

PILOT-SCALE INCINERATION OF PCB-CONTAMINATED SEDIMENTS FROM THE HOT SPOT OF THE NEW BEDFORD HARBOR SUPERFUND SITE

L. R. Waterland and W. E. Whitworth
Acurex Environmental Corporation
Incineration Research Facility
Jefferson, Arkansas 72079

M.K. Richards
U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
Cincinnati, Ohio 45268

ABSTRACT

A detailed test program was performed at the U.S. Environmental Protection Agency's (EPA's) Incineration Research Facility (IRF) to define the incineration characteristics of contaminated marine sediments from the Hot Spot in New Bedford Harbor, a Superfund site near New Bedford, MA. The sediments at this site are contaminated with PCB concentrations of 4,000 to over 200,000 mg/kg, as well as with trace metals, chiefly cadmium, chromium, copper, and lead, at concentrations up to several hundred mg/kg. The test program was designed to evaluate the effects of incineration operating conditions on the composition of the discharge streams.

Three incineration tests were performed using native sediments spiked with pure PCB Askarel transformer fluid. The third test also included a period of operation with native (unspiked) sediment alone. Spiking was performed to increase the sediment PCB content from nominally 6,000 to nominally 46,000 mg/kg, a level that allowed an unambiguous determination of whether a regulatory level PCB destruction and removal efficiency (DRE) of 99.9999% could be achieved. For the three spiked sediment tests, plans were to vary kiln exit gas temperature from 816° to 982°C (1,500° to 1,800°F). Average test temperatures achieved were 824° and 984°C (1,516° and 1,803°F).

Test results show that greater than 99.9999% PCB DRE ($100 \cdot [1 - \text{flue gas emission rate/feerate}]$) was achieved at both kiln temperatures with the afterburner operated at 1,208°C (2,206°F). However, with a kiln solids residence time of 0.5 hr, the treated sediments (kiln ash) were still PCB-contaminated. In tests with the PCB-spiked sediment feed, incinerated without dewatering, kiln ash contained 128 to 245 mg/kg of PCBs. The PCBs in the kiln ash discharge accounted for between 0.08% and 0.14% of the PCBs fed, regardless of kiln temperature. For a native (unspiked) sediment feed incinerated without dewatering, the kiln ash contained 100 mg/kg of PCBs, which accounted for 0.44% of the PCBs introduced in the sediment feed. The wet scrubber system discharge flue gas contained low levels of polychlorinated dibenzo-p-dioxins (PCDDs) and higher levels of dibenzofurans (PCDFs), chiefly total tetra-CDF (TCDF), penta-CDF (PeCDF), and hexa-CDF (HxCDF). The 2,3,7,8-tetra-CDD (2,3,7,8-TCDD) toxicity equivalent emissions were in the nominal 0.05 to 0.10 ng/dscm range.

Of the contaminant trace metals, chromium and copper were relatively nonvolatile. The kiln ash discharge accounted for nominally 80% to 90% of the discharged amount of these metals. These fractions were not affected by kiln temperature in the range tested. Cadmium and lead exhibited relatively volatile behavior, and increasingly so at the higher kiln temperature. At low kiln temperature the kiln ash discharge accounted for 53% of the lead and 61% of the cadmium discharged. At higher kiln temperature these fractions decreased to the nominal 10% to 20% range for cadmium and the 20% range for lead. Scrubber exit flue gas fractions (cadmium and lead) and scrubber liquor fractions (cadmium) increased accordingly. Neither treated sediments nor the scrubber liquor were toxicity characteristic (TC) hazardous wastes based on their cadmium, chromium, or lead concentrations. However, the lead content of scrubber liquor toxicity characteristic leaching procedure (TCLP) leachate was near the TC regulatory level. This suggests that the scrubber liquor discharge from a wet scrubber could be a TC hazardous waste in the incineration of higher-than-tested lead-containing sediments, or under extended scrubber operation at minimum blowdown.

Test results suggest that incineration would be an effective treatment option for the site sediments. However, sediment dewatering before incineration, and/or incinerating at longer kiln solids residence times might be required to yield a treated sediment not contaminated by PCBs. If a wet scrubber were used for particulate and acid gas control, the scrubber blowdown discharge might require further treatment to stabilize leachable lead levels. In addition, lead levels in flue gas emissions from a wet scrubber air pollution control system (APCS) might be of concern.

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INTRODUCTION

EPA Region 1 is conducting the remedial design (RD) for the remediation of a Superfund site located in New Bedford Harbor near New Bedford, MA. According to the record of decision (ROD) document of 1990, the EPA has identified approximately 10,000 yd³ of contaminated sediment in a 5-acre area of the harbor. This area has been identified as the Hot Spot Operable Unit and incineration of the dredged sediment has been selected as the treatment option. EPA Region 1 requested that test burns be conducted at EPA's IRF to support the RD for this Superfund site.

The primary objective of this test program was to obtain data to support the RD plans and specifications. Therefore, the test conditions were designed to evaluate the effectiveness of varying incinerator operating conditions in the destruction of PCBs and other pollutants. Specifically, the test program attempted to answer these questions:

- Can incineration effectively destroy PCBs to the required regulatory level DRE of 99.9999% in the flue gas emission?
- What is the distribution of the contaminant trace metals in the discharge streams during incineration of the sediment?
- What are the effects of incineration excess air and temperature on organic constituent destruction and metals distributions, including the leachability of the metals from the kiln ash?
- What is the effectiveness of the air pollution control system (APCS), with design and operating characteristics similar to those of the IRF venturi/packed-column scrubber, in collecting particulate and trace metals?
- Can the treated sediment (i.e., kiln ash) from the incinerator be disposed of as nonhazardous solid waste?

The test program consisted of a set of three incineration tests in the rotary kiln incineration system (RKS) at the IRF. These tests were aimed at evaluating PCB destruction and the fate of contaminant trace metals in the sediment as functions of kiln temperature and kiln excess air level.

TEST PROGRAM

Test Facility

A process schematic of the RKS is shown in Fig. 1. The IRF RKS consists of a primary combustion chamber, a transition section, and a fired afterburner chamber. After exiting the afterburner, flue gas flows through a quench section followed by a primary APCS. The primary APCS for these tests consisted of a venturi scrubber followed by a packed-column scrubber. Downstream of the primary APCS, a backup secondary APCS, comprised of a demister, an activated-carbon adsorber, and a high-efficiency particulate (HEPA) filter, is in place.

Test Waste Description

Eight 30-gal drums of sediments were dredged from the Hot Spot area of New Bedford Harbor for these tests. A characterization sample representing each drum was shipped to the IRF for prettest analyses. These samples were subjected to proximate, PCB, and hazardous constituent trace metals analyses. The results of these analyses showed that the average total PCB concentration of the eight drums was 5,300 mg/kg as received. The level required in an RKS feed to be able to just establish 99.9999% DRE at a typical RKS feedrate of 68 kg/hr (150 lb/hr) is 5,100 mg/kg, just below the average dredged drum characterization sample level. Consequently, it was decided to spike the test sediment to higher PCB concentrations to provide a margin in the ability to establish 99.9999% DRE. The material used to spike the sediments was an Askarel transformer fluid comprised of roughly 75%

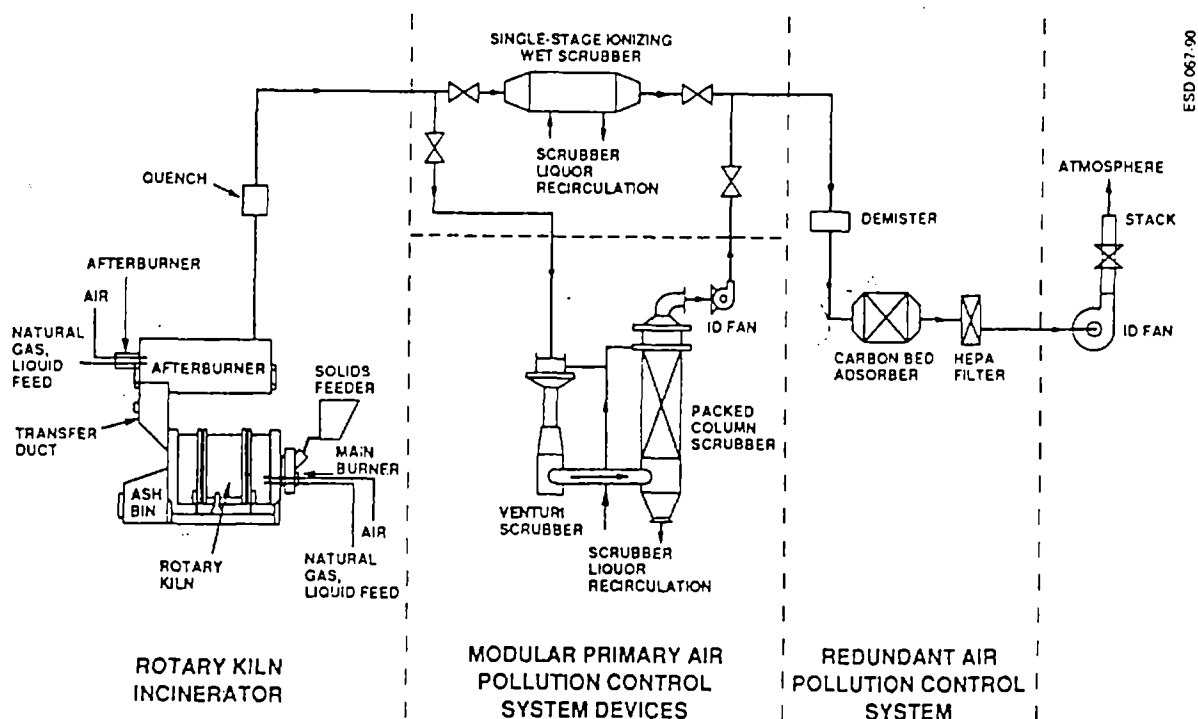


Fig. 1. Schematic of the IRF rotary kiln incineration system.

Aroclor 1242 and 25% Aroclor 1254. Resulting spiked feed levels were 3.48% Aroclor 1242 and 1.11% Aroclor 1254.

For the test program, all eight drums of sediment were shipped to the IRF, where they were combined to form one test feed material. Before testing, the combined sediments were repackaged into 1.5-gal fiberpack containers for feeding to the RKS via the ram feeder system. The PCB spike was added to the sediments during this packaging. In addition to spiked sediments, a number of fiberpack drums were prepared without the PCB spike for testing using only the native sediment.

Test Conditions

The test series was designed to evaluate the effects of incinerator operating conditions on PCB destruction and trace metal distributions in the incinerator discharge streams. The operating parameters to be varied were kiln exit gas temperature and kiln excess air (exit flue gas O₂). Three tests were to cover the range of target kiln exit flue gas temperatures of 816° and 982°C (1,500° and 1,800°F) and target kiln exit O₂ levels of 6% to 10%. For all tests, the operating conditions noted in Table I were to be held at the nominal values noted in the table.

Table II summarizes the actual incinerator exit temperatures and flue gas levels, including their ranges and averages for each test during flue gas sampling. These are compared

with the respective target conditions. During Test 3, unspiked native sediment was fed to the kiln for a period of time to collect kiln ash associated with native sediment feed only. Test 3a represents the period of native sediment feed; Test 3b represents the period of spiked sediment feed for the third test.

For all tests, the average kiln exit gas temperature was within 8°C (16°F) of the respective target temperature. The actual O₂ levels at the kiln exit were generally higher than the target concentrations. The higher O₂ levels experienced resulted from higher than expected air inleakage into the kiln chamber because of the inability to tightly secure a rotating kiln seal. The minimum O₂ achievable was 9% at the kiln exit. The maximum O₂ tested was 11.2%. As a practical matter, these two levels present comparable combustion environments. Consequently, it was not possible to test kiln excess air as a variable.

Sampling and Analysis Procedures

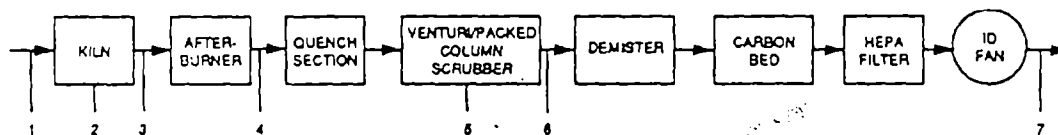
The scope of the sampling effort undertaken during this test program is illustrated in Fig. 2, in which the sampling locations are identified. Specifically, the sampling effort during each test consisted of:

- Collecting samples of the sediment feed from each drum received, as well as a composite sample from the mixing container in which all sediments received were blended before the sediments were packaged into feed fiberpacks.
- Collecting a composite sample of the kiln ash.
- Collecting a composite sample of the scrubber liquor.
- Continuously measuring O₂ levels in the kiln exit and afterburner exit flue gases; O₂, CO, CO₂, NO_x, and total unburned hydrocarbon (TUHC) levels at the venturi/packed-column scrubber exit; and O₂, CO, and CO₂ levels in the stack.
- Sampling flue gas at the scrubber system exit for PAHs and PCBs.
- Sampling flue gas at the scrubber system exit for PCDDs and PCDFs.

TABLE I

Incinerator System Operating Conditions Held Constant

Operating condition	Value
Kiln solids residence time	0.5 hr
Total sediment feedrate	68.2 kg/hr (150 lb/hr)
Scrubber blowdown rate	0 L/min (0 gpm) or minimum operable
Venturi liquor flowrate	76 L/min (20 gpm)
Venturi pressure drop	6.2 kPa (25 in WC)
Packed tower liquor flowrate	115 L/min (30 gpm)
Scrubber liquor temperature	49°C (120°F)



Sampling point	Sediment feed (composite)	Kiln ash (composite)	Venturi/packed-column scrubber liquor (composite)	Continuous flue gas monitoring (CEMs)	Method 0010 (PCBs and PAHs)	Method 0010 (PCDDs/PCDFs)	Method 0030 (Volatile organics)	Particle size distribution (Cascade Impactor)	Method 5 (Particulate, trace metals)	Method 5 (Particulate, HCl)
1	X									
2		X								
3				X						
4				X				X	X	
5			X							
6				X	X	X	X		X	X
7				X						X

Fig. 2. Sampling matrix.

TABLE II

Actual Versus Target Operating Conditions for the New Bedford Harbor Tests

Test	Date	Temperature, °C (°F)				Flue gas O ₂ , %		
		Target	Minimum	Maximum	Average	Target	Range	Average
Kiln exit								
1	3/15/91	816 (1,500)	755 (1,391)	907 (1,665)	824 (1,516)	6	5.8 to 13.9	11.2
2	3/19/91	982 (1,800)	945 (1,733)	1,022 (1,871)	984 (1,803)	6	6.6 to 12.0	9.0
3a	3/21/91	982 (1,800)	939 (1,723)	1,010 (1,850)	981 (1,797)	10	7.2 to 11.5	9.3
3b	3/21/91	982 (1,800)	968 (1,775)	999 (1,831)	985 (1,805)	10	7.0 to 11.4	10.0
Afterburner exit								
1	3/15/91	1,204 (2,200)	1,195 (2,183)	1,221 (2,229)	1,208 (2,206)	7	3.2 to 8.2	6.4
2	3/19/91	1,204 (2,200)	1,201 (2,194)	1,213 (2,216)	1,208 (2,206)	7	3.6 to 7.4	6.0
3a	3/21/91	1,204 (2,200)	1,194 (2,181)	1,226 (2,239)	1,208 (2,206)	7	2.9 to 7.6	6.4
3b	3/21/91	1,204 (2,200)	1,198 (2,188)	1,214 (2,217)	1,208 (2,206)	7	4.3 to 8.0	7.0

- Sampling flue gas at the scrubber system exit for volatile organics.
- Sampling flue gas upstream of the scrubber system for particle size distribution.
- Sampling flue gas upstream and downstream of the scrubber system for particulate and trace metals using a variation of EPA Method 5 modified for multiple metals capture.
- Sampling downstream of the scrubber system and at the stack downstream of the secondary APCS for particulate and HCl using Method 5 to comply with permit requirements.

An aliquot of the composited sediment feed and each test's kiln ash was subjected to the TCLP leaching procedure and analyzed for cadmium, chromium, copper, and lead. Waste feed samples, kiln ash samples, and scrubber liquor samples were analyzed separately for PCBs, PAHs, and cadmium, chromium, copper, and lead. The composite sediment feed sample was also subjected to proximate (moisture, ash content, and heat content) analysis and ultimate (C, H, O, N, S, Cl) analysis.

TEST RESULTS

The results of the test program are discussed in the subsections that follow. Test results are grouped by analyte class.

PCB, Semivolatile and Volatile Organic, and Dioxin/Furan Analysis Results

Table III summarizes the PCB contents of each incineration test sample. As noted in the table, the spiked sediment feed contained 3.48% Aroclor 1242 and 1.11% Aroclor 1254. The kiln ash resulting from the incineration of the sediments (both spiked and native), without dewatering, had substantially reduced, though still significant, PCB contents. The kiln ash for the spiked wet sediment feeds contained between 96 and 177 mg/kg of Aroclor 1242, and between 32 and 84 mg/kg of Aroclor 1254. Interestingly, within the range of

TABLE III
PCB Analysis Results

Sample	PCB Concentration	
	Aroclor 1242	Aroclor 1254
Spiked sediment feed, %	3.48	1.11
Test 1:		
Kiln ash, mg/kg	133	84
Scrubber liquor, µg/L	< 1	< 0.3
Scrubber exit flue gas, µg/dscm	0.76	0.22
Test 2:		
Kiln ash, mg/kg	96	32
Scrubber liquor, µg/L	< 1	< 0.3
Scrubber exit flue gas, µg/dscm	0.54	0.21
Test 3b:		
Kiln ash, mg/kg	177	68
Scrubber liquor, µg/L	< 1	< 0.3
Scrubber exit flue gas, µg/dscm	< 0.26	< 0.09
Composite native feed, mg/kg	4,850	1,300
Test 3a:		
Kiln ash, mg/kg	57	44
Scrubber liquor, µg/L	< 1	< 0.3

the variability of the data, the higher kiln temperature tested for Tests 2 and 3 did not result in significantly lower kiln ash PCB concentrations than the lower temperature tested in Test 1. The kiln ash resulting from native sediment feed incinerated without watering also contained significant PCB levels, 57 mg/kg Aroclor 1242 and 44 mg/kg Aroclor 1254.

No scrubber liquor sample contained detectable PCB at practical quantitation limits (PQLs) of 1 µg/L for Aroclor 1242 and 0.3 µg/L for Aroclor 1254. The scrubber exit flue gas contained low, though measurable, levels of both PCB formulations in Tests 1 and 2.

Table IV summarizes the degree of PCB decontamination achieved in each test, in terms of the fraction of the amount of PCB introduced in the incinerator feed accounted for by the resulting kiln ash. As shown in the table, about 0.1% of the Aroclor 1242 and about 0.1% to 0.2% of the Aroclor-1254 fed in spiked sediments was accounted for in the kiln ash produced. The remaining 99.8 to 99.9% was removed and largely destroyed, as discussed below. Higher fractions of feed PCBs were present in the kiln ash from the native sediment test: 0.3% for Aroclor 1242 and 0.9% for Aroclor 1254.

TABLE IV

PCB Decontamination Effectiveness

Parameter	Aroclor 1242	Aroclor 1254
Test 1:		
Sediment feed		
Concentration, %	3.48	1.11
Amount fed, kg	9.87	3.15
Kiln ash		
Concentration, mg/kg	133	84
Amount discharged, g	11.3	7.1
Fraction of amount fed, %	0.11	0.22
Test 2:		
Sediment feed		
Concentration, %	3.48	1.11
Amount fed, kg	9.87	3.15
Kiln ash		
Concentration, mg/kg	96	32
Amount discharged, g	7.3	2.5
Fraction of amount fed, %	0.07	0.08
Test 3a:		
Sediment feed		
Concentration, %	0.485	0.130
Amount fed, kg	1.11	0.30
Kiln ash		
Concentration, mg/kg	57	44
Amount discharged, g	3.5	2.7
Fraction of amount fed, %	0.32	0.91
Test 3b:		
Sediment feed		
Concentration, %	3.48	1.11
Amount fed, kg	11.05	3.52
Kiln ash		
Concentration, mg/kg	177	68
Amount discharged, g	14.1	5.3
Fraction of amount fed, %	0.13	0.15

The data shown in Tables III and IV confirm that incineration under the conditions tested was not sufficient to completely decontaminate the sediments. The incineration temperatures tested, 820° to 980°C (1,500° to 1,800°F), were typical of those that have resulted in successful decontamination, as was the kiln solids residence time (0.5 hr). The New Bedford Harbor marine sediments, however, contained substantial moisture; the composite sediments tested were 64% moisture. Evidently, with such high moisture content, solids bed temperatures were not raised to levels needed for more complete PCB destruction in the residence time available.

Longer solids residence times, 1 hr in the IRF's experience, would have likely allowed more complete PCB decontamination. Further testing would be required to verify this supposition.

Table V takes the scrubber exit flue gas PCB concentrations noted in Table V and combines them with sediment feedrate and flue gas flowrate data to give the PCB DREs achieved for the tests. DRE is defined as:

$$100 \cdot (1 - \text{emission rate}/\text{feedrate})$$

As shown in the Table III, greater than the regulation-required 99.9999% PCB DRE was achieved for all three tests.

No PAH compounds analyzed for were detected in any sample at PQLs of 50 mg/kg in sediment feed, 1.3 mg/kg in kiln ash, 20 µg/L in scrubber liquor, and 6 µg/dscm in scrubber exit flue gas.

Results of the scrubber exit flue gas PCDD/PCDF measurements showed that total tetra-CDD (TCDD), penta-CDD (PeCDD), hexa-CDD (HxCDD), and hepta-CDD (HpCDD) levels were in the nominal 0.01 to 0.02 ng/dscm range for all three tests, with octa-CDD (OCDD) levels in the 0.03 to 0.06 ng/dscm range. Flue gas PCDF levels were significantly greater, ranging up to about 2.8 ng/dscm for total TCDF. The 2,3,7,8-TCDD toxicity equivalents corresponding to the isomer concentrations measured ranged from nominally 0.05 to 0.10 ng/dscm over the three tests.

Trace Metal Discharge Distributions

Two primary objectives of the test program were (1) to evaluate the fate of the contaminant trace metals cadmium, chromium, copper, and lead in the incineration treatment of the New Bedford Harbor sediments (2) and to investigate whether changes in incineration conditions affected the distribution of these metals in the incinerator discharges. Table VI summarizes the concentrations of the test metals in sediment samples and in each of the incinerator discharge streams.

The concentrations of chromium and copper in resulting kiln ashes were higher than the composite sediment feed sample for all tests and were higher for cadmium and lead for the low-kiln-temperature test (Test 1). This reflects the weight reduction in going from sediment to kiln ash during incineration. However, the cadmium and lead concentrations in kiln ash were significantly lower in the high-kiln-temperature tests (Tests 2 and 3) when compared to the Test 1 kiln ash concentrations and were also lower than the corresponding sediment feed concentrations. Flue gas cadmium and lead concentrations, both in the afterburner exit flue gas and the scrubber exit flue gas were generally higher for Tests 2 and 3 than for Test 1 as well. Both these trends are the result of the volatile behavior of these two metals. The extent of volatilization of these metals was evidently higher in Tests 2 and 3 than in Test 1, giving rise to lower kiln ash, and generally higher flue gas, concentrations of these metals for the higher temperature tests.

Table VI also notes the TCLP regulatory limit for the three TCLP metals determined. Comparing composite feed and kiln ash TCLP leachate and scrubber liquor metal concentrations to the TCLP regulatory levels shows that neither the composite sediment feed nor any test's kiln ash would be a TC hazardous waste based on leachable cadmium, chromium, or lead concentrations.

TABLE V
PCB DREs

Parameter	Test 1 (3/15/91)	Test 2 (3/19/91)	Test 3b (3/21/91)
Sediment feed:			
Sediment feedrate, kg/hr	69.5	69.5	69.3
Aroclor 1242 feedrate, g/hr	2,420	2,420	2,410
Aroclor 1254 feedrate, g/hr	773	773	771
Scrubber exit flue gas:			
Flue gas flowrate, dscm/min	33.9	32.9	30.6
Aroclor 1242 concentration, $\mu\text{g}/\text{dscm}$	0.76	0.54	< 0.26
emission rate, $\mu\text{g}/\text{hr}$	1.6	1.1	< 0.5
DRE, %	99.999936	99.999956	> 99.999980
Aroclor 1254 concentration, $\mu\text{g}/\text{dscm}$	0.22	0.21	< 0.09
emission rate, $\mu\text{g}/\text{hr}$	0.5	0.5	< 0.2
DRE, %	99.99994	99.99994	> 99.99998

TABLE VI
Trace Metals Analysis Results

Sample	Cd	Cr	Cu	Pb
Sediment feed:				
Composite, mg/kg	7.4	161	308	236
Composite TCLP leachate, mg/L	0.11	0.041	0.066	1.2
Test 1 (3/15/91):				
Kiln ash, mg/kg	9.5	376	608	277
Kiln ash TCLP leachate, mg/L	0.26	0.048	6.3	0.71
Afterburner exit flue gas, $\mu\text{g}/\text{dscm}$	42.3	219	571	1,030
Scrubber exit flue gas, $\mu\text{g}/\text{dscm}$	34.9	158	421	903
Scrubber liquor, mg/L	0.14	1.9	4.5	8.8
Test 2 (3/19/91):				
Kiln ash, mg/kg	2.7	434	828	75.6
Kiln ash TCLP leachate, mg/L	0.046	0.030	3.01	0.17
Afterburner exit flue gas, $\mu\text{g}/\text{dscm}$	77.6	136	768	1,814
Scrubber exit flue gas, $\mu\text{g}/\text{dscm}$	55.3	73.2	436	1,273
Scrubber liquor, mg/L	0.27	1.4	2.6	5.4
Test 3a (3/21/91):				
Kiln ash, mg/kg	2.3	367	785	96
Test 3b (3/21/91):				
Kiln ash, mg/kg	2.0	357	721	62
Kiln ash TCLP leachate, mg/L	0.043	0.03	3.0	0.41
Afterburner exit flue gas, $\mu\text{g}/\text{dscm}$	51.6	126	519	984
Scrubber exit flue gas, $\mu\text{g}/\text{dscm}$	79.0	83.9	750	2,020
Scrubber liquor, mg/L	0.73	1.3	3.4	5.6
TCLP regulatory level, mg/L	1.0	5.0	— ^a	5.0

^a — = Not a TCLP metal.

The scrubber liquor cadmium and chromium concentrations noted in Table VI are below the TCLP regulatory level for all three tests. In contrast, the scrubber liquor lead concentrations exceed the regulatory level for all three tests. However, the scrubber liquor metal concentrations noted in the table are for the total scrubber liquor, which contains

suspended solids. A true TCLP leachate was prepared from the three-test composite scrubber liquor that was held in a storage tank until all analyses were completed. This leachate was analyzed for lead and found to contain 4.2 mg/L, less than the TCLP regulatory level. Thus, the scrubber liquor for these tests was also not a TC hazardous waste.

The metal concentrations shown in Table VI can be combined with feed soil and discharge stream mass flowrate information to better show how the metals distribute among the discharge streams as a function of incineration condition. These distributions are summarized in Table VII. The distribution fractions in Table VII have been normalized to the total amount of each metal measured in all the discharge streams analyzed. Thus, these normalized values represent fractions that would have resulted had mass balance closure in each case been 100%. Use of distribution fractions normalized in this manner allows clearer data interpretation, because they remove variable mass balance closure as a source of test-to-test data variability.

Actual mass balance closures achieved around the conventional incineration system portion of the RKS ranged from 52% to 103% for cadmium, 72% to 79% for chromium, 71% to 86% for copper, and 38% to 66% for lead. These levels are considered good compared with past experience on achieving trace metal mass balance closures from a variety of combustion sources, including incinerators. Typical mass balance closure results from this past experience have been, at best, in the 30% to 200% range.

Several interesting observations emerge from the data in Table VII. Chromium and copper exhibited relatively nonvolatile behavior. The kiln ash discharge represented the predominant fraction of the discharged amount for these two metals; kiln ash accounted for 88% to 92% of the chromium measured in the discharges and 82% to 89% of the copper. These distributions were not affected by kiln temperature in the range tested (i.e., 824° to 985°C [1,516° to 1,805°F]).

In contrast, cadmium and lead exhibited relatively volatile behavior. At the low-kiln-temperature test (Test 1) conditions, the kiln ash accounted for 53% (lead) to 61% (cadmium) of the metals measured in the discharges. Even at this relatively low incineration temperature, a significant amount of each metal evidently vaporized in the kiln and was carried into the afterburner and downstream to augment the amount entrained in flyash carried out of the kiln.

Evident vaporization was enhanced at the high-temperature-test (Tests 2 and 3) condition. For these tests, the kiln ash accounted for significantly decreased fractions of cadmium and lead measured in the discharges, 8% to 19% for cadmium and 19% to 23% for lead. Of the metals measured and accounted for, scrubber exit flue gas and scrubber liquor fractions were higher than the kiln ash fractions at this high-temperature condition. Indeed, 36% to 42% of the cadmium discharged and 42% to 55% of the lead measured in the discharges escaped the incineration system and the venturi/packed-column scrubber.

Table VIII summarizes the apparent scrubber collection efficiencies calculated for each metal measured in the test program. In calculating apparent collection efficiency, it is assumed that the flowrate of metals at the scrubber inlet can be obtained by summing the flows in the two scrubber discharge streams: the scrubber exit flue gas and the scrubber liquor. Apparent scrubber collection efficiency is defined as scrubber liquor fraction divided by the sum of scrubber liquor fraction and scrubber exit flue gas fraction. The data in Table VIII show that, at the low-kiln-temperature test condition, apparent collection efficiencies for chromium, copper,

TABLE VII

Normalized Trace Metal Distributions

Test	1 (3/15/91)	2 (3/19/91)	3b (3/21/91)
Kiln exit temperature, °C	824	984	985
(°F)	(1,516)	(1,803)	(1,805)
Kiln exit O ₂ , %	11.2	9.0	10.0
	Apparent distribution, % of metal measured		
Cadmium	61	19	8
Kiln ash	23	42	36
Scrubber exit flue gas	16	39	56
Scrubber liquor	100	100	100
Chromium			
Kiln ash	88	92	92
Scrubber exit flue gas	4	2	2
Scrubber liquor	8	6	6
Total	100	100	100
Copper			
Kiln ash	83	89	82
Scrubber exit flue gas	6	5	10
Scrubber liquor	11	6	8
Total	100	100	100
Lead			
Kiln ash	53	23	19
Scrubber exit flue gas	17	42	55
Scrubber liquor	30	35	26
Total	100	100	100

TABLE VIII

Apparent Scrubber Collection Efficiencies

Test	1 (3/15/91)	2 (3/19/91)	3b (3/21/91)
Kiln exit temperature, °C (°F)	824 (1,516)	984 (1,803)	985 (1,805)
Kiln exit O ₂ , %	11.2	9.0	10.0
	Apparent scrubber collection efficiency, %		
Cadmium	41	48	50
Chromium	69	79	62
Copper	66	53	33
Lead	64	45	23

and lead were comparable, and in the nominal 65% to 70% range. Collection efficiency for cadmium was lower at 41%. At the high-kiln-temperature test conditions, cadmium and chromium efficiencies were relatively unchanged. Copper and lead collection efficiencies decreased.

Particulate and HCl Emissions Data

For the three tests, flue gas particulate levels at the scrubber exit ranged from 70 to 101 mg/dscm (0.03 to 0.04 grains/dscf), corrected to 7% O₂. These levels were below the 180 mg/dscm at (0.08 grains/dscf), 7% O₂, hazardous waste incinerator performance standard.

The sediments incinerated during this test program contained 0.85% chlorine. Measured HCl concentrations at the scrubber exit ranged from 0.2 to 2.4 ppm, with corresponding emission rates ranging from 0.7 to 7.2 g/hr. These emission rates were less than the hazardous waste incinerator performance standard floor of 2 kg/hr. The scrubber system HCl collection efficiencies ranged from 98.8% to 99.9% of the chlorine fed.

CONCLUSIONS

Test conclusions are as follows:

- Greater than 99.9999% DRE of the PCBs in the site sediments can be achieved in the scrubber exit flue gas, as calculated by the regulatory definition, at incineration temperatures of both 824°C (1,516°F) and 984°C (1,803°F) in a rotary kiln with an afterburner operated at 1,208°C (2,206°F). However, when sediments that had not been dewatered were incinerated at a kiln solids residence time of 0.5 hr, the treated sediments (kiln ash) were still PCB-contaminated. In tests with a PCB-spiked sediment feed, the kiln ash discharge accounted for between 0.08% to 0.14% of the PCB fed regardless of kiln temperature. For a native (unspiked) sediment feed, the kiln ash accounted for 0.44% of the PCBs feed.
- Of the contaminant trace metals, chromium and copper were relatively nonvolatile. The kiln ash dis-

charge accounted for nominally 80% to 90% of the measured discharged amounts of these metals. These fractions were not affected by the range of kiln temperatures tested.

- Of the contaminant trace metals, cadmium and lead exhibited relatively volatile behavior, and increasingly so at the high kiln exit gas temperature (984°C [1,803°F]). The kiln ash discharge contained 53% of the lead and 61% of the cadmium accounted for in the discharges at the low kiln temperature (824°C [1,516°F]). These fractions decreased to the nominal 10% to 20% range for cadmium and the 20% range for lead at the high kiln temperature. Scrubber exit flue gas fractions (cadmium and lead) and scrubber liquor fractions (cadmium) increased accordingly. Mass balance closures achieved were 52% to 62% for cadmium in two of the three tests performed, and ranged from 38% to 66% for lead over the three tests.
- Based on recovered scrubber liquor and scrubber exit flue gas concentrations, apparent scrubber collection efficiencies were in the nominal 65% to 70% range for chromium, copper, and lead at the low kiln temperature, and lower, at 41%, for cadmium. Cadmium and chromium collection efficiencies were apparently unaffected by increased kiln temperature, although copper and lead collection efficiency decreased to the 33% to 53% range for copper and the 23% to 45% range for lead.
- Neither treated sediments nor the scrubber liquor discharges would exhibit the TC based on their cadmium, chromium, or lead concentrations.

The test results suggest that incineration would be an effective treatment option for the site sediments. However, sediment dewatering before incineration, or incinerating at higher kiln solids residence times (perhaps up to 1 hr), might be required to yield a treated sediment not contaminated by PCBs.