waste solids for removal by the retrieval pump.

The oxalic acid dissolution process leached additional waste constituents directly from the sludge and also reacted with carbonates in the waste to increase solid waste porosity. Both the loss of carbonates and the agitation of the waste increased the surface area of waste available for leaching waste constituents during subsequent sluicing and acid dissolution events.

During acid dissolution, operations were performed using oxalic acid with a concentration of 0.9 molar. A mixer-eductor was used to recirculate the oxalic acid in SST C-106. The acid dissolution reaction for each acid batch reached steady state (i.e., reaction complete with no further dissolution) after an average of 7 days. After the acid reaction reached steady state, dissolved wastes were transferred via a pump to DST AN-106 at a controlled rate using a near surface buried or aboveground hose-in-hose transfer line. The mixer-eductor in riser 7 was removed after the fifth batch of oxalic acid was added to the tank and was replaced with a second sluicer. This was required to provide a more advantageous location in order to remove the waste not reached by the first sluicer nozzle.

Recirculation of the oxalic acid batches was no longer possible after removal of the mixer eductor following the fifth acid batch. However, good contact between the waste and acid was realized without recirculation as most of the waste had been leveled into a thin layer, allowing the majority of the waste to be submerged in acid.

The sluicing technology utilized a hydraulic process that deployed an articulated high-pressure water head that physically broke-up sludge, entrained solids, and soluble waste and moved the resultant slurry to the retrieval pump intake. Sluicing in this campaign was initiated after the third acid batch and used after each subsequent oxalic acid batch to remove additional waste.

2.3 WASTE VOLUME MEASUREMENT TECHNOLOGIES

The amount of waste resident in SST C-106 was determined by three methods. Two complementary material balance techniques were used during retrieval operations using the flow totalizer and DST AN-106 Enraf level readings to calculate liquid transfers and waste volumes. After completion of retrieval, the third method (CCMS) of volume determination was used to establish the final waste volume. In addition to the waste on the bottom of the tank, the CCMS method provided estimates of residual waste remaining on the tank wall and stiffener rings and waste contained in equipment identified as abandoned in the tank. The CCMS is described in detail in Section 2.3.3.

2.3.1 Material Balance

Administrative controls (HNF-SD-WM-TSR-006, *Tank Farms Technical Safety Requirements*) required that a material balance be performed during all waste transfers to account for all liquid and solid waste bounded within the system. The data requirement to perform the material balance calculations included the flow and time, flow totalizer readings at SST C-106 during transfers out, liquid level of SST C-106 and DST AN-106, normal transfer material balances, the volume of acid put into the tank, the amount of water added, and the volume of caustic rinse.

The SST C-106 liquid surface was expected to exhibit a slight negative trend during monitoring periods because of evaporative losses. In addition, the waste was expected to effervesce (offgas) due to the acid reaction with carbonates with the effect of a slight loss of mass. The oxalic acid dissolution process therefore introduced inherent inaccuracies in the material balance calculations that although minimal, were not easily measured. For example, the amount of offgas could not be measured with the effect that the material balance could be inaccurate by a small percentage of the total sludge left in the tank. Additionally, solids changed volume as they were dissolved in the acid and although the mass remained constant, the volume and level could have been affected. Eventually some of the oxalates produced by the acid reacting with waste solids had the potential of forming insoluble oxalate solids. The acid was neutralized when pumped to DST AN-106 and the dissolved solids re-precipitated as different chemical compounds. The oxalic acid was neutralized into insoluble sodium oxalate, so additional solids that were not present in SST C-106 were being created. These phenomena were recognized as contributing to inaccuracies in liquid volume measurements, but were not easily quantified.

2.3.2 Waste Immersion Technology

Waste immersion required filling SST C-106 with a known volume of liquid to a tank level that covered the waste. This volume of liquid was compared to the known volume of tank geometry corresponding to the level of liquid in the tank at that time. The difference between the liquid volume added and the volume calculated for an empty tank described the volume of waste remaining in the tank. The Enraf level detectors were used to determine the liquid level and provided input to the volume calculation. The level changes were measured using the Enraf Series 854 Advanced Technology Gauge (ATG). The Series 854 ATG is widely used throughout the petroleum industry to measure tank volume and specifically in the Hanford Site tank farms for primary tank waste surface level measurements. The ATG uses the principle of buoyancy to track level changes within each tank. As installed at the Hanford Site, a displacer is suspended from a thin wire and lowered into the tank until the instrument load cell detects a loss in weight resulting from the displacer contacting a liquid or solid surface. The Enraf system maintains a weight that is a fraction less than the true weight of the displacer, such that the displacer is primarily suspended from the wire and only slightly supported by the surface medium. The instrument tracks the position of the displacer and continuously reports the level of the encountered liquid or solid.

The instrument is capable of an absolute accuracy of ± 0.04 in. at 100 ft, and a repeatability of ± 0.004 in. under ideal conditions (vendor specification). The Hanford Site uses the top of a ball valve as the primary depth reference, but because the calibration surface is not flat this practice introduces a potential calibration error of ± 0.10 in. Therefore, the applicable accuracy is ± 0.10 in. based on the rounded ball valve calibration. And although the true precision (repeatability) of the gauge is ± 0.004 in., Hanford Site applications only read the gauge to two decimal places. As a result, the applicable precision for Hanford Site applications is ± 0.01 in.

2.3.3 Video Camera/CAD Modeling System

The CCMS documents the calculation of the post-retrieval residual waste volume in the bottom of the tank and was included in the DQOs. Also included in the CCMS analysis are estimates of the residual waste remaining on the tank wall, the stiffener rings, and in equipment abandoned in the tank. Waste volume was determined by a topographic model based on information obtained from video observations and observations of still video. To support these calculations, an in-tank video of SST C-106 was taken on February 4, 2004. The camera was located in riser 14 at heights of 25, 15, and 8 ft above the bottom of the tank.

2.3.3.1 CCMS Uncertainty Determination. *Results of the Video Camera/CAD Modeling System Test* (RPP-18744) contain the calculations for the estimate of percentage uncertainty in calculating waste volume using the CCMS method. Mock-up tests at the Cold Test Facility were performed to provide data for estimating the percentage uncertainty following the approved test plan (RPP-17663). The approved test plan calls for an 80% confidence level for the uncertainty used in conjunction with the CCMS for the final residual volume estimate of solid waste. This uncertainty was determined to be + 18% and - 17%, at the 80% confidence level, for the total volume. The uncertainty calculated at the 95% confidence level is ± 26% and was calculated using the same methods used for the 80% confidence level in RPP-18744.

2.3.3.2 CCMS Tank Bottom Waste Volume Calculations. The volume of the residual waste in the bottom of SST C-106 was determined using the CCMS with the AutoCAD Land Development Desktop Release 2i software. The AutoCAD Land Development Desktop is being used by the CCMS to determine waste volumes remaining in a waste storage tank by calculating the volume within the three-dimensional coordinates of a series of points, which are identified on the waste surface. The waste surface point coordinates are determined using observations from a video camera imaging system in conjunction with known tank geometry and available tank and waste information. The tank bottom dimensionally is an inverted dome (dished bottom) with a spherical segment base radius of approximately 33.74 ft. The dished bottom center is 12 in. deep and has a volume of approximately 13,380 gal. Internal tank dimensions are documented in *Waste Retrieval Sluicing System Campaign Number 3 Solids Volume Transferred Calculation* (HNF-5267).

AutoCAD Land Development Desktop was also used to model the residual waste configurations on the surface of various tank components and to determine these volumes. Using the software, a digital terrain model was built with the information obtained from viewing a video recording and still photographs taken from the video (RPP-19866, *Calculation for the Post-Retrieval Waste Volume Determination for Tank 241-C-106*).

2.3.3.3 CCMS In-tank Equipment Waste Volume Calculations. The amount of residual waste in the equipment in SST C-106 was determined by using the in-tank video and tank information to determine the equipment remaining in the tank. Video evaluation was also used to estimate the dimensions of hoses and pipes in the tank and this information, including equipment drawings, was used to estimate the volume of waste in the equipment. The calculations for the residual waste volume in the equipment are provided in RPP-19866, Appendix B.

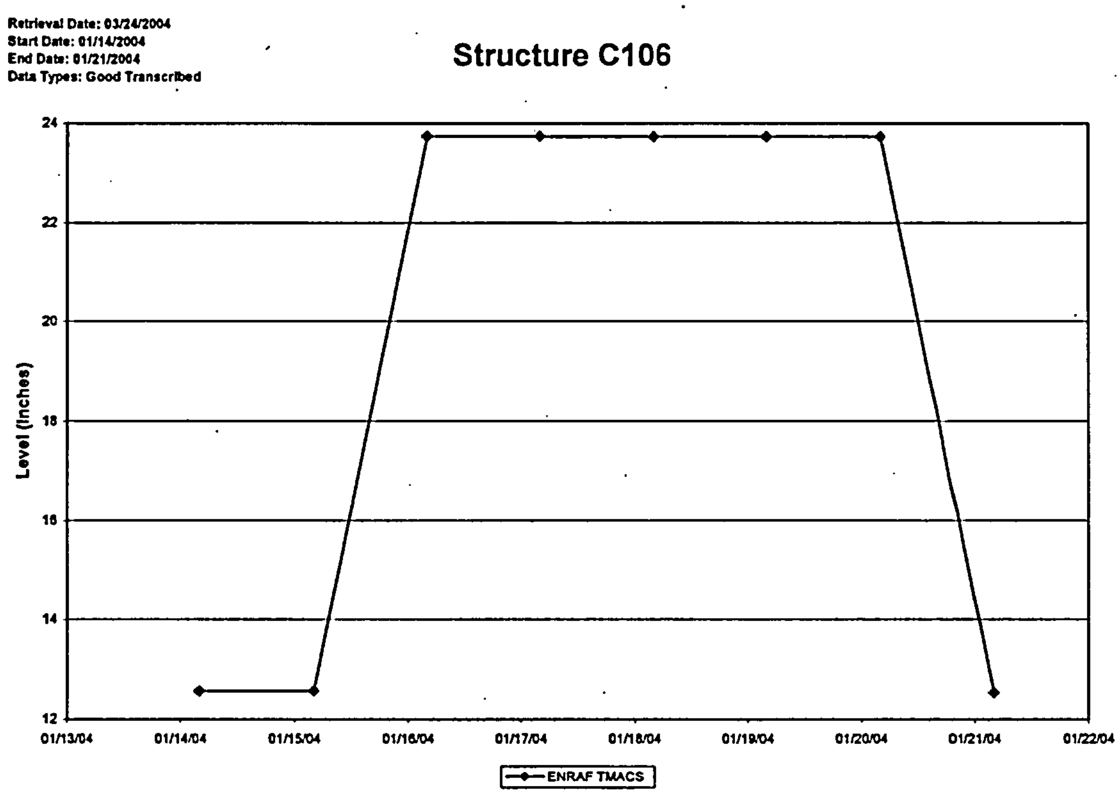
2.3.3.4 CCMS Stiffener Ring Waste Volume Calculations. The four stiffener rings are structural members welded to the side of the interior tank wall. The stiffeners were observed to have the heaviest amount of crusted waste on the bottom ring closest to the bottom of the tank. The accumulated waste dissipated as the rings graduated up the wall with the top ring having no observed waste. The amount of waste on the stiffener rings was estimated by visually estimating the size of any waste clumps and by visual examination of still video to determine if a waste film was present. Based on the observations, an average waste thickness was estimated for each stiffener ring and used for the calculation to determine waste volume (RPP-19866).

2.3.3.5 CCMS Tank Wall Waste Volume Calculations. Based on the lack of video evidence of waste on the tank side wall, the volume of waste on this surface was estimated to be zero. Only a small amount of waste was observed on the tank wall, and because it appeared to be the result of the sluicing of the stiffener rings, the volume of that waste was included as part of the stiffener ring calculation. No other waste was observed on the tank wall.

2.4 LEAK DETECTION

Although there was no indication that leakage occurred during retrieval operations as verified by material balance calculations, and there was no historical data or operational data that supported that SST C-106 had leaked waste, it was necessary to establish whether a leak had occurred in order to provide required input to the post-retrieval risk analysis. Therefore, the waste immersion technique was used both to provide a final estimate of the waste remaining in SST C-106 at the completion of the last campaign and to provide measurable evidence that leakage did or did not occur. At the termination of retrieval operations, a total of 42,000 gal of water was added to immerse all the waste in the tank for a final estimate of residual waste volume using this technique. The volume of liquid added was equivalent to the highest liquid level that occurred during retrieval operations and provided an equivalent location and liquid pressure profile to all tank surfaces exposed to liquid during the retrieval campaign. After the addition of 42,000 gal of liquid to SST C-106, the liquid addition level did not change during the 5 days from January 15, 2004 to January 20, 2004 and this was recorded in the Tank Monitoring and Control System operational logs (see Figure 1). This was an indication that no leakage occurred during retrieval operations and thus waste volumes released due to leaks were considered to be zero.

Figure 1. Liquid Addition to Single-Shell Tank 241-C-106.



DATE	ENRAF TMACS (tank liquid level in inches)
1/14/2004 4:02	12.56
1/15/2004 4:02	12.57
1/16/2004 4:02	23.74
1/17/2004 4:02	23.74
1/18/2004 4:02	23.73
1/19/2004 4:02	23.73
1/20/2004 4:02	23.73
1/21/2004 4:02	12.53

Notes:

No change in tank liquid level over 5-day period.

TMACS = Tank Monitoring and Control System.

2.5 RETRIEVAL PERFORMANCE

Several methods were used to evaluate the removal of waste during retrieval operations and to determine when the retrieval technologies would reach the point of diminishing returns. Material balance utilizing flow totalizers and liquid level Enraf readings were used to document the efficacy of waste removal and ultimately the performance of both the modified sluicing and oxalic acid waste dissolution technologies. Carefully measured volumes of both oxalic acid and water were added to SST C-106 and the volume of liquid pumped from SST C-106 was also measured. The difference between the liquid volume pumped to DST AN-106 and the volume of acid and water added also provided an estimate of waste removed for each operation.

Before the start of retrieval operations, an estimate of the volume of waste remaining in SST C-106 was made and a known volume of water was added to the tank and verified by a liquid level measurement. The amount of waste left in the tank prior to the start of this retrieval was estimated by water immersion to be 18,000 gal, most of which were assumed to be solids.

After the last sluicing operation, the volume of waste left in SST C-106 was estimated by submerging all the waste. The difference between the known volume that submerged the waste and the transferred volume determined the remaining waste. The amount of waste removed per unit batch was tracked to determine the effective completion of the acid/waste reaction and to determine an endpoint of diminishing returns for the selected technology. At retrieval completion waste samples were taken to evaluate the waste inventory per volume of waste and to identify the contaminants of concern remaining.

2.6 CAMPAIGN CHRONOLOGY

The chronology for the retrieval operations in SST C-106 is shown below.

- About 187,000 gal of waste were removed from SST C-106 during the retrieval operation in 1998 and 1999. At that time 62,000 gal of residual waste were left in the tank which included an estimated 5,200 gal of solids.
- Evaporation of water reduced the volume that was left following the end of sluicing in 1999 to about 36,000 gal. About 18,000 gal of residual supernatant was pumped from the tank, starting April 1, 2003. The waste remaining in SST C-106 after the supernatant was pumped was approximately 18,000 gal of predominately solid matter.
- The sluicer in riser 3 was used to level the solids and rinse soluble constituents. Approximately 37,000 gal of sluicing liquid was pumped into the tank starting June 9, 2003. Starting waste volume was determined.
- The first oxalic acid batch was added, starting August 7, 2003.
- The second oxalic acid batch was added, starting August 27, 2003.
- The third oxalic acid batch was added, starting September 16, 2003.

- To prepare for sluicing, the pump was replaced and the new pump tested, starting October 3, 2003.
- The first modified sluicing operation was conducted, starting October 14, 2003.
- The fourth oxalic acid batch was added, starting October 20, 2003.
- The second modified sluicing operation was conducted, starting October 28, 2003.
- The fifth oxalic acid batch was added, starting October 30, 2003.
- To allow for additional spray head coverage, the mixer-eductor was replaced by the second sluicer, starting November 6, 2003.
- The third modified sluicing operation was conducted, starting December 4, 2003.
- The sixth oxalic acid batch was added, starting December 14, 2003.
- The fourth modified sluicing operation was conducted, starting December 28, 2003.

The results of material balance calculations are shown in Table 1. The starting waste volume was determined by waste immersion (material balance) calculations and review of in-tank video. The ending volume is a preliminary estimate from the volume increases in DST AN-106 and material balance calculations.

Table 1. Material Balance Calculations for Oxalic Acid and Sluicing Batches in 2003. (2 sheets)

Date	Oxalic acid added (gal) [a]	Water including sluice water added (gal)[b]	Estimated waste removed (gal)[c]	Waste remaining (estimated from transfer balances) (gal)	Waste remaining (estimated from transfer balances) (ft^3)
Start	--	--	--	18,000	2,406
August 7	15,803	579	1,441	16,559	2,214
August 27	25,957	1,343	2,131[d]	14,428	1,929
September 16	31,686	1,021	4,727[d]	9,701	1,297
October 14	--	56,160	4,873	4,828	645
October 20	31,772	1,960	-2,597[d]	7,425	993
October 28	--	46,472	1,607	5,818	778
October 30	15,632	908	80	5,738	767
December 4	--	59,228	857	4,881	653
December 14	21,169	315	547	4,334	579
December 28	--	83,501	217	4,117	550
Total	142,019	251,487	13,883	--	--

Table 1. Material Balance Calculations for Oxalic Acid and Sluicing Batches in 2003. (2 sheets)

Date	Oxalic acid added (gal) [a]	Water including sluice water added (gal)[b]	Estimated waste removed (gal)[c]	Waste remaining (estimated from transfer balances) (gal)	Waste remaining (estimated from transfer balances) (ft^3)

Notes:

[a] Acid was added in measured batches.

[b] Water additions are based on metered inputs.

[c] Waste removed is calculated by subtracting inputs (acid or water added) from the volume change in DST AN-106 as measured by Enraf.[1]

[d] The estimate of waste removed is dependent on the liquid heel remaining from the previous batch. The liquid heel volumes varied significantly for some of the September and October batches. Two different pumps were involved in these operations.

[1] Enraf is a trademark of Enraf-Nonius, N.V. Verenigde Instrumentenfabrieken, Enraf-Nonius Corporation Netherlands, Rontegenweg 1, Delft, Netherlands.

DST = double-shell tank.

2.7 RESULTS

2.7.1 Acid Dissolution

The purpose of the acid dissolution process was to dissolve and breakdown the sludge and the solid waste prior to sluicing. The result of this reaction included increased solution density and smaller waste particle size that allow for increased waste removal once sluicing commenced. The smaller particle size enabled more waste to be entrained during sluicing and subsequently pumped out of the tank. To ensure all waste was subject to an acid reaction, the sludge was leveled with sluice water before the initial addition of acid. The estimated 18,000 gal of waste left in the tank prior to retrieval was equivalent to a layer that averaged about 6.5 in. across the bottom of the 75-ft diameter tank. After oxalic acid was added, the waste was soaked to allow the waste digestion process to complete (acid reaction stabilized) and during the soak period, the acid pool was agitated to facilitate the acid-waste reaction. At the completion of the soak period, the retrieval pump was used to remove the solution from the tank including the entrained waste.

A summary of the material balance of the acid batches is presented in Table 2. The material balance for the acid batches was recorded to determine the approximate volume of waste that was transferred with each batch. The extended contact time for acid batch #5 resulted from additional field activities to remove the mixer-eductor and to install the second sluicer. Contact time for batch #5 was not included in the average of 7 days for an acid bath to reach steady state.

Table 2. Material Balance Estimates for Oxalic Acid Additions to Single-Shell Tank 241-C-106.

Acid batch	(A) Volume of acid added (gal)	(B) Volume of water added (gal)	(C) Volume transferred to DST AN-106 (gal)	(D) Volume increase (gal)	Approximate duration of acid contact (days)
1	15,803	579	17,829	1,447	12
2	25,957	1,343	29,431	2,131[a]	5
3	31,686	1,021	37,434	4,727[a]	5
4	31,772	1,960	31,135	-2,597[a]	6
5	15,632	908	16,620	80	35[b]
6	21,169	315	22,031	547	9

Notes:

[a] The estimate of waste removed is dependent on the liquid heel remaining from the previous batch. The liquid heel volumes varied significantly for some of the September and October batches. Two different pumps were involved in these operations.

[b] The mixer–eductor was removed and the 2nd sluicer added leading to this extended soak of 35 days.

DST = double-shell tank.

D = C- (A+B)

The pH of the acid in SST C-106 was monitored during the last acid batch. The pH of the solution showed a gradual increase in the first 6 days and then showed no increase during the rest of the contact period suggesting the acid reaction had reached steady state. The increase in pH was an indication that acid had reacted with the waste heel. However, the average pH over the last 4 days was approximately 0.79, but never reached the expected acid depletion endpoint (a pH of about 1.5), suggesting that the exposed waste was fully reacted and that additional unreacted acid remained. This was an indication that the remaining waste contained solids that would not react to additional exposure to oxalic acid as predicted by the laboratory testing.

The waste recoveries of less than 3% per acid batch processed and the presence of unreacted acid in the last oxalic acid bath addition combined with an observed declining trend of waste removed for each technology indicated a limit of this technology to remove additional waste from SST C-106 had occurred.

2.7.2 Modified Sluicing

The equipment configuration of the single sluicing nozzle reached the limit of operational effectiveness to retrieve solid waste after the fourth acid dissolution cycle and second sluicing retrieval. The sluicer nozzle located in riser 3 was no longer effective in moving solids from the far side of the tank to the pump, which was in the middle of the tank. Additionally, sluicing by this nozzle created piles of solids against the tank walls in the location of the tank circumference farthest from the sluicer toward the opposite wall. Thus, the motive force of the sluicer nozzle at this configuration was not able to move the remaining waste toward the pump inlet.

In response to this diminished performance, a second sluicer nozzle was installed in the tank in riser 7. This second sluicer head was located to break up the remaining waste piles and move the waste to the pump inlet to be pumped out of the tank. Following this sluicing campaign, oxalic acid was added for a sixth time to dissolve the additional remaining waste. The residual waste volume represents the quantity remaining after sluicing following the sixth oxalic acid addition.

Table 3 contains the material balance of the sluicing operations. The material balance for the sluicing operations was recorded to determine the approximate volume of waste that was transferred with each batch. A sluicing efficiency based on percent solids in the slurry was calculated as a measure of the technology performance. The gradual decrease from 8% waste in sluicing operation number 1 to 0.3% waste in sluicing operation number 4 shows that the limits of technology (modified sluicing) had been reached.

Table 3. Material Balance Estimates for Sluice Water Additions to Single-Shell Tank 241-C-106.

Sluice Operation	Volume of water added (gal)	Volume transferred to DST AN-106 (gal)	Volume increase (gal)	Approximate efficiency, estimated volume percent waste
1	56,160	61,033	4,873	8
2	46,472	48,079	1,607	3.3
3	59,228	60,085	857	1.4
4	83,501	83,718	217	0.3

Note:

DST = double-shell tank.

The average sluicing efficiency in the first sluicing operation was about 8% entrained waste by volume. The amount of entrained waste removed was estimated from the volume increase in DST AN-106 as compared to the volume of water used to sluice the waste in SST C-106. The retrieval efficiency in subsequent batches was declining and was calculated at 3.3%, 1.4%, and 0.3%. At the completion of the last retrieval, the metal bottom of the tank had been exposed throughout the circumference of the tank. The exception was the solids near the tank wall that were out of reach of the nozzle motive force or in the shadow of the sluicing equipment. Additionally, some pieces or piles of debris remained in place because they were too large to mobilize by sluicing or were too large to enter the pump intake.

It should be noted that the efficiency calculations are affected by the amount of solids left in the pump heel volume. If the pump heel included all solid waste before sluicing and no solid waste existed after sluicing, the waste solid volume would be changed by as much as 800 gal. For example, during the fourth sluicing operation, the maximum amount of solids removed could have been as much as 272 gal plus 800 gal resulting in 1,072 gal. The efficiency for this example would have been about 1.3%. Since a significant amount of water is always left in the pump heel before and after sluicing, the actual efficiency would have been closer to the efficiency calculated in Table 3.

2.7.3 In Process Waste Volume Measurement

The liquid in SST C-106 was pumped to DST AN-106 on January 20, 2004, and based on the DST AN-106 Enraf liquid level, the volume transferred was 39,332 gal. The difference between the volume measured in SST C-106 and the transferred volume describes the estimated volume remaining in SST C-106, which was about 2,722 gal (approximately 364 ft^3).

The volume of water transferred to DST AN-106 was also measured by a flow totalizer that indicated 39,470 gal. The estimated volume remaining in SST C-106 based on the flow totalizer readings were approximately 2,584 gal (approximately 345 ft^3). The subsequent video examination of the tank bottom after water removal showed a small liquid heel surrounding the pump near the center of the tank. The remaining solids were thinly distributed around the bottom of the tank and solids are visible in the liquid heel.

2.7.4 Video Camera/CAD Modeling System Waste Volume Determination

2.7.4.1 Summary of Results. The total volume of post-retrieval residual waste in SST C-106 and the waste volumes associated with the various waste components are given in Table 4 and were calculated by the CCMS at a confidence level of 95%. The total post-retrieval waste volume in SST C-106 is estimated to be 370.33 + 97/-95 ft^3. This estimate using the CCMS method is in agreement with the waste immersion (material balance) using the Enraf level measurements (364 ft^3) and the material balance using the flow totalizer (345 ft^3). The waste volume included in equipment remaining in the tank adds approximately 5 ft^3 to the total, while the waste volume on the stiffener rings comprises about 5% (approximately 17.3 ft^3) of the total volume of waste remaining in the tank.

Table 4. Waste Volume for Single-Shell Tank 241-C-106 (using 95% confidence level).

Waste location	Waste volume (ft^3)	Estimated uncertainty (%)		Estimated uncertainty (ft^3)	
		+	-	+	-
Bottom of tank	336.89	27%	27%	90.96	90.96
Equipment in tank	4.84	0%	25%	0.00	1.21
Stiffener rings	17.30	18%	0%	3.11	0.00
Liquid waste	11.30	27%	27%	3.05	3.05
Total	370.33 (nominal)	26%	26%	97.12	95.22
Total Waste ± Uncertainty	370.33± Uncertainty →			**467.45**	**275.11**

2.7.4.2 Estimate of Waste in Bottom of Tank. Table 5 shows the volumes of solids and liquids estimated by the CCMS. The waste is uniformly spread out over the bottom of the tank with several raised areas of solids observed and the majority of the raised areas are located on the northeast side of the tank near the tank wall. Additionally, a kidney-shaped pool of liquid extends northeast from around the bottom of the center of the tank. The determination of the uncertainty associated with the CCMS method is discussed in RPP-19866.

Table 5. Single-Shell Tank 241-C-106 Waste Volume in Tank Bottom.

Component	Waste volume		
	m^3	ft^3	gal
Solid phase	9.541	336.89	2,520
Supernatant phase	0.320	11.30	85
Total	9.861	348.19	2,605

The error calculated at the 95% confidence level is ± 26% using the same methods for the 80% confidence level as described in RPP-18744.

2.7.4.3 Estimate of Waste Volume in Equipment. Potential waste-containing equipment remaining in the tank included three transfer pumps, three suction floats, and various lengths of hoses and pipes. Two of the transfer pumps are known to contain no waste because they were flushed and drained. The volume in the third pump was assumed to be negligible since it was drained after its last use. Therefore these components are not included in Table 6.

Using the upper and lower estimates made for hose lengths and diameters, the volume of waste contained in the equipment remaining in SST C-106 is estimated to range from 4.7 ft^3 (35 gal) to 4.84 ft^3 (36 gal). Table 6 provides the breakdown, by component, for the upper estimate and these volumes were calculated assuming that the waste holding portions of this equipment was full of waste. However, the suction floats were positioned on the bottom of the tank with their openings facing downward and thus may contain little or no waste. Therefore, the estimated uncertainty for the waste volume in the equipment is + 0/-1.21 ft^3 (+ 0/- 9 gal).

Table 6. Single-Shell Tank 241-C-106 Waste Volume in Equipment in Tank.

Component	Quantity	Total waste volume		
		m^3	ft^3	gal
Suction floats	3	0.034	1.21	9
3-in. hoses	2	0.032	1.13	8
4-in. pipes	2	0.069	2.42	18
Hose attached to thermocouple tree	1	0.002	0.08	1
Total		0.137	4.84	36

2.7.4.4 Estimate of Waste on Stiffener Rings. The waste volume remaining on the stiffener rings is estimated to be 17.3 ft^3 (129 gal) and volumes for each ring are provided in Table 7. No waste was observed in the video on the top ring which is also above the maximum design waste level and therefore the volume is estimated to be 0 ft^3. Estimates for the lower rings are based on best estimates of the average waste thickness on each ring ($^3/_8$ in., ¾ in., and 1 in. for stiffener rings #2, #3, and #4, respectively. The error associated with the thickness is estimated to be + $^3/_8$ in. and – 0 in., resulting in a volume error of + 3/- 0 ft^3 (+ 23/- 0 gal).

Table 7. Single-Shell Tank 241-C-106 Waste Volume on Stiffener Rings.

Component	Waste Volume		
	m^3	ft^3	gal
Stiffener ring #1 (top)	0	0	0
Stiffener ring #2	0.086	3.05	23
Stiffener ring #3	0.173	6.11	46
Stiffener ring #4 (bottom)	0.231	8.14	61
Total	0.490	17.30	129

Note:
Sum of gallons does not equal total gallons because of rounding.

2.7.4.5 Estimates of Waste on Tank Wall. The tank wall was estimated to have no waste on its surface. Only a small amount of waste was observed on the tank wall, and because it appeared to be the result of the sluicing of the stiffener rings, the volume of that waste was included as part of the stiffener ring calculation. No other waste was observed on the tank wall.

2.8 CONCLUSIONS

The objective of this retrieval was to remove tank waste to the limits of the retrieval technologies selected and to leave no more than 360 ft^3 of residual waste in the tank. The performance data of the two retrieval technologies tracked the efficacy of the technologies to remove waste, provided an estimate of the waste volume remaining in SST C-106, and provided the basis for concluding that the technical limits of a modified sluicing/acid dissolution process had been met. The technical limits of modified sluicing and acid dissolution processes were indicated by a declining trend of waste recovery. The last acid dissolution removed 3% volume of waste in SST C-106 and the last sluicing operation resulted in 0.3% volume of solids removed from SST C-106. Additionally, the last acid batch resulted in an incomplete acid dissolution reaction confirmed by unreacted oxalic acid remaining at the completion of the process. This was an indication that the remaining exposed waste was fully reacted and not subject to additional substantive dissolution as predicted by the laboratory testing. The process data presented a declining trend of performance that was likely to continue especially for acid dissolution. This would leave only sluicing to remove additional waste and this technology was also in a declining trend of retrieval efficiency. Based on these results, it was determined that the limits of technology for both the modified sluicing and oxalic acid technologies had been reached.

The waste volume remaining after retrieval completion has been documented by a number of methods that included, prior to completion, waste immersion (using the DST AN-106 Enraf readings) and material balance (using the flow totalizer) calculations. At the completion of retrieval, a CCMS calculation was performed to determine the remaining waste volume. This modeling of solid and liquid waste was developed and qualified by testing to establish a final volume of waste remaining in the tank at the completion of retrieval operations and to verify and compare with the waste immersion estimate via Enraf level readings and material balance (using the flow totalizer) volume calculations. The CCMS calculation was subject to errors calculated at the confidence level of 95%. The additional waste included at the 95% confidence level that is required to be removed to meet the criteria of less than 360 ft^3 was 107.5 ft^3 (370.33 ft^3 + 97.12 ft^3 = 467.45 ft^3). Removing the estimated 11.3 ft^3 of supernatant in SST C-106, if feasible, would not reduce the residual waste volume sufficiently to meet the criteria of less than 360 ft^3 for the 95% confidence level. Based on the declining efficiencies of the modified sluicing and acid dissolution technologies, it was estimated that additional sluicing would not remove sufficient waste volumes to less than 360 ft^3 inclusive of the 95% uncertainty addition of waste.

The above discussion demonstrates three key points to conclude that the modified sluicing/acid dissolution process reached the technological limits to remove waste.

1. **Acid Dissolution** - The purpose of the acid dissolution process was to dissolve and breakdown the sludge and the solid waste prior to sluicing. The result of this reaction included increased solution density and a smaller waste particle size which allowed increased waste removal once sluicing commenced. The smaller particle size enabled more waste to be entrained during sluicing and subsequently pumped out of the tank. The estimated 18,000 gal of waste left in the tank prior to retrieval was equivalent to a layer that averaged about 6.5 in. across the bottom of the 75-ft diameter tank. After oxalic acid was added, the waste was soaked to allow the waste digestion process to complete (acid reaction stabilized) and the acid pool was agitated by the mixer-eductor to facilitate the acid-waste reaction. At the completion of the soak period, the retrieval pump was used to remove the solution including entrained waste from the tank.

   The acid dissolution reacted as predicted in the process control plan and the data was recorded for each batch until steady-state pH readings were attained. Oxalic acid was added in six separate batches during the retrieval and the dissolution performance ended in diminished returns for the last two acid batches. In the final batch, the pH of the solution showed a gradual increase during the first 6 days indicating that the acid had reacted with the waste and then no increase (steady state) during the rest of the contact period. The average pH over the last 4 days was approximately 0.79, but never reached the expected acid depletion endpoint (a pH of about 1.5), indicating that the exposed waste was fully reacted. This was an indication that all the waste available to dissolve had reacted, that waste remained unreacted, and that the limits of this technology to further dissolve and entrain waste had been reached. The result of waste forms not dissolving in the acid are consistent with the laboratory testing, which documented that up to 30% of the solids would not dissolve in oxalic acid (RPP-17158).

2. **Waste Entrainment** - The waste solids remaining were resistant to further breakdown to a smaller size either by acid dissolution or by mechanical breakup by the sluicing stream. This was documented by the diminished mass transfer of solids in the waste slurry pumped from the tank. Therefore, the remaining solids would not likely be entrained in the waste slurry at a rate equal to or higher than the efficiencies documented in the last sluicing batches.

3. **Sluicing Nozzle Efficiency** - The waste that could be mobilized to the pump intake had been moved to within the influence of the pump and retrieved as shown in the post-retrieval video. The performance criteria of the sluicing nozzle included breaking up the solid waste and also moving the waste to the pump intake. In this retrieval, when the acid dissolution performance began to diminish, the single sluicing nozzle also became ineffective in moving the remaining solid waste to the pump inlet. The mixer-eductor was then removed and replaced in that location by a second nozzle which allowed the remaining piles of waste to be either moved toward the pump inlet or spread out to facilitate additional exposure of waste surfaces to acid. During the last sluicing, the two nozzles were not able to appreciably move additional waste to the pump inlet as indicated by the diminishing amount of entrained waste recorded.

In summation, each technology had reached a level of diminished performance that required termination of retrieval operations.

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