Cesium Precipitation Kinetic Studies

by

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CESIUM PRECIPITATION KINETIC STUDIES

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1.0 Summary

The data obtained from the tests described in this document provide results for determining tank size for in the proposed Small-Tank Tetraphenylborate (STTP) facility. The data clearly indicate the following.

- The degree of agitation during addition of NaTPB significantly affects the rate of cesium precipitation.
- The Na^+ concentration of the waste solution moderately affects the rate of cesium precipitation.
- The percent excess of NaTPB moderately affects the rate of cesium precipitation.
- The ratio of K^+ to Cs^+ and Hg^{2+} to Cs^+ only slightly influence the rate of cesium precipitation.
- Decontamination to a Cs-137 concentration below 30 nCi/g occurred in less than 1.5 h with a 100% excess of NaTPB in a 5.0 M Na^+ solution when stirred at a rate of 300 rpm. For the same solution composition and stirring speed but using 33% excess NaTPB, the decontamination required a longer time, but completed within 24 h.

The study also examined the relative kinetics of mercury reaction with tetraphenylborate but chemical analyses remain incomplete at this time. A future revision of this report will detail those studies.

2.0 Introduction

The Salt Disposition Systems Engineering Team identified Small Tank Tetraphenylborate Precipitation (STTP) as one of the four alternatives to replace the In-Tank Precipitation Facility at the Savannah River Site.¹ One economical uncertainty associated with the proposed STTP facility involves determination of tank size. Tank size and throughput depend on the kinetics of tetraphenylborate precipitation, and specifically on the time required to reach cesium decontamination. The High Level Waste Engineering (HLWE) Flow Sheet Team requested the Savannah River Technology Center (SRTC) examine cesium decontamination kinetics.² This report details that study.

The work included the following objectives.

- 1) Obtain decontamination factor (DF) data to assist in defining size requirements for the Continuously Stirred Tank Reactors (CSTRs).
- 2) Confirm mercury precipitation occurs significantly faster than cesium decontamination.
- 3) Determine the amount of excess NaTPB required to provide high reliability in decontamination within 24 h cycle.

3.0 Experimental

This task consists of five sets of single effects tests examining the influence of potentially significant variables on tetraphenylborate precipitation kinetics. Test variables included sodium ion concentration (Na^+), the ratio of potassium ion concentration (K^+) to cesium ion concentration (Cs^+), mercury ion concentration (Hg^{2+}), percent excess sodium tetraphenylborate (NaTPB), and agitation rate. (Note: percent excess NaTPB refers to the amount of NaTPB required for precipitation of K^+ , Cs^+ , and Hg^{2+}). All tests used a similar procedure and equipment.

Personnel prepared stock solutions for each set of tests with an average salt composition. The following subsections describe the compositions used in each Test Set. The first four sets of tests varied a selected parameter at three levels maintaining the other variables constant. The last Test Set examined the effect of mixing. In all tests, personnel placed 100 mL of the respective solutions into 250 mL beakers and added cesium-137 into the stock solutions at a concentration of $\sim 1.0 \times 10^6$ d/m/mL.* The tests added non-radioactive cesium, potassium, and mercury at the desired concentrations. In all tests, a variable speed paddle stirrer agitated the solution during the first 5 minutes of the precipitation reaction. The mixture stirred at 70 rpm unless otherwise noted (Test Sets E and F used an initial rate of 300 rpm). Sodium tetraphenylborate solution (0.55 M) addition to the agitated test solutions occurred at a rate of 3.0 mL/m

* Note: 1.0×10^6 d/m/mL equals 450 nCi/mL or 3.8×10^{-8} M Cs. The gamma counting detection limit used in this study to measure decontamination depended on sample size and counting time. For the conditions of these tests, the detection limit equaled 30 nCi/g.

using a peristaltic pump. After 5 minutes of reaction, personnel transferred the test mixtures to 125-mL polyethylene bottles and placed in a pre-heated water bath/shaker at 25 °C. (Tests sets A through D were continuously shaken gently while Test Set F was shaken vigorously.) Periodically, approximately 5 mL or 15 mL samples were removed using a syringe, filtered using 0.45 micron disposable syringe filters, and submitted for analysis. Routine analytical protocols³ were used to determine the concentration of Cs⁺ (gamma counting), K⁺ (atomic adsorption), and Hg²⁺ (atomic adsorption) in each test.

Personnel prepared test solutions from reagent grade chemicals using calibrated balances checked daily before use. The weights used for balance checks received calibration by the SRTC Standards Laboratory. The accuracy of glassware used to measure volumes was verified by gravimetric methods using water as a standard. Temperature measurements used equipment calibrated by the SRTC Standards Laboratory. Temperature monitoring occurred at least once per day to ensure a constant temperature reading within a range of ± 1 °C. All M&TE used in this task received calibration or verification for accuracy prior to their use. Blanks and control samples were submitted for analysis to monitor preparations and analytical methods. Blanks consisted of stock solutions of the salt matrix. Control samples contained a defined quantity of the analyte of interest in the salt matrix. All pertinent instructions, results, and calculations were recorded in a numbered notebook (WSRC-NB-98-00122) in accordance with Manual L1, SRTC Procedures Manual, procedure 4.19.⁴ Laboratory notebook provide lifetime storage as a record.

3.1 Test Set A: Effect of Sodium Concentration

Test Set A investigated the effect of varying Na⁺ on cesium precipitation. The set include three tests with different Na⁺ concentrations (4.0 M, 5.0 M, and 6.0 M). The K⁺, Cs⁺, and Hg²⁺ concentrations, percent excess NaTPB, and initial rate of agitation (70 rpm) remained constant. The following table shows the test design. Tests occurred in duplicate. Table 1 of Section 7 shows the compositions of the three salt solutions.

Test ID	Na ⁺ (M)	K ⁺ (M)	Cs ⁺ (M)	Hg ²⁺ (M)	% Excess NaTPB	Initial Stirring Rate (rpm)
A-1	4.0	0.013	0.00013	5.0×10^{-4}	33	70
A-2	4.0					
A-3	5.0					
A-4	5.0					
A-5	6.0					
A-6	6.0					

3.2 Test Set B: Effect of Potassium Concentration

These tests examined the effect of varying the K⁺ to Cs⁺ ratio on cesium precipitation. The three tests used different K⁺ concentrations (0.0033, 0.013, and 0.052 M – 25:1, 100:1, and 400:1 K⁺ : Cs⁺ ratio, respectively) while keeping the Na⁺, Cs⁺, and Hg²⁺ concentrations, percent excess NaTPB, and initial rate of agitation (70 rpm) constant. Personnel performed the tests in duplicate. The following table shows the test design. Table 2 of Section 7 defines the composition of the test solutions.

Test ID	Na ⁺ (M)	K ⁺ (M)	Cs ⁺ (M)	Hg ²⁺ (M)	% Excess NaTPB	Initial Stirring Rate (rpm)
B-1	5.0	0.0033	0.00013	5.0×10^{-4}	33	70
B-2		0.0033				
B-3		0.013				
B-4		0.013				
B-5		0.052				
B-6		0.052				

3.3 Test Set C: Effect of Mercury Concentration

These tests examined the effect of varying the K⁺ to Cs⁺ ratio on cesium precipitation. The three tests used different K⁺ concentrations (0.0033, 0.013, and 0.052 M – 25:1, 100:1, and 400:1 K⁺ : Cs⁺ ratio, respectively) while keeping the Na⁺, Cs⁺, and Hg²⁺ concentrations, percent excess NaTPB, and initial rate of agitation (70 rpm) constant. Personnel performed the tests in duplicate. The following table shows the test design. Table 2 of Section 7 defines the composition of the test solutions.

Test ID	Na ⁺ (M)	K ⁺ (M)	Cs ⁺ (M)	Hg ²⁺ (M)	% Excess NaTPB	Initial Stirring Rate (rpm)
C-1	5.0	0.013	0.00013	1.2×10^{-4}	33	70
C-2				1.2×10^{-4}		
C-3				5.0×10^{-4}		
C-4				5.0×10^{-4}		
C-5				20×10^{-4}		
C-6				20×10^{-4}		

3.4 Test Set D: Effect of Percent Excess Sodium Tetrphenylborate

Personnel studied the influence of excess NaTPB on the cesium precipitation. Experiments used different percents of excess NaTPB (33, 67, 78, 100%) according to the following design. Personnel only repeated the tests with 33 and 100% excess NaTPB in this series. Table 4 (Section 7) provides the relevant compositions.

Test ID	Na ⁺ (M)	K ⁺ (M)	Cs ⁺ (M)	Hg ²⁺ (M)	% Excess NaTPB	Initial Stirring Rate (rpm)
D-1	5.0	0.013	0.00013	5.0×10^{-4}	33	70
D-2					33	
D-3					67	
D-4					78	
D-5					100	
D-6					100	

3.5 Test Set F: Effect of Increased Agitation

The work investigated the influence of mixing in replicated tests using different percents of excess NaTPB (33 and 100 %). These experiments were stirred rapidly (300 rpm) with a paddle stirrer for 5 minutes at the start of testing. The test design follows while Table 5 (Section 7) provides additional detail.

Test ID	Na ⁺ (M)	K ⁺ (M)	Cs ⁺ (M)	Hg ²⁺ (M)	% Excess NaTPB	Initial Stirring Rate (rpm)
F-1	5.0	0.013	0.00013	5.0×10^{-4}	33	300
F-2					33	
F-3					100	
F-4					100	

4.0 Results and Discussion

All tests used a starting concentration of total (i.e., radioactive plus non-radioactive) cesium of 0.00013 M. Each test solution contained 1.0×10^6 d/m/mL (i.e., 450 nCi/mL, 380 nCi/g, or 3.8×10^{-8} M) of cesium-137. The total cesium approximately equals that expected in SRS waste. However, the starting radioactive cesium concentration in these tests represents 750 times less than expected in SRS waste (assuming Cs-137 constitutes 22% of the total cesium). The appendices contain the measured initial cesium for the experiments. The appendices also shows the equivalent cesium values assuming starting conditions equal to that for the radioactive waste, denoted as 'STTP Theoretical' where

$$\text{STTP Theoretical} = 756 * \text{Cs-137 (measured)}.$$

The remainder of this document will only refer to the STTP theoretical Cs-137 concentration when discussing decontamination of cesium. (Note K⁺ and Hg²⁺ data analyses continue as this document goes to publication. A future revision of the report will contain that information.).

4.1 Test Set A: Effect of Sodium Concentration

Appendix A and Figure 1 contain the data from Test Set A. Examination of Figure 1 indicates that the time required to reduce the Cs-137 concentration to less than 30 nCi/g depends upon the Na⁺. Only Tests A-1 and A-2, with 33% excess NaTPB at 4.0 M sodium, that achieved a 30 nCi/g limit during 72 hours of testing. This dependence likely reflects the rate of dissolution of insoluble NaTPB. The solubility of NaTPB depends on sodium concentration. The solubility of NaTPB 4.0 M salt solution significantly exceeds that for 5.0 or 6.0 M solution and hence the dissolution rate may prove much faster in these dilute solutions. However, even in a 4.0 M Na⁺ solution, the time required to achieve a 30 nCi/g limit fell between 24 and 48 hours for these mild mixing conditions and limited excess NaTPB.

4.2 Test Set B: Effect of Potassium Concentration

Figure 2 shows the data from Test Set B. (Appendix B for numerical data.) The data indicate that the relative concentration of potassium shows minor influence on the rate of precipitation of cesium. No tests in this series removed cesium to the target final value within 72 hours. The observation that cesium

Figure 1. Small Tank Tetraphenylborate Precipitation theoretical concentration of Cs-137 as a function of time and Na^+ . Tests A-1 and A-2 contained 4.0 M Na^+ , A-3 and A-4 used 5.0 M Na^+ , while A-5 and A-6 held 6.0 M Na^+ .

Figure 2. Small Tank Tetraphenylborate Precipitation theoretical concentration of Cs-137 as a function of time and K^+ . Tests B-1 and B-2 contained 0.0033 M K^+ , B-3 and B-4 used 0.013 M K^+ , while B-5 and B-6 held 0.052 M K^+ .

precipitates faster with an increase in the $K^+ : Cs^+$ ratio is attributed solely to the fact that an increased K^+ concentration (relative to a stable Cs^+ concentration) requires a larger quantity of NaTPB to maintain the same percent excess NaTPB (i.e., the ratio of NaTPB to Cs^+ decreases as potassium increases).

4.3 Test Set C: Effect of Mercury Concentration

Figure 3 shows the influence of mercury content on the rate of cesium precipitation; Appendix C contains the measured values. Mercury and potassium show similar minor effects. Increased mercury (with a constant cesium concentration) results in an increased rate of cesium precipitation.

4.4 Test Set D: Effect of Percent Excess Sodium Tetraphenylborate

Appendix D contains the data from Test Set D. Figure 4 also shows this information. The data indicate that the percent excess NaTPB provides a significant influence on the rate of precipitation of CsTPB. Of the six tests conducted at 5.0 M Na^+ , the two tests with a 100% excess of NaTPB achieved the target limit of 30 nCi/g in less than 48 hours. The test conducted with a 78% excess of NaTPB required between 47 and 70 hours to achieve the 30 nCi/g limit. Tests with 33 and 67% excess NaTPB did not achieve the 30 nCi/g limit within three days.

4.5 Test Set F: Effect of Increased Agitation

Tests F-1 and F-2 shared the same composition as a set of eight other experiments (A-3, A-4, B-3, B-4, C-3, C-4, D-1, and D-2). All used 33% excess NaTPB. However personnel stirred Tests F-1 and F-2 at 300 rpm for the first 5 minutes, including the period of NaTPB addition, versus 70 rpm for the other set. Figure 5 shows the cesium precipitation behavior. The results conclusively show that increased agitation during addition of NaTPB solution results in decontamination within 24 hours. Only one test (D-1) stirred at a rate of 70 rpm achieved decontamination within 72 hours.

Figure 6 contains a similar comparison for tests using 100% excess NaTPB. The two tests (i.e., F-3 and F-4) conducted with mixing at a rate of 300 rpm achieved the target decontamination limit of 30 nCi/g in less than 1.5 hours. The tests mixed at a rate of 70 rpm (i.e., D-5 and D-6) required between 22 and 47 hours to achieve decontamination.

Figure 3. Small Tank Tetraphenylborate Precipitation theoretical concentration of Cs-137 as a function of time and Hg^{2+} . Tests C-1 and C-2 contained 1.2×10^{-4} M Hg^{2+} , C-3 and C-4 used 5.0×10^{-4} M Hg^{2+} , while C-5 and C-6 held 20×10^{-4} M Hg^{2+} .

Figure 4. Small Tank Tetraphenylborate Precipitation theoretical concentration of Cs-137 as a function of time and percent excess NaTPB. Tests D-1 and D-2 used 33% excess NaTPB, D-3 added 67% excess NaTPB, D-4 held 78% excess NaTPB, and D-5 and D-6 contained 100% excess NaTPB.

Figure 5. Small Tank Tetraphenylborate Precipitation theoretical concentration of Cs-137 as a function of time and agitation with 33% excess NaTPB. Tests A-3, A-4, B-3, B-4, C-3, C-4, D-1, and D-2 stirred initially at a rate of 70 rpm. Tests F-1 and F-2 stirred initially at a rate of 300 rpm.

Figure 6. Small Tank Tetraphenylborate Precipitation theoretical concentration of Cs-137 as a function of time and agitation with 100% excess NaTPB. Tests D-5 and D-6 stirred initially at a rate of 70 rpm. Tests F-1 and F-2 stirred initially at a rate of 300 rpm.

5.0 Conclusions

The data obtained from the tests described in this document provide results for determining tank size for design throughput of SRS waste in the proposed STTP facility. The data clearly indicate the following.

- The degree of agitation during addition of NaTPB significantly affects the rate of cesium precipitation.
- The Na^+ concentration of the waste solution moderately affects the rate of cesium precipitation.
- The percent excess of NaTPB moderately affects the rate of cesium precipitation.
- The ratio of K^+ to Cs^+ and Hg^{+2} to Cs^+ only slightly influence the rate of cesium precipitation.
- A target Cs-137 concentration of 30 nCi/g was achieved in less than 1.5 h with a 100% excess of NaTPB in a 5.0 M Na^+ solution when stirred at a rate of 300 rpm. A target Cs-137 concentration of 30 nCi/g was achieved in less than 24 h with a 33% excess of NaTPB in a 5.0 M Na^+ solution when stirred at a rate of 300 rpm.

Data contained in this document addressed two of the three defined objectives. Mercury data was not available to address the third objective at the time this document was issued. This document will be revised upon receipt of that data. For the purpose of time and cost, this test program did not address the influence of temperature or order of chemical addition. Minimal risk is involved with these parameters since testing utilized a minimum bounding temperature of 25 °C and the current planned order of chemical addition (i.e., NaTPB addition to salt solution waste). This is thought to be true since (1) the kinetics of precipitation should be faster at the potentially higher temperatures that will be observed in the plant and (2) the order of chemical addition performed in these tests (i.e., NaTPB to salt solution) should lead to slower kinetics than the reverse order (i.e., salt solution to NaTPB) because of NaTPB solubility and sodium ion concentration.

6.0 References

1. P. L. Rutland et al., "Bases, Assumptions, and Results of the Flowsheet Calculations for the Initial Eighteen Salt Disposition Alternatives", WSRC-RP-98-00166, 25 June 1998.
2. P. L. Rutland, "Scoping Tests for Small Tank ITP-Salt Team Phase 3 Evaluation," HLE-TAR-98059, Rev. 0, July 14, 1998.
3. "Obtaining Analytical Services," Manual L1, Procedure 3.07, Rev. 1, November 1, 1996.
4. "Technical Notebook Use," Manual L1, Procedure 4.19, Rev. 5, February 2, 1998.

7.0 Tables

Table 1. Sodium ion test solution concentrations.

Component	Concentration	Concentration	Concentration
Na ⁺ (M)	4.0	5.0	6.0
K ⁺ (M)	0.013	0.013	0.013
Cs ⁺ (M)	0.00013	0.00013	0.00013
OH ⁻ (M)	1.36	1.71	2.05
NO ₃ ⁻ (M)	1.53	1.91	2.29
NO ₂ ⁻ (M)	0.37	0.46	0.56
AlO ₂ ⁻ (M)	0.22	0.28	0.33
CO ₃ ²⁻ (M)	0.11	0.14	0.17
SO ₄ ²⁻ (M)	0.11	0.13	0.16
Cl ⁻ (M)	0.018	0.022	0.027
F ⁻ (M)	0.023	0.029	0.034
PO ₄ ³⁻ (M)	0.007	0.009	0.011
NaTPB (% excess) ^a	33	33	33
Hg ²⁺ (M) ^b	5.0 x 10 ⁻⁴	5.0 x 10 ⁻⁴	5.0 x 10 ⁻⁴

^a % excess NaTPB relative to the amount required for precipitation of K⁺, Cs⁺, and Hg²⁺.^b 5.0 x 10⁻⁴ molar equals 100 mg/L mercury.

Table 2. Potassium ion test solution concentrations.

Component	Concentration
Na ⁺ (M)	5.0
K ⁺ (M)	0.0033, 0.013, 0.052
Cs ⁺ (M)	0.00013
OH ⁻ (M)	1.71
NO ₃ ⁻ (M)	1.91
NO ₂ ⁻ (M)	0.46
AlO ₂ ⁻ (M)	0.28
CO ₃ ²⁻ (M)	0.14
SO ₄ ²⁻ (M)	0.13
Cl ⁻ (M)	0.022
F ⁻ (M)	0.029
PO ₄ ³⁻ (M)	0.009
NaTPB (% excess) ^a	33
Hg ²⁺ (M) ^b	5.0 x 10 ⁻⁴

^a % excess NaTPB relative to the amount required for precipitation of K⁺, Cs⁺, and Hg²⁺.^b 5.0 x 10⁻⁴ molar equals 100 mg/L mercury.

Table 3. Mercury ion test solution concentrations.

Component	Concentration
Na ⁺ (M)	5.0
K ⁺ (M)	0.013
Cs ⁺ (M)	0.00013
OH ⁻ (M)	1.71
NO ₃ ⁻ (M)	1.91
NO ₂ ⁻ (M)	0.46
AlO ₂ ⁻ (M)	0.28
CO ₃ ²⁻ (M)	0.14
SO ₄ ²⁻ (M)	0.13
Cl ⁻ (M)	0.022
F ⁻ (M)	0.029
PO ₄ ³⁻ (M)	0.009
NaTPB (% excess) ^a	33
Hg ²⁺ (M) ^b	1.2 x 10 ⁻⁴ , 5.0 x 10 ⁻⁴ , 20 x 10 ⁻⁴

^a % excess NaTPB relative to the amount required for precipitation of K⁺, Cs⁺, and Hg²⁺.^b 1.2 x 10⁻⁴, 5.0 x 10⁻⁴, and 20 x 10⁻⁴ molar equals 25, 100, and 400 mg/L mercury.

Table 4. Percent excess NaTPB test solution concentrations.

Component	Concentration
Na ⁺ (M)	5.0
K ⁺ (M)	0.013
Cs ⁺ (M)	0.00013
OH ⁻ (M)	1.71
NO ₃ ⁻ (M)	1.91
NO ₂ ⁻ (M)	0.46
AlO ₂ ⁻ (M)	0.28
CO ₃ ²⁻ (M)	0.14
SO ₄ ²⁻ (M)	0.13
Cl ⁻ (M)	0.022
F ⁻ (M)	0.029
PO ₄ ³⁻ (M)	0.009
NaTPB (% excess)^a	33, 67, 78, 100
Hg ²⁺ (M) ^b	5.0 x 10 ⁻⁴

^a % excess NaTPB relative to the amount required for precipitation of K⁺, Cs⁺, and Hg²⁺.^b 5.0 x 10⁻⁴ molar equals 100 mg/L mercury.**Table 5. Increased agitation test solution concentrations.**

Component	Concentration
Na ⁺ (M)	5.0
K ⁺ (M)	0.013
Cs ⁺ (M)	0.00013
OH ⁻ (M)	1.71
NO ₃ ⁻ (M)	1.91
NO ₂ ⁻ (M)	0.46
AlO ₂ ⁻ (M)	0.28
CO ₃ ²⁻ (M)	0.14
SO ₄ ²⁻ (M)	0.13
Cl ⁻ (M)	0.022
F ⁻ (M)	0.029
PO ₄ ³⁻ (M)	0.009
NaTPB (% excess)^a	33, 100
Hg ²⁺ (M) ^b	5.0 x 10 ⁻⁴

^a % excess NaTPB relative to the amount required for precipitation of K⁺, Cs⁺, and Hg²⁺.^b 5.0 x 10⁻⁴ molar equals 100 mg/L mercury.

8.0 Appendices

8.1 Appendix A. Test Set A Data: Effect of Sodium Concentration

Test A-1					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	380	287598	1	NA ^a	NA
2.5	24.9	18861	15	NA	NA
4.4	20.6	15572	18	NA	NA
8.4	15.5	11710	25	NA	NA
23.6	8.28	6259	46	NA	NA
47.7	< 8.29E-03	< 6.26	> 45913	NA	NA
70.7	< 9.58E-03	< 7.24	> 39711	NA	NA

^aNA indicates sample pending analysis.

Test A-2					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	380	287356	1	NA ^a	NA
2.3	23.8	17988	16	NA	NA
4.1	17.8	13432	21	NA	NA
8.2	12.9	9782	29	NA	NA
23.4	5.50	4159	69	NA	NA
47.5	< 6.57E-03	< 4.97	> 57841	NA	NA
70.5	< 8.29E-03	< 6.26	> 45874	NA	NA

^aNA indicates sample pending analysis.

Test A-3					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	375	283691	1	NA ^a	NA
2.1	57.4	43429	7	NA	NA
3.9	44.5	33636	8	NA	NA
8.1	33.5	25312	11	NA	NA
23.3	25.1	18979	15	NA	NA
47.3	22.5	16980	17	NA	NA
70.3	19.9	15057	19	NA	NA

^aNA indicates sample pending analysis.

Test A-4					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	375	283131	1	NA ^a	NA
2.0	66.2	50064	6	NA	NA
3.8	48.3	36509	8	NA	NA
8.0	36.2	27399	10	NA	NA
23.2	28.5	21520	13	NA	NA
47.2	24.4	18446	15	NA	NA
70.2	21.3	16124	18	NA	NA

^aNA indicates sample pending analysis.

Test A-5					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	351	264999	1	NA ^a	NA
1.9	73.5	55552	5	NA	NA
3.7	55.4	41864	6	NA	NA
7.9	41.2	31160	9	NA	NA
23.0	34.1	25803	10	NA	NA
47.1	30.3	22926	12	NA	NA
70.1	27.8	21050	13	NA	NA

^aNA indicates sample pending analysis.

Test A-6					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	360	272202	1	NA ^a	NA
1.8	75.4	56973	5	NA	NA
3.6	54.7	41344	7	NA	NA
7.8	40.7	30800	9	NA	NA
22.9	33.9	25628	11	NA	NA
47.1	31.3	23631	12	NA	NA
70.0	28.2	21340	13	NA	NA

^aNA indicates sample pending analysis.**8.2 Appendix B. Test Set B Data: Effect of Potassium Concentration**

Test B-1					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	377	284729	1	NA ^a	NA
1.7	84.9	64217	4	NA	NA
3.4	70.0	52900	5	NA	NA
7.7	58.9	44547	6	NA	NA
22.8	44.0	33231	9	NA	NA
47.0	35.9	27139	10	NA	NA
69.9	31.5	23791	12	NA	NA

^aNA indicates sample pending analysis.

Test B-2					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	375	283850	1	NA ^a	NA
1.5	104.4	78901	4	NA	NA
3.3	81.1	61345	5	NA	NA
7.6	65.6	49622	6	NA	NA
22.7	48.8	36913	8	NA	NA
46.9	40.5	30655	9	NA	NA
69.8	35.5	26863	11	NA	NA

^aNA indicates sample pending analysis.

Test B-3					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	384	290230	1	NA ^a	NA
1.4	69.8	52758	6	NA	NA
3.1	48.0	36297	8	NA	NA
7.5	33.0	24930	12	NA	NA
22.6	26.3	19903	15	NA	NA
46.7	22.0	16635	17	NA	NA
69.7	19.1	14462	20	NA	NA

^aNA indicates sample pending analysis.

Test B-4					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	379	286395	1	NA ^a	NA
1.3	81.7	61752	5	NA	NA
3.0	55.5	41989	7	NA	NA
7.4	38.0	28702	10	NA	NA
22.5	29.7	22468	13	NA	NA
46.6	25.9	19583	15	NA	NA
69.5	22.5	17040	17	NA	NA

^aNA indicates sample pending analysis.

Test B-5					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	373	281638	1	NA ^a	NA
1.2	40.9	30919	9	NA	NA
2.9	25.2	19018	15	NA	NA
7.3	17.9	13531	21	NA	NA
22.4	14.2	10757	26	NA	NA
46.5	12.0	9103	31	NA	NA
69.4	8.93	6752	42	NA	NA

^aNA indicates sample pending analysis.

Test B-6					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	377	284760	1	NA ^a	NA
1.1	43.1	32553	9	NA	NA
2.7	26.3	19847	14	NA	NA
7.2	17.8	13431	21	NA	NA
22.3	14.4	10861	26	NA	NA
46.4	11.6	8734	33	NA	NA
69.3	9.13	6900	41	NA	NA

^aNA indicates sample pending analysis.

8.3 Appendix C. Test Set C Data: Effect of Mercury Concentration

Test C-1					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)	Cs-137 DF	K (M)	Hg (M)
0.0	376	284410	1	NA ^a	NA
2.2	59.7	45096	6	NA	NA
4.5	45.4	34308	8	NA	NA
7.9	37.4	28283	10	NA	NA
23.3	30.4	23006	12	NA	NA
47.6	25.5	19315	15	NA	NA
71.0	22.5	17013	17	NA	NA

^aNA indicates sample pending analysis.

Test C-2					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)	Cs-137 DF	K (M)	Hg (M)
0.0	376	284594	1	NA ^a	NA
2.1	55.9	42236	7	NA	NA
4.3	43.4	32796	9	NA	NA
7.7	35.2	26600	11	NA	NA
23.2	29.0	21961	13	NA	NA
47.5	25.2	19070	15	NA	NA
70.9	22.0	16621	17	NA	NA

^aNA indicates sample pending analysis.

Test C-3					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)	Cs-137 DF	K (M)	Hg (M)
0.0	378	285688	1	NA ^a	NA
2.0	49.3	37274	8	NA	NA
4.2	36.2	27340	10	NA	NA
7.7	29.8	22540	13	NA	NA
23.1	24.6	18578	15	NA	NA
47.5	20.7	15660	18	NA	NA
70.8	18.5	14005	20	NA	NA

^aNA indicates sample pending analysis.

Test C-4					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)	Cs-137 DF	K (M)	Hg (M)
0.0	382	288927	1	NA ^a	NA
1.9	56.6	42822	7	NA	NA
4.1	42.5	32152	9	NA	NA
7.6	33.2	25084	12	NA	NA
23.0	26.3	19917	15	NA	NA
47.3	22.5	17042	17	NA	NA
70.7	19.9	15070	19	NA	NA

^aNA indicates sample pending analysis.

Test C-5					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical		K (M)	Hg (M)
		Cs-137 (nCi/g)	Cs-137 DF		
0.0	378	285399	1	NA ^a	NA
1.7	36.5	27560	10	NA	NA
4.0	22.1	16697	17	NA	NA
7.5	16.9	12807	22	NA	NA
22.9	11.8	8934	32	NA	NA
47.2	8.5	6412	45	NA	NA
70.6	6.17	4661	61	NA	NA

^aNA indicates sample pending analysis.

Test C-6					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical		K (M)	Hg (M)
		Cs-137 (nCi/g)	Cs-137 DF		
0.0	373	281644	1	NA ^a	NA
1.6	43.4	32791	9	NA	NA
3.8	28.5	21509	13	NA	NA
7.4	22.0	16655	17	NA	NA
22.7	16.7	12661	22	NA	NA
47.1	13.5	10178	28	NA	NA
70.5	13.4	10145	28	NA	NA

^aNA indicates sample pending analysis.**8.4 Appendix D. Test Set D Data: Effect of Percent Excess Sodium Tetraphenylborate**

Test D-1					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical		K (M)	Hg (M)
		Cs-137 (nCi/g)	Cs-137 DF		
0.0	379	286880	1	NA ^a	NA
1.4	75.5	57050	5	NA	NA
3.6	49.6	37509	8	NA	NA
7.2	36.4	27504	10	NA	NA
22.6	27.9	21123	14	NA	NA
47.0	24.4	18479	16	NA	NA
70.3	< 2.33E-03	< 1.76	> 162631	NA	NA

^aNA indicates sample pending analysis.

Test D-2					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical		K (M)	Hg (M)
		Cs-137 (nCi/g)	Cs-137 DF		
0.0	380	287231	1	NA ^a	NA
1.3	72.4	54761	5	NA	NA
3.5	47.1	35627	8	NA	NA
7.1	35.0	26480	11	NA	NA
22.5	27.8	21012	14	NA	NA
46.8	23.7	17945	16	NA	NA
70.2	20.9	15834	18	NA	NA

^aNA indicates sample pending analysis.

Test D-3					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical		K (M)	Hg (M)
		Cs-137 (nCi/g)	Cs-137 DF		
0.0	383	289628	1	NA ^a	NA
1.2	53.4	40399	7	NA	NA
3.4	30.6	23152	13	NA	NA
7.0	22.6	17109	17	NA	NA
22.4	16.2	12253	24	NA	NA
46.7	11.4	8595	34	NA	NA
70.1	7.79	5890	49	NA	NA

^aNA indicates sample pending analysis.

Test D-4					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical		K (M)	Hg (M)
		Cs-137 (nCi/g)	Cs-137 DF		
0.0	384	290083	1	NA ^a	NA
1.0	45.9	34678	8	NA	NA
3.3	24.6	18580	16	NA	NA
6.9	17.9	13526	21	NA	NA
22.3	11.2	8452	34	NA	NA
46.6	4.94	3736	78	NA	NA
70.0	< 1.80E-03	< 1.36	> 212595	NA	NA

^aNA indicates sample pending analysis.

Test D-5					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical		K (M)	Hg (M)
		Cs-137 (nCi/g)	Cs-137 DF		
0.0	378	285860	1	NA ^a	NA
0.9	37.4	28289	10	NA	NA
3.2	20.5	15492	18	NA	NA
6.8	14.5	10949	26	NA	NA
22.2	7.51	5680	50	NA	NA
46.5	< 8.02E-03	< 6.06	> 47169	NA	NA
69.9	< 2.08E-03	< 1.57	> 181676	NA	NA

^aNA indicates sample pending analysis.

Test D-6					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical		K (M)	Hg (M)
		Cs-137 (nCi/g)	Cs-137 DF		
0.0	384	290021	1	NA ^a	NA
0.8	42.8	32368	9	NA	NA
3.0	20.4	15422	19	NA	NA
6.8	14.4	10899	27	NA	NA
22.1	7.02	5306	55	NA	NA
46.4	< 8.02E-03	< 6.06	> 47856	NA	NA
69.8	< 2.27E-03	< 1.71	> 169125	NA	NA

^aNA indicates sample pending analysis.

8.5 Appendix F. Test Set F Data: Effect of Increased Agitation

Test F-1					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	379	286672	1	NA ^a	NA
1.6	14.1	10637	27	NA	NA
3.8	9.36	7079	40	NA	NA
7.1	5.03	3806	75	NA	NA
21.1	< 5.19E-03	< 3.92	> 73105	NA	NA
30.3	< 9.27E-03	< 7.01	> 40913	NA	NA
49.6	< 1.04E-02	< 7.87	> 36438	NA	NA

^aNA indicates sample pending analysis.

Test F-2					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	261	197629	1	NA ^a	NA
1.5	16.1	12190	16	NA	NA
3.7	9.50	7186	28	NA	NA
7.0	5.59	4225	47	NA	NA
21.0	< 5.19E-03	< 3.92	> 50398	NA	NA
30.2	< 2.33E-03	< 1.76	> 112035	NA	NA
49.5	< 1.22E-02	< 9.22	> 21436	NA	NA

^aNA indicates sample pending analysis.

Test F-3					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	381	287852	1	NA ^a	NA
1.3	< 1.83E-02	< 13.8	> 20815	NA	NA
3.5	< 1.83E-02	< 13.8	> 20815	NA	NA
6.8	< 6.59E-03	< 4.98	> 57747	NA	NA
20.9	< 3.72E-03	< 2.81	> 102479	NA	NA
30.0	< 2.33E-03	< 1.76	> 163181	NA	NA
49.4	< 8.02E-03	< 6.06	> 47498	NA	NA

^aNA indicates sample pending analysis.

Test F-4					
Time (h)	Experimental Cs-137 (nCi/g)	STTP Theoretical Cs-137 (nCi/g)		K (M)	Hg (M)
0.0	378	285799	1	NA ^a	NA
1.2	< 1.83E-02	< 13.8	> 20666	NA	NA
3.4	< 1.83E-02	< 13.8	> 20666	NA	NA
6.7	< 3.21E-03	< 2.43	> 117719	NA	NA
20.8	< 4.15E-03	< 3.13	> 91175	NA	NA
29.9	< 2.33E-03	< 1.76	> 162017	NA	NA
49.3	< 8.02E-03	< 6.06	> 47159	NA	NA

^aNA indicates sample pending analysis.

9.0 Distribution

CC: G. E. Abell, 704-3N
B. N. Attaway, 773-A
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N. E. Bibler, 773-A
J. D. Carlson, 703-H
J. T. Carter, 704-25S
G. L. Cauthen, 241-119H
W. C. Clark, 704-56H
C. L. Crawford, 773-41A
Dr. E. Cussler, 704-3N
N. R. Davis, 703-H
R. A. Dimenna, 773-42A
L. O. Dworjanyn, 779-2A
R. E. Eibling, 704-T
H. H. Elder, 704-S
S. D. Fink, 773-A
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J. R. Fowler, 704-3N
M. W. Geeting, 773-24A
J. C. Griffin, 773-A
T. Hang, 773-42A
D. T. Hobbs, 773-A
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B. L. Lewis, 703-H
T. J. Lex, 703-H
P. E. Lowe, 773-41A
D. J. McCabe, 773-42A
J. W. McCollough, 703-H
M. S. Miller, 704-56H
T. M. Monahan, 703-H
J. P. Morin, 703-H
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C. A. Nash, 773-42A
L. M. Nelson, 773-43A
L. M. Papouchado, 773-A
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S. F. Piccolo, 704-3N
M. R. Poirier, 676-T
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W. E. Stevens, 773-A
P. C. Suggs, 704-3N
R. F. Swingle, 773-A
W. L. Tamosaitis, 773-A
G. A. Taylor, 704-196N
W. B. VanPelt, 676-1T
D. D. Walker, 773-A
Dr. J. Watson, 704-3N
W. R. Wilmarth, 773-42A
G. T. Wright, 773-A
J. E. Young, 773-A
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WPTS Files, 773-A, c/o S. Poston, 773-A
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