This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-09SR22505 with the U.S. Department of Energy.

Exploring Engineering Control through Process Manipulation of Radioactive Liquid Waste Tank Chemical Cleaning

Submitted to

Department of Global Environmental Health Science
Tulane School of Public Health & Tropical Medicine

in partial fulfillment of the requirements for the degree

Master of Science in Public Health
Environmental Health Science / Industrial Hygiene

By

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4/25/2014

Abstract

One method of remediating legacy liquid radioactive waste produced during the cold war, is aggressive in-tank chemical cleaning. Chemical cleaning has successfully reduced the curie content of residual waste heels in large underground storage tanks; however this process generates significant chemical hazards. Mercury is often the bounding hazard due to its extensive use in the separations process that produced the waste. This paper explores how variations in controllable process factors, tank level and temperature, may be manipulated to reduce the hazard potential related to mercury vapor generation. When compared using a multivariate regression analysis, findings indicated that there was a significant relationship between both tank level (p value of 1.65×10^{-23}) and temperature (p value of 6.39×10^{-6}) to the mercury vapor concentration in the tank ventilation system. Tank temperature showed the most promise as a controllable parameter for future tank cleaning endeavors. Despite statistically significant relationships, there may not be confidence in the ability to control accident scenarios to below mercury's IDLH or PAC-III levels for future cleaning initiatives.

Introduction

As industrial hygienists strive to anticipate potential workplace exposures and consider process modification interventions, they are challenged by multiple unknown variables. New processes that involve complex and unpredictable reactions can make selecting the most controllable chemical or physical factors of the process problematic, as is the case for liquid waste remediation at the Savannah River Site (SRS).

SRS is the home of 45 underground storage tanks of radioactive liquid waste, associated with processing nuclear material (Savannah River Remediation, 2013). Mercury was used extensively as part of the material separation process, and now constitutes a significant chemical hazard associated with the removal of waste from the tanks and maintaining tank systems. Initial mercury characterizations of the waste showed that the primary exposure hazard to employees was from inhalation of elemental and dimethyl mercury (Thaxton G. D 2003). Monitoring conducted between 2001 and 2007 identified elevated tank temperature and mixing as aggravating factors that accompanied the highest mercury releases. Mercury concentrations measured at sources (tank headspaces) were thought to be conservatively bounded by 5mg/m^3 (Thaxton, Plummer, & Layton, 2006) until monitoring performed during chemical cleaning operations challenged that bounding assumption. Chemical cleaning consisted of using extreme environments combined with aggressive mixing and high temperatures to dissolve the sludge heel remaining in the waste tanks after all the readily accessible soluble material had been removed (Davis, et al., 2009). Mercury source concentrations were in excess of the NIOSH IDLH level of 10 mg/m^3. Tank ventilation systems are credited to protect workers from a release of particulate contaminants and prevent waste tank explosions due to hydrogen gas buildup; however these systems were not designed to protect workers from significant gas or vapor hazards. Because the tanks are in the process of being decommissioned, extensive infrastructure investments would be impractical. Therefore understanding process metrics that control the mercury generation rate would provide a powerful engineering control to prevent worker overexposure.

The goal of this paper is to determine what relationship exists between tank temperature, tank level, and mercury concentration. Understanding that there are a number of varying estimates of the effect of temperature on mercury's vapor pressure, the mercury vapor pressure was considered to respond to temperature according to a simple inverse–log relationship(Huber, Laescke, & Friend, 2006). Additionally the liquid supernatant may act as a barrier to vapor emission because it normally rests on top of the denser sludge heel, which is believed to contain the majority of physically bound mercury. During chemical cleaning the supernate and heel are mixed by pumps operating at a fixed speed and depth. Mercury liberated from the heel may be difficult to suspend uniformly throughout the supernatant, and may be less present near the top. Therefore the depth of material in the tank may influence the rate of mercury vapor generation.

During previous chemical cleaning processes, a large amount of mercury was liberated via mechanisms that are not completely understood. This presented a challenge to the site safety basis, which was partially based on the assumption that the radiological consequences of a catastrophic failure always bounded the chemical consequences. Additionally modeling of pollutant generation rates and available atmospheric data demonstrated a significant potential to create hazardous conditions for co-located workers given higher than normal toxicant release rates and less than ideal weather conditions (Kabela, 2011). Without a clear basis or methodology to bound mercury generation during future evolutions, the control strategy was redesigned. The new control strategy included monitoring the release rate of mercury through the ventilation system at a frequency that would alert the facility prior to the formation of potentially hazardous conditions, thereby allowing for appropriate response action. The monitoring data was also seen as a tool to analyze controllable process variables in order to understand the drivers behind the increased mercury generation.

Research Objectives

The objective was to examine how the tank temperature and tank level relate to the mercury vapor in the tank ventilation system and generate a predictive model. This was accomplished through multivariate regression analysis where the null hypothesis was: no significant relationship exists between changes in tank temperature or tank level and changes in the mercury vapor concentration. The test had the ability to detect a significant relationship between tank temperature or tank level and the mercury discharge concentration with 95% confidence. The goal was to develop a bounding model based on these and other process factors such that they can be manipulated to reduce the chemical vapor hazard for co-located workers during future operations.

Method

Measurements were taken using a modified Mercury Tracker 3000 customized by Mercury Instruments USA for use with a dilution attachment to mix the sample stream with a regulated amount of compressed air. The dilution system maintained the sample mixture at a constant temperature of 110 +/- 2 ºF with a dilution factor of 20. The sample was taken from a filter test port located after the installed ventilation system HEPA filter. The sample passes through an additional HEPA filter (connect directly to the instrument) in order to protect the analyzer in the event of contamination breakthrough in the tank ventilation system.

The strike was conducted continuously over a one month period and the measurement frequency goal was twice a shift. While the instrument had data logging capability, measurements were collected by due to ventilation configuration control restrictions. This monitoring validated the existing ventilation system configuration by showing that it provided dispersion such that the ground level concentrations did not exceed site action levels for mercury (Kabela, 2011). The existing sampling protocol specified action levels that triggered field monitoring when the mercury concentration reached a level that could result in elevated ground level concentrations.

Data associated with the initial stage of chemical cleaning (acid addition) was below the adjusted 2 mg/m^3 detection limit of the instrument. Once the mercury concentration in the headspace rose above the detection limit, the concentration did not return below the detection limit until after the chemical cleaning process. Sampling data was analyzed using the multivariate regression analysis available with MS Excel 2013. Mercury Vapor Concentration was listed as the dependent variable, while the independent variables were tank level, in inches, and the transformed tank temperature in °K. The temperature data transformation was performed by determining $e^{1/T}$. Two additional variables were added to delineate differences that may have occurred between acid strikes, such as changes in sludge content or liquid mercury presence in the slurry. The intent of adding these dummy variables was to lend statistical power to the test, recognizing that there were multiple other potential changes that might have been driving differences from strike to strike.

Results

The range of mercury concentration over time is graphed alongside the tank temperature as shown in Figure 1. Periods where no concentration data is shown indicate that the mercury concentration was less than 2 mg/m^3. During the first acid strike, significantly more supernatant was added to the tank in order to avoid neutralizing the solution during the initial mixing. Thus the tank level of the first strike was significantly higher (>50 inches) than strikes 2 and 3 (each reached a height of around 35 inches).

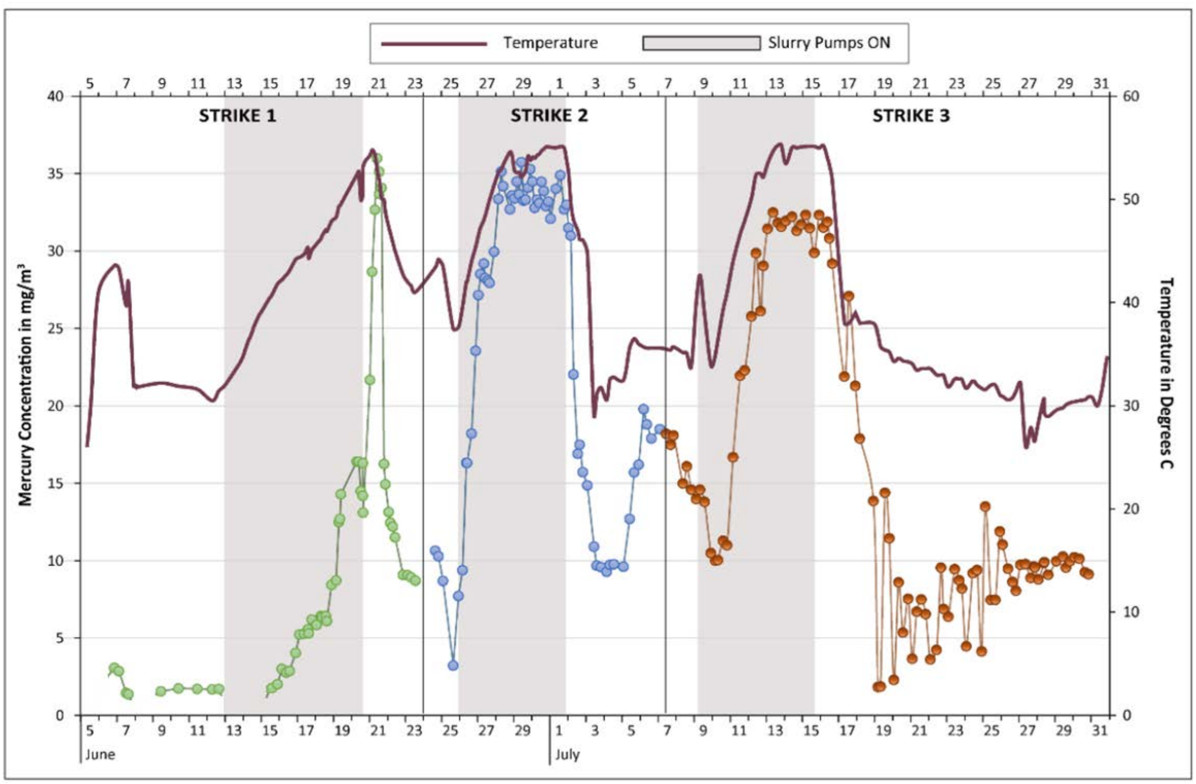
The linear regression output table, captured in

Table 1: Regression Analysis Summery, revealed a significant correlation between tank temperature and mercury concentration, as well as between tank level and mercury concentration. The correlation between the dummy variables that delineated the strike (1, 2, or 3) and the mercury concentration was also significant. The resulting regression equation was

$$[Hg] = 93512 - 93205\, e^{1/T} - 0.13h + 10.6\, D_2 + 9.9 D_3$$

where Hg = mercury concentration expressed in mg/m3, T = absolute temperature expressed in °K, h = tank level expressed in inches, and D2 , D3 are the dummy variables that delineate the various strikes such that the initial strike value was zero, D2 = 1 for the second strike, and D3 = 1 for the third strike.

Figure 1: Mercury Concentration Plotted with Tank Temperature



The plots of observed and expected values as illustrated in Figures 2 and 3, show that tank level appeared to have the best predictive value on the high end of the tank level range. This could be a consequence from increased distance between the liquid surface and the depth of the mixing pumps, potentially reducing the likelihood that churned sludge would break the surface of the waste mixture. Alternatively, the slurry in the tank may have been steadily progressing towards a uniform mixture and the duration of the mixing stage of the first strike was not long enough to reach an equilibrium between the suspended and settling mercury.

Table 1: Regression Analysis Summery

Regression Statistics	
Multiple R	0.849798142
R Square	0.722156881
Adjusted R Square	0.710699433
Standard Error	3.867592608
Observations	102

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	3771.247945	942.812	63.02947	3.81E-26
Residual	97	1450.952441	14.95827		
Total	101	5222.200385			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	935121	7051	13.26	1.63E-23	79518	107506
e^(1/Temperature)	-93206	7029	-13.26	1.65E-23	-107156	-79255
Tank Level	-0.131	0.0274	-4.77	6.39E-06	-0.185	-0.0764
Second Strike	10.60	1.08	9.84	2.97E-16	8.46	12.73
Third Strike	9.92	1.17	8.47	2.65E-13	7.59	12.23

Figure 2: Observed vs Predicted Concentrations from Temperature

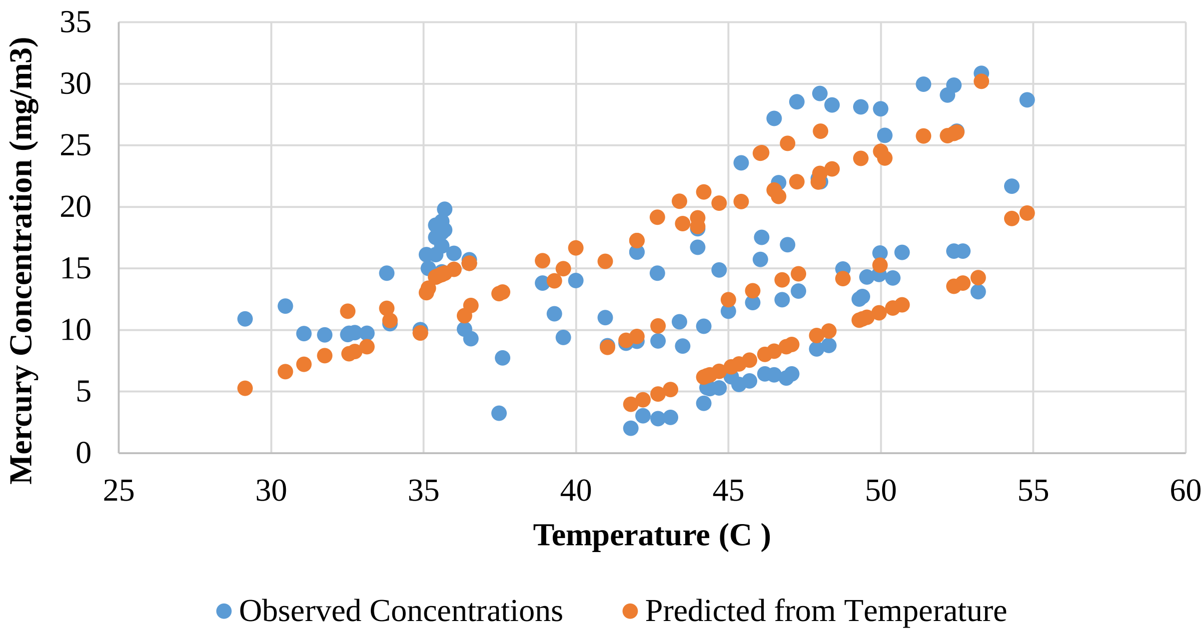
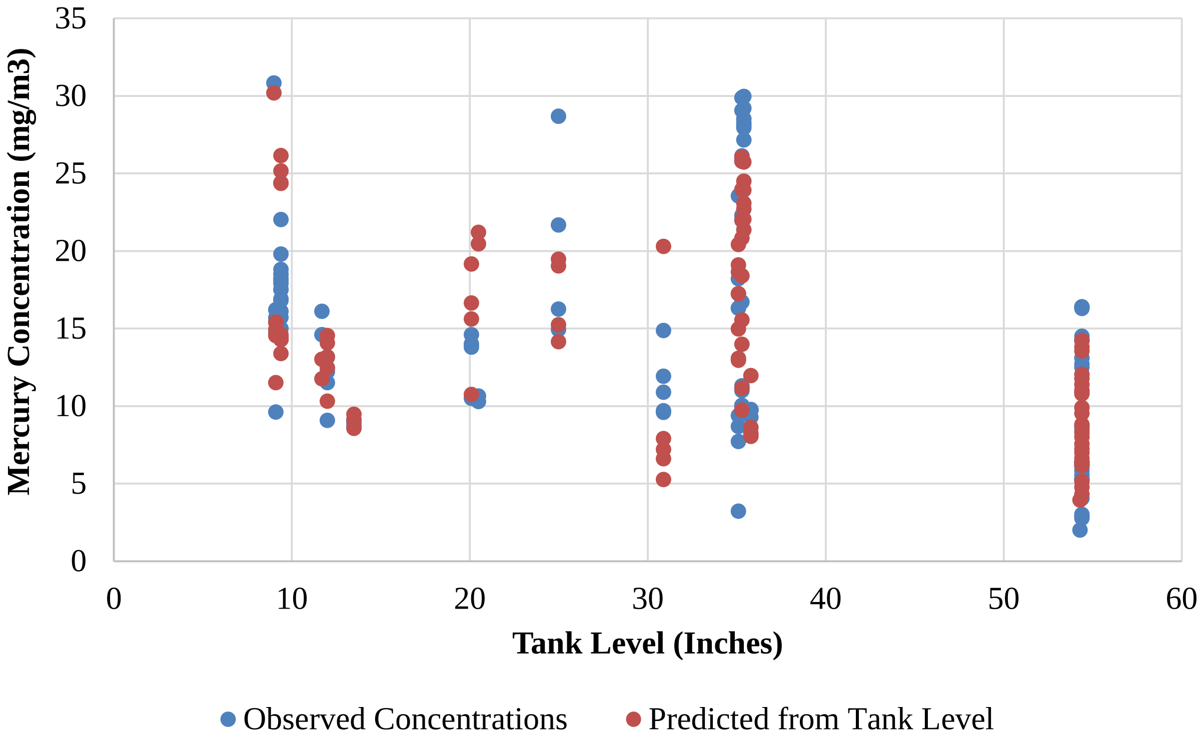


Figure 3: Observed vs Predicted Concentrations from Tank Level



The residual plot of the temperature, as shown in Figure 4, appears to have a slight curve, possibly implying that the temperature/concentration relationship may not strictly take the form of a standard Arrenius relationship. However, this adjustment has come the closest to flattening the residual curve thus far and has the advantage of a defendable technical justification.

Figure 4: Tank Temperature Residual Plot

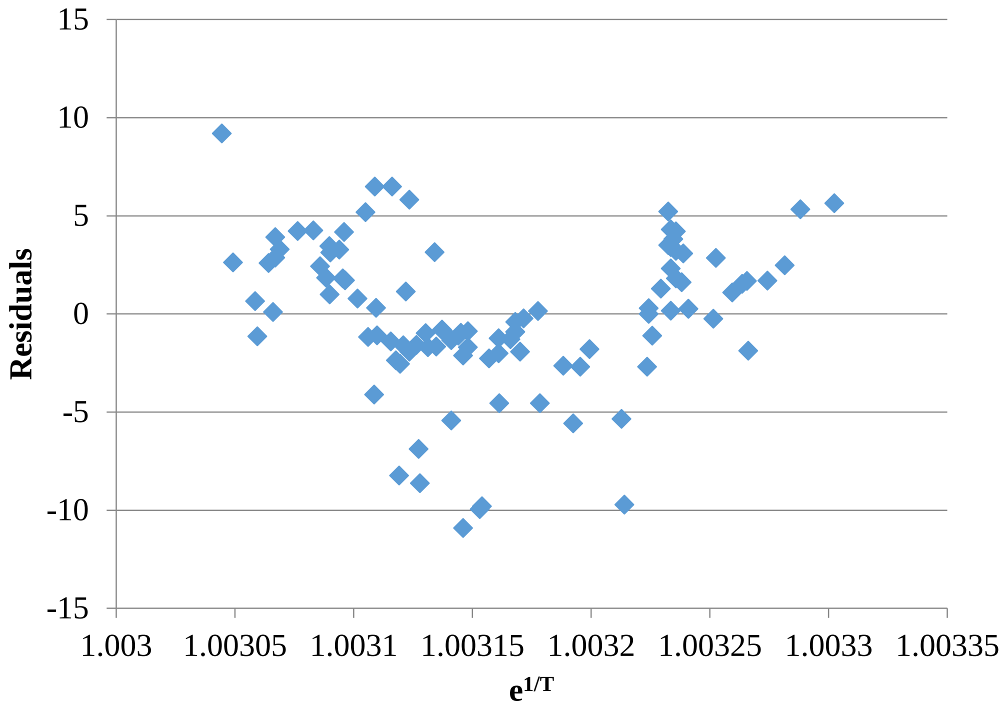
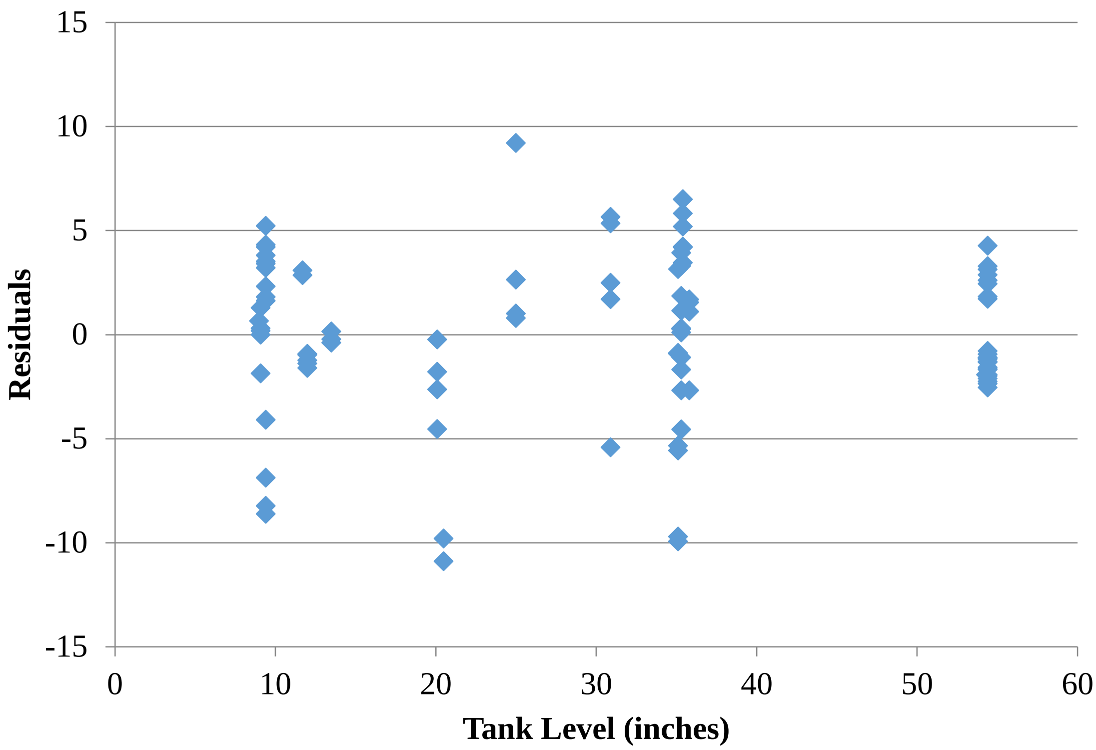


Figure 5: Tank Level Residual Plot



Discussion

The diluted analyzer represented a significant improvement in the ability to characterize the mercury concentrations in the stack. Our previous direct reading instruments, which used gold film adsorption to detect the mercury vapor, can be sensitive to temperature changes and humidity is a known interference. The UV Absorption method may have been more stable, not responding the same to low level humidity changes and benefited from the temperature regulated dilution module (Mercury Instruments Analytical Technologies, 2012).

Variations between the strikes in: mixture agitation, mercury content in the sludge, and other unknown variables, could have significant effects on the generation rate of mercury vapor. The significance of these variations is captured in the coefficients for the dummy variables used to delineate the data points from each strike. The coefficients for these variables are both highly significant and of similar value. One potentially significant variation was the degree of mixture agitation during the first strike. The first strike contained more liquid and the slurry pump orientation was set to distribute flow across the entire tank, whereas pump configuration for the second and third strikes was different. Mixing during these strikes was directed at the largest remaining sludge mound, effectively knocking it down and spreading the remaining material around the tank. Also, the first strike was believed to be where most of the reaction took place between the sludge and acid, as that was when the NOx concentrations were highest and a faint discolored emission, believed to be NO_2, was visible at the top of the stack.

Furthermore gaps in the cleaning operation, due to either pump repositioning or management reevaluation, appear to coincide with at least one span where higher residual data points were observed. Divergence from the best fit equation appears to grow larger during a mixing pause at the end of strike two, from around July 6th until the pumps were restarted shortly after the evening of July 9^{th}. At this point, there does not appear to be sufficient information to exclude this portion of data from the analysis; rather it should be noted that while the intent of this study was to determine controllable variables under bounding conditions of an actively mixed waste tank, not all data collected strictly fell under these conditions. Care may need to be taken to more precisely delineate measurements between these sampling environments during future operations.

The amount of time it took the mercury concentration to rise may convey a more than is apparent from the dataset. The oxalic acid added to the tank was heated to 50°C prior to addition, and the dissolution of sludge commenced immediately as evidenced by the evolution of NOx. The tank remained near that temperature which would have suggested the mercury concentration should have been orders of magnitude higher than was observed, based on the model previously outlined Laboratory analysis of short duration carbon sorbent samples showed that concentrations were in the 0.1000 mg/m3 range. However, mixing pumps were not engaged until the tank level rose to a height of 9 inches and even then exhibited technical problems such that they were slowly brought online. Bringing slurry pumps online contributed to a slow buildup of heat in the tank, and it was after the slurry pumps had all been brought online and were functioning properly that the mercury levels rose into a range where they could be measured. Thus one should consider the heat parameter defined by this equation as not only an expression of tank temperature but also a potential indicator of the degree of agitation.

Lapses in the dataset are a result of the radiologically contaminated worksite, instrument software issues, and primary ventilation failure. The process of entering and exiting the area and the need to transcribe data points either by hand or over a radio contributed to some missing data points and was compounded by the additional risk of losing the instrumentation to contamination. A reliable backup set of information was rendered unusable because the instrument dilution factor was changed near the end of the process and the change wiped the previous measurements from the onboard memory. Mercury Instruments USA has notified of the issue and is currently modifying their software such that it will retain measurements through changes in dilution factor settings. Failure of the tank ventilation system (unexpected solids formation reduced airflow rates below functional levels) resulted in the use of the emergency backup ventilation system. Data collection at the stack was terminated because of this, and no data is available to track the decline of the mercury generation as the tank returned to a dormant state. This information will be valuable to collect moving forward and may alleviate some uncertainty.

The data collection process was further complicated by the fact that all measurements were collected in a radiologically contaminated area. The process of entering and exiting the area and the need to transcribe data points either by hand or over a radio may have contributed to some missing data points. Additional risk existed in the potential to lose the instrumentation to the inability to decontaminate it for recalibration after the project completed, the need to station the borrowed air compressor in a clean area, and the management of the hoses running across radiological boundaries, understanding that even minor failure to handle the hose connection and disconnection properly or small pressurized air leak could result in physical injury accompanied by the spread of contamination or an uptake of contaminated material.

Confidence in the ability to bound chemical exposure hazards is a desirable commodity moving forward with the mission to remove the liquid radioactive waste and close the waste tanks at the Savannah River Site and elsewhere in the DOE complex (Kvartek, Carlton, Denham, Eldridge, & Newman, 1994) (Thaxton, 2007). The most significant cost savings would be had in the ability to clean and close the waste tanks without generating potential hazards where credible accident scenarios could result in personnel exposures in excess of 8.9 mg/m^3 (PAC-III level). While the limited testing and observation thus far has not identified all the necessary control points to reduce the in-tank concentrations that far, the recognition of factors that could change the hazard potential has led to the development of more efficient administrative monitoring and control strategies. Given that this tank was amongst the first of many to require aggressive cleaning campaigns, the lessons learned will significantly improve the focus of our analysis when cleaning the next waste tank.

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Data Appendix

Date	Time	SLPs on	Tank Temp (°C)	Transfer taking place?	Comment	STRIKE	[Hg]	exp(1/T(K))	Tank Level (inches)	Strike 2? (1=Yes)	Strike 3? (1=Yes)
6/15/2013	10:00:00 PM	Yes	41.8	No		ONE	2.013	1.00317	54.3	0	0
6/16/2013	3:45:00 AM	Yes	42.2	No		ONE	3.011	1.003166	54.4	0	0
6/16/2013	10:00:00 AM	Yes	42.7	No		ONE	2.775	1.003161	54.4	0	0
6/16/2013	2:00:00 PM	Yes	43.1	No		ONE	2.883	1.003157	54.4	0	0
6/16/2013	10:20:00 PM	Yes	44.2	No		ONE	4.045	1.003146	54.4	0	0
6/17/2013	3:30:00 AM	Yes	44.4	No		ONE	5.236	1.003144	54.4	0	0
6/17/2013	9:30:00 AM	Yes	44.7	No		ONE	5.29	1.003141	54.4	0	0
6/17/2013	2:37:00 PM	Yes	45.35	No		ONE	5.56	1.003135	54.4	0	0
6/17/2013	3:30:00 PM	Yes	44.3	No		ONE	5.3	1.003145	54.4	0	0
6/17/2013	7:45:00 PM	Yes	45.1	No		ONE	6.2	1.003137	54.4	0	0
6/18/2013	2:10:00 AM	Yes	45.7	No		ONE	5.85	1.003131	54.4	0	0
6/18/2013	7:50:00 AM	Yes	46.2	No		ONE	6.42	1.003126	54.4	0	0
6/18/2013	9:30:00 AM	Yes	46.5	No	4 slurry pumps running	ONE	6.34	1.003124	54.4	0	0
6/18/2013	2:32:00 PM	Yes	47.08	No	4 slurry pumps running	ONE	6.429	1.003118	54.4	0	0
6/18/2013	3:40:00 PM	Yes	46.9	No	4 slurry pumps running	ONE	6.09	1.00312	54.4	0	0
6/18/2013	10:00:00 PM	Yes	47.9	No	4 slurry pumps running	ONE	8.439	1.00311	54.4	0	0
6/19/2013	4:00:00 AM	Yes	48.3	No	4 slurry pumps running	ONE	8.721	1.003106	54.4	0	0
6/19/2013	7:30:00 AM	Yes	49.3	No	4 slurry pumps running	ONE	12.5	1.003096	54.4	0	0

Date	Time	SLPs on	Tank Temp (°C)	Transfer taking place?	Comment	STRIKE	[Hg]	exp(1/T(K))	Tank Level (inches)	Strike 2? (1=Yes)	Strike 3? (1=Yes)
6/19/2013	9:00:00 AM	Yes	49.4	No	4 slurry pumps running	ONE	12.7	1.003095	54.4	0	0
6/19/2013	10:15:00 AM	Yes	49.55	No	4 slurry pumps running	ONE	14.3	1.003094	54.4	0	0
6/20/2013	7:30:00 AM	Yes	52.4	No		ONE	16.4	1.003067	54.4	0	0
6/20/2013	10:00:00 AM	Yes	52.7	No		ONE	16.4	1.003064	54.4	0	0
6/20/2013	12:50:00 PM	Yes	49.95	No	4 slurry pumps running	ONE	14.5	1.00309	54.4	0	0
6/20/2013	3:30:00 PM	Yes	50.4	No	4 slurry pumps running	ONE	14.2	1.003086	54.4	0	0
6/20/2013	3:30:00 PM	Yes	50.7	No	4 slurry pumps running	ONE	16.3	1.003083	54.4	0	0
6/20/2013	4:00:00 PM	No	53.2	No		ONE	13.1	1.00306	54.4	0	0
6/21/2013	1:00:00 AM	Yes	54.3	Yes		ONE	21.67	1.003049	25	0	0
6/21/2013	4:00:00 AM	Yes	54.8	Yes		ONE	28.674	1.003045	25	0	0
6/21/2013	7:30:00 PM	No	49.98	No	Transfer ended at 1300	ONE	16.245	1.00309	25	0	0
6/21/2013	9:30:00 PM	NO	48.76	No	Transfer ended at 1300	ONE	14.941	1.003102	25	0	0
6/22/2013	2:00:00 AM	No	47.3	No	Transfer ended at 1300	ONE	13.145	1.003116	12	0	0
6/22/2013	4:00:00 AM	No	46.77	No	Transfer ended at 1300	ONE	12.456	1.003121	12	0	0
6/22/2013	7:30:00 AM	No	45.8	No		ONE	12.202	1.00313	12	0	0
6/22/2013	10:25:00 AM	No	45	No		ONE	11.515	1.003138	12	0	0
6/22/2013	9:00:00 PM	No	42.7	No		ONE	9.084	1.003161	12	0	0
6/23/2013	3:00:00 AM	No	42	No		ONE	9.068	1.003168	13.5	0	0
6/23/2013	7:30:00 AM	No	41.65	No		ONE	8.92	1.003172	13.5	0	0

Date	Time	SLPs on	Tank Temp (°C)	Transfer taking place?	Comment	STRIKE	[Hg]	exp(1/T(K))	Tank Level (inches)	Strike 2? (1=Yes)	Strike 3? (1=Yes)
6/23/2013	1:30:00 PM	No	41.04	No		ONE	8.707	1.003178	13.5	0	0
6/24/2013	3:39:00 PM	No	43.4	No	Acid Unloading started at 1300, 43.4 C	TWO	10.65	1.003154	20.5	1	0
6/24/2013	8:00:00 PM	No	44.2	No	Acid addition complete	TWO	10.29	1.003146	20.5	1	0
6/25/2013	2:00:00 AM	No	43.5	No	Water addition, 43.5 C	TWO	8.69	1.003153	35.1	1	0
6/25/2013	3:30:00 PM	No	37.48	No	End of water addition	TWO	3.23	1.003214	35.1	1	0
6/25/2013	10:30:00 PM	Yes	37.6	No	Slurry pumps started, 37.6 C	TWO	7.715	1.003213	35.1	1	0
6/26/2013	4:00:00 AM	Yes	39.59	No	Annulus to primary transfer	TWO	9.387	1.003192	35.1	1	0
6/26/2013	9:00:00 AM	Yes	42	No		TWO	16.32	1.003168	35.1	1	0
6/26/2013	10:00:00 AM	Yes	42	No		TWO	16.321	1.003168	35.1	1	0
6/26/2013	4:00:00 PM	Yes	44	No		TWO	18.215	1.003148	35.1	1	0
6/26/2013	9:30:00 PM	Yes	45.42	No		TWO	23.55	1.003134	35.1	1	0
6/27/2013	1:00:00 AM	Yes	46.5	No		TWO	27.165	1.003124	35.4	1	0
6/27/2013	3:45:00 AM	Yes	47.25	No		TWO	28.525	1.003116	35.4	1	0
6/27/2013	8:12:00 AM	Yes	48	No		TWO	29.2	1.003109	35.4	1	0
6/27/2013	10:00:00 AM	Yes	48.4	No		TWO	28.26	1.003105	35.4	1	0
6/27/2013	1:35:00 PM	Yes	49.35	No		TWO	28.1	1.003096	35.4	1	0
6/27/2013	4:00:00 PM	Yes	50	No	50 C Temp	TWO	27.95	1.00309	35.4	1	0
6/27/2013	9:55:00 PM	Yes	51.4	No		TWO	29.96	1.003076	35.4	1	0
7/2/2013	7:30:00 AM	No	48.03	No		TWO	22.03	1.003109	9.4	1	0
7/2/2013	1:20:00 PM	No	46.94	No		TWO	16.91	1.003119	9.4	1	0
7/2/2013	3:45:00 PM	No	46.1	No	Caustic addition	TWO	17.5	1.003127	9.4	1	0

Date	Time	SLPs on	Tank Temp (°C)	Transfer taking place?	Comment	STRIKE	[Hg]	exp(1/T(K))	Tank Level (inches)	Strike 2? (1=Yes)	Strike 3? (1=Yes)
					(250 gal)						
7/2/2013	8:00:00 PM	No	46.05	No		TWO	15.72	1.003128	9.4	1	0
7/3/2013	2:00:00 AM	No	44.7	No		TWO	14.87	1.003141	30.9	1	0
7/3/2013	7:30:00 AM	No	30.47	No		TWO	11.93	1.003288	30.9	1	0
7/3/2013	10:30:00 AM	No	29.15	No	Water addition (to 35"), 29.1 C	TWO	10.9	1.003303	30.9	1	0
7/3/2013	2:20:00 PM	No	31.08	No		TWO	9.69	1.003282	30.9	1	0
7/3/2013	8:00:00 PM	No	31.76	No		TWO	9.59	1.003274	30.9	1	0
7/4/2013	3:30:00 AM	No	36.56	No		TWO	9.28	1.003224	35.8	1	0
7/4/2013	7:50:00 AM	No	32.56	No		TWO	9.73	1.003266	35.8	1	0
7/4/2013	1:15:00 PM	No	32.75	No		TWO	9.77	1.003264	35.8	1	0
7/4/2013	8:00:00 PM	No	33.15	No		TWO	9.73	1.003259	35.8	1	0
7/5/2013	2:00:00 AM	No	32.52	No		TWO	9.62	1.003266	9.1	1	0
7/5/2013	10:00:00 AM	No	35.6	No		TWO	14.7	1.003234	9.1	1	0
7/5/2013	1:19:00 PM	No	36.5	Yes	12 to 51 Transfer (24.3 in)	TWO	15.4	1.003224	9.1	1	0
7/5/2013	4:00:00 PM	No	36.5	No		TWO	15.7	1.003224	9.1	1	0
7/5/2013	10:00:00 PM	No	36	No		TWO	16.2	1.003229	9.1	1	0
7/6/2013	4:45:00 AM	No	35.7	No		TWO	19.8	1.003233	9.4	1	0
7/6/2013	9:00:00 AM	No	35.6	No		TWO	18.8	1.003234	9.4	1	0
7/6/2013	3:00:00 PM	No	35.6	No		TWO	17.9	1.003234	9.4	1	0
7/6/2013	8:20:00 PM	No	35.7	No		TWO	18.1	1.003233	9.4	1	0
7/7/2013	2:00:00 AM	No	35.4	No		TWO	18.5	1.003236	9.4	1	0
7/7/2013	10:30:00 AM	No	35.5	No		TWO	18.2	1.003235	9.4	1	0
7/7/2013	4:15:00 PM	No	35.4	No		TWO	17.5	1.003236	9.4	1	0
7/7/2013	8:00:00 PM	No	35.4	No		TWO	16.1	1.003236	9.4	1	0

Date	Time	SLPs on	Tank Temp (°C)	Transfer taking place?	Comment	STRIKE	[Hg]	exp(1/T(K))	Tank Level (inches)	Strike 2? (1=Yes)	Strike 3? (1=Yes)
7/8/2013	3:30:00 AM	No	35.6	No		TWO	16.8	1.003234	9.4	1	0
7/8/2013	9:00:00 AM	No	35.16	No	Acid addition started	THREE	15	1.003238	9.4	0	1
7/8/2013	2:00:00 PM	No	35.1	No		THREE	16.1	1.003239	11.7	0	1
7/8/2013	8:00:00 PM	No	33.8	No		THREE	14.6	1.003253	11.7	0	1
7/9/2013	2:30:00 AM	No	40	No	Acid addition ended / water addition	THREE	14	1.003188	20.1	0	1
7/9/2013	7:40:00 AM	No	42.67	No		THREE	14.6	1.003161	20.1	0	1
7/9/2013	1:30:00 PM	No	38.91	No		THREE	13.8	1.003199	20.1	0	1
7/9/2013	10:00:00 PM	No	33.9	No	Slurry pumps started	THREE	10.5	1.003252	20.1	0	1
7/10/2013	4:00:00 AM	Yes	34.9	No		THREE	10	1.003241	35.3	0	1
7/10/2013	4:00:00 AM	Yes	34.9	No		THREE	10	1.003241	35.3	0	1
7/10/2013	7:15:00 AM	Yes	36.35	No		THREE	10.05	1.003226	35.3	0	1
7/10/2013	2:15:00 PM	Yes	39.3	No		THREE	11.3	1.003195	35.3	0	1
7/10/2013	7:30:00 PM	Yes	40.96	No		THREE	11	1.003179	35.3	0	1
7/11/2013	3:30:00 AM	Yes	44	No		THREE	16.7	1.003148	35.3	0	1
7/11/2013	1:00:00 PM	Yes	46.65	No		THREE	21.96	1.003122	35.3	0	1
7/11/2013	7:00:00 PM	Yes	47.95	No		THREE	22.3	1.003109	35.3	0	1
7/12/2013	4:00:00 AM	Yes	50.14	No		THREE	25.8	1.003088	35.3	0	1
7/12/2013	10:00:00 AM	Yes	52.4	No		THREE	29.872	1.003067	35.3	0	1
7/12/2013	4:00:00 PM	No	52.5	No		THREE	26.13	1.003066	35.3	0	1
7/12/2013	7:40:00 PM	Yes	52.19	No		THREE	29.055	1.003069	35.3	0	1
7/16/2013	11:35:00 AM	Yes	53.3	Yes	12 to 51 transfer started at 0030. Level 28.47 In,	THREE	30.83	1.003059	9	0	1

Date	Time	SLPs on	Tank Temp (°C)	Transfer taking place?	Comment	STRIKE	[Hg]	exp(1/T(K))	Tank Level (inches)	Strike 2? (1=Yes)	Strike 3? (1=Yes)
					Reduced exhaust flow of 1.72 in water (126 fpm)						