



## Project Summary

# The Fate of Trace Metals in a Rotary Kiln Incinerator with a Venturi/Packed Column Scrubber

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A 5-week series of pilot-scale incineration tests, employing a synthetic waste feed, was performed at the U.S. Environmental Protection Agency's (EPA) Incineration Research Facility (IRF) to evaluate the fate of trace metals fed to a rotary kiln incinerator equipped with a venturi scrubber/packed column scrubber. Eight tests studied the fate of five hazardous constituent and four nonhazardous constituent trace metals as a function of incinerator operating temperatures and feed chlorine content. Three tests evaluated the valence state of chromium in emissions and discharges as a function of feed valence state and chlorine content.

Chromium test results indicated that, when no chlorine was present in the feed, 95% of the measured chromium was discharged in the kiln ash, 1% to 2% in the scrubber exit flue gas, and 3% in the scrubber liquor. With chlorine in the feed, these fractions were 85%, 4%, and 11%, respectively. Kiln ash contained negligible hexavalent chromium Cr(+6) for all tests. Scrubber exit flue gas Cr(+6) as a fraction of total chromium was nominally 15% with no feed chlorine, increasing to 50% with chlorine-containing feed. The scrubber liquor Cr(+6) fraction was 20% to 30% with Cr(+3) feed, increasing to about 60% with Cr(+6) feed.

Parametric trace metal test results confirmed that cadmium, lead, and bismuth are relatively volatile, based on normalized discharge distribution data. Less than 32% of these metals were discharged in the kiln ash. Barium, cop-

per, strontium, chromium, and magnesium are relatively nonvolatile; more than 75% of the amounts discharged were present in kiln ash. Surprisingly, arsenic was found to be relatively nonvolatile. Apparent scrubber collection efficiencies generally correlated with observed volatilities and were 36% to 45% for volatile metals. Except for copper, nonvolatile metals were collected at 49% to 88% efficiency. Increased feed chlorine significantly increased the volatility of cadmium, lead, and bismuth. It also shifted the afterburner exit particulate to smaller size distributions.

The average mass balance closures around the kiln ash/scrubber discharges ranged from 48% to 96% for individual metals. Overall average closure was 71%. From past experience, trace metal mass balance closure results for combustion sources are typically in the 30% to 200% range.

*This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).*

### Introduction

The RCRA hazardous waste incinerator performance standards promulgated by EPA in January 1981 established particulate and HCl emission limits and mandated 99.99% destruction removal efficiency for principal organic hazardous constituents (POHCs). Subsequent risk assessments have suggested that, of the total risk to human health



and the environment from otherwise properly operated incinerators, hazardous constituent trace metal emissions may pose the largest component. Currently, the data base available to support regulations on trace metal emissions from incinerators is very sparse.

In response to these data needs, an extensive series of tests was conducted at EPA's IRF, with funding support from the Office of Solid Waste (OSW), to investigate the fate of trace metals fed to a rotary kiln incinerator equipped with a venturi/packed column scrubber for particulate and acid gas control.

A primary objective was to investigate the fate of five hazardous constituent trace metals fed in a synthetic solid waste matrix, as a function of incinerator operating temperatures and feed chlorine content. These five metals were arsenic, barium, cadmium, chromium, and lead.

As part of the EPA Risk Reduction Engineering Laboratory's program to support the development of regulations concerning trace metal emissions, a separate OSW-sponsored effort by another EPA contractor is developing a numerical model to aid in predicting the relative distribution of trace metals in incinerator discharges. Thus, a second objective was to supply data to evaluate the predictive capabilities of this model and perhaps to guide further model refinement. To support this objective, the tests also included four nonhazardous constituent trace metals: bismuth, copper, magnesium, and strontium.

In the absence of information on the predominant valence state of chromium in incinerator discharges, risk assessments have generally assumed that the entire discharge is in the more toxic hexavalent form. This assumption has resulted in specifying conservative chromium emission limits in the regulatory process. Hence, another objective of this program was to develop data on the valence state of chromium discharges as a function of chlorine and chromium valence state in the feed.

## Test Program

The test program consisted of both an eight-test, parametric, trace metals series (Tests 4 through 11, in which the test waste feed contained nine metals), and a three-test chromium valence state series (Tests 1, 2, and 3, in which the feed contained either Cr(+3) or Cr(+6)). All tests were performed in the rotary kiln incinerator system (RKS) at the IRF.

Figure 1 illustrates a simplified RKS schematic, and Table 1 summarizes its design characteristics. The system consists of a rotary kiln chamber, a transition section,

and a fired afterburner chamber. The primary air pollution control system (APCS) consists of a quench section, a venturi scrubber, and a packed column scrubber. In addition, a backup APCS, consisting of a carbon-bed adsorber and a high efficiency particulate (HEPA) filter, was in place to ensure that organic compound and particulate emissions were negligible during less-than-optimal test conditions.

## Synthetic Test Mixture

The synthetic waste fired during the test program was composed of a clay absorbent containing 30% (weight) organic liquids. Trace metals, in aqueous solution form, were metered onto the solid, which was fed to the rotary kiln via a screw feeder.

Table 2 lists the metal concentrations of the synthetic feed waste for each test. Chromium inherent in the clay contributed about 50% of the actual feed chromium. Magnesium in the clay accounted for virtually all of the actual feed magnesium.

The organic liquid, a mixture of toluene and varying amounts of tetrachloroethylene and chlorobenzene, supplied the heat content and POHC. It also introduced chlorine at levels ranging from zero to nominally 8% by weight. The analyzed fractions of these organics are listed in Table 3.

## Test Conditions

For all tests, the clay/organic liquid was fed at about 63 kg/hr (140 lb/hr). The aqueous metal solution was injected at 1 L/hr. Estimated solids residence time in the kiln was 1 hr. The test variables for the parametric tests were feed chlorine content (0%, 4%, and 8%), kiln temperature (816°, 871°, and 927°C), and afterburner temperature (982°, 1093°, and 1204°C). The three levels for these variables constituted a factorial experimental matrix.

For the three chromium tests, chromium valence state and chlorine content of the waste feed were varied. Two tests had trivalent chromium feed. One of these had no chlorine and the other had nominally 8% chlorine in the feed. The third test had hexavalent chromium and no chlorine in the feed. Incinerator operating conditions during these tests were held constant: kiln temperature at about 870°C and afterburner temperature at about 1093°C.

For all tests, excess air was targeted at 11.5% oxygen in the kiln and 7.5% oxygen in the afterburner exit flue gas. These were successfully maintained within  $\pm 1.5\%$  for all tests. Figure 2 illustrates the actual and target incinerator temperatures. For all tests, the primary APCS operated at design conditions, with venturi pressure drop at 5.0 to

6.2 kPa (20" to 25" W.C.) and scrubber pH averaging 7.1.

## Sampling and Analysis

Continuous emission monitors were arranged to monitor O<sub>2</sub>, CO, CO<sub>2</sub>, NO<sub>x</sub>, and total unburned hydrocarbon (TUHC) concentrations at the kiln exit, the afterburner exit, the scrubber exit, and the stack. Other samples collected were feed, scrubber blowdown water, kiln ash, and flue gas at the afterburner and scrubber exits. Samples were also collected at the stack for evaluating hazardous waste management permit compliance. Since the target analytes differed for the two test series, the sampling and analysis matrix was tailored specifically for each series.

For the parametric trace metal tests, composite feed samples were subjected to ultimate, volatile organic, and trace metal analyses. Virgin clay samples were subjected to trace metal analyses to determine background metal concentrations. Composite kiln ash samples were collected and analyzed for metals.

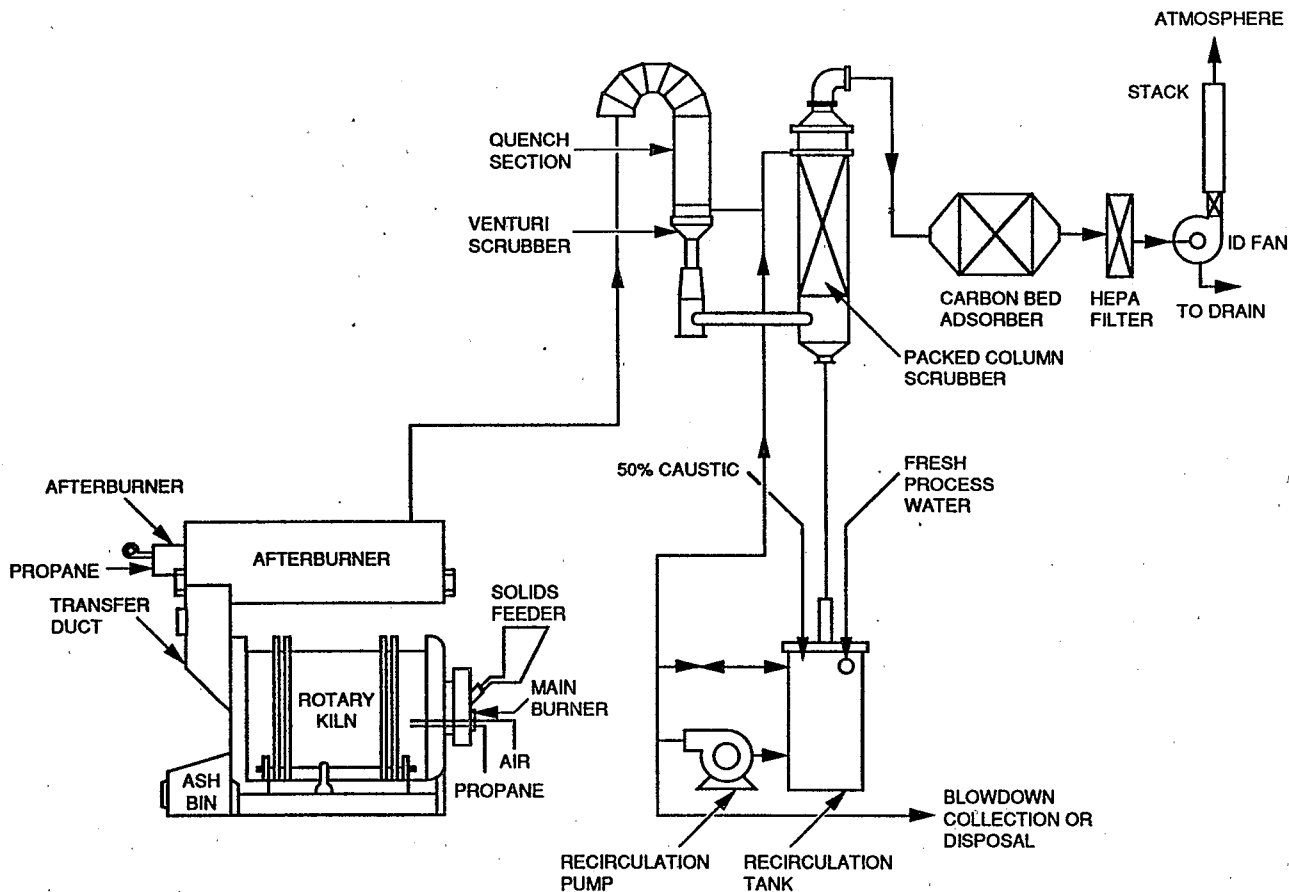
Flue gas sampling at the afterburner exit consisted of volatile organic sampling train (VOST) sampling and a variation of a Reference Method 17\* train that allowed collection of large particulate mass, HCl, and any vapor phase metals. At the scrubber exit, a VOST train collected samples for volatile organic analyses and a Method 5\* train modified for vapor phase metal capture collected samples for metal analyses. At the stack, a Method 5 train sampled for HCl and particulate for permit compliance.

For the chromium-valence tests, composite feed samples were subjected to ultimate, volatile organic, and total chromium analyses. Composite grab samples of chromium spike solution, scrubber blowdown, and kiln ash were collected during each test for total chromium and Cr(+6) analyses.

Flue-gas sampling employed two variations of a Method 5 train. At the afterburner exit, one train with impingers containing 0.1N NaOH followed by HNO<sub>3</sub>/H<sub>2</sub>O<sub>2</sub> sampled for particulate load and total chromium. Simultaneously, a second train with the filter removed sampled for Cr(+6) and, during test 3, for HCl. Impingers in this train contained 0.1N NaOH which was believed to be better able to preserve Cr(+6). A similar arrangement was duplicated at the scrubber exit.

The VOST samples were subjected to purge and trap GC/FID for organic analysis. The grab composite samples of feed, ash,

\* 40 CFR, Part 60, Appendix A, July 1, 1989.



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Figure 1. Schematic of the IRF rotary kiln system.

scrubber liquor, and the Method 5 and Method 17 train samples were subjected to inductively coupled argon plasma spectroscopy or atomic absorption spectroscopy methods for metal analysis.

## Test Results

### Trace Metal Discharge Distributions

When subjected to incineration conditions, the metals are expected to vaporize to varying degrees, depending on their volatilities. Figure 3 shows the amounts of metal found in each discharge stream, normalized to the total found in the three discharge streams: kiln ash, scrubber exit flue gas, and scrubber liquor. In Figure 3, the bar for each metal represents the range in the fraction accounted for by each discharge stream over all eight parametric tests, with the average fraction from all tests noted by the midrange tick mark. Metal discharge distribution data in Figure 3 are plotted versus the metal's "volatility" temperature. A metal's volatility temperature is the tem-

perature at which a principal vapor species of the metal has a vapor pressure of  $10^{-6}$  atm. Figure 3 shows that the more volatile metals, i.e., those having lower volatility temperatures (Cd, Bi, and Pb), tend to be less prevalent in the kiln ash. The more refractory metals, i.e., those with higher volatility temperatures (Ba, Cu, Sr, Cr, and Mg) tend to be found predominantly in the kiln ash. This observation is consistent with expectation.

The notable exception, arsenic, exhibited unexpected refractory behavior and remained predominantly in the kiln ash. Arsenic's plotted volatility temperature is that for  $As_2O_3$ . The fact that arsenic was observed to be significantly less volatile than expected, based on the  $As_2O_3$  volatility temperature, suggests that  $As_2O_3$  was not a predominant arsenic species in the incinerator and that some other, less volatile species (perhaps an arsenate) was the favored arsenic compound. An alternative explanation is that strong chemical interaction occurred between arsenic and the clay feed matrix.

It is interesting to note the sharp break in observed volatility between lead and bismuth (average kiln ash fractions of 20% to 32%) and barium (average kiln ash fraction of 77%). Six of the eight parametric tests were performed with kiln temperature of 870°C, one at 825°C, and one at 930°C. These temperatures are right in the range of the volatility temperature change from 621°C (Bi) and 627°C (Pb) to 849°C (Ba).

### Metal Distributions in Scrubber System

The above observations suggest that substantial portions of the volatile metals escaped the incinerator. For effective control, these need to be captured by the venturi and packed column scrubber system. Figure 4 shows that this may not be the case. The apparent scrubber collection efficiency averaged only 36% to 45% for the volatile metals (Cd, Bi, and Pb). Collection efficiencies for the most refractory metals (Sr, Mg, and Cr) averaged greater than 65%. This behavior is consistent with ex-

**Table 1. Design Characteristics of the IRF Rotary Kiln System:**

Characteristics of the Kiln Main Chamber	
Length, outside	2.61 m (8 ft 7 in)
Diameter, outside	1.22 m (4 ft)
Length, inside	2.13 m (7 ft)
Diameter, inside	0.95 m (3 ft 1-1/2 in)
Chamber volume	1.74 m <sup>3</sup> (61.36 ft <sup>3</sup> )
Construction	0.63 cm (0.25 in) thick cold rolled steel
Refractory	12.7 cm (5 in) thick high alumina castable refractory, variable depth to produce a frustraconical effect for moving solids
Rotation	Clockwise or counterclockwise 0.2 to 1.5 rpm
Solids retention time	1 hr (at 0.2 rpm)
Burner	American Combustion Burner, rated at 880 kW (3.0 MMBtu/hr) with dynamic O <sub>2</sub> enhancement capability
Primary fuel	Propane
Feed system	
Liquids	Positive displacement pump via water-cooled lance
Sludges	Moyno pump via front face, water-cooled lance
Solids	Metered twin-auger screw feeder or fiber pack ram feeder
Temperature (max)	900 °C (1650 °C)

Characteristics of the Afterburner Chamber	
Length, outside	3.05 m (10 ft)
Diameter, outside	1.22 m (4 ft)
Length, inside	2.74 m (9 ft)
Diameter, inside	0.91 m (3 ft)
Chamber volume	1.80 m <sup>3</sup> (63.6 ft <sup>3</sup> )
Construction	0.63 cm (0.25 in) thick cold rolled steel
Refractory	15.24 cm (6 in) thick high alumina castable refractory
Gas residence time	1.2 to 2.5 sec, depending on temperature and excess air
Burner	American Combustion Burner rated at 440 kW (1.5 MMBtu/hr) with dynamic O <sub>2</sub> enhancement capability
Primary fuel	Propane
Temperature (max)	1200 °C (2200 °F)

Characteristics of the Air Pollution Control System	
System capacity	
Inlet gas flow	107 m <sup>3</sup> /min (3773 acfm) at 1200 °C (2200 °F) and 101 kPa (14.7 psia)
Pressure drop	
Venturi scrubber	7.5 kPa (30 in WC)
Packed column	1.0 kPa (4 in WC)
Liquid flow	
Venturi scrubber	77.2 L/min (20.4 gpm) at 69 kPa (10 psig)
Packed column	116 L/min (30.6 gpm) at 69 kPa (10 psig)
pH control	Feedback control by NaOH solution addition

**Table 2. Integrated Feed Metal Concentrations for the Parametric Trace Metals Test Series**

Metal	Metal Concentration (ppm)											
	Indigenous (in clay)	Test 1 (9/29/89)	Test 2 (9/28/89)	Test 3 (9/26/89)	Test 4 (9/14/88)	Test 5 (8/25/88)	Test 6 (9/16/88)	Test 7 (8/30/88)	Test 8 (9/7/88)	Test 9 (9/9/88)	Test 10 (9/20/88)	Test 11 (9/22/88)
Arsenic					25	23	23	24	19	19	32	33
Barium					36	33	33	39	36	36	36	37
Bismuth	12				98	75	95	84	85	99	110	120
Cadmium					5	4	4	5	4	4	6	5
Chromium (total) (+6)	53	79	84	85	68	64	61	68	66	66	66	67
		41	1.6	1.6								
Copper					260	230	240	310	260	260	270	310
Lead	3				33	26	26	34	28	28	33	32
Magnesium	22,000				17,700	17,700	16,700	17,000	17,700	17,900	16,100	16,500
Strontium	34				190	140	140	170	150	160	200	200

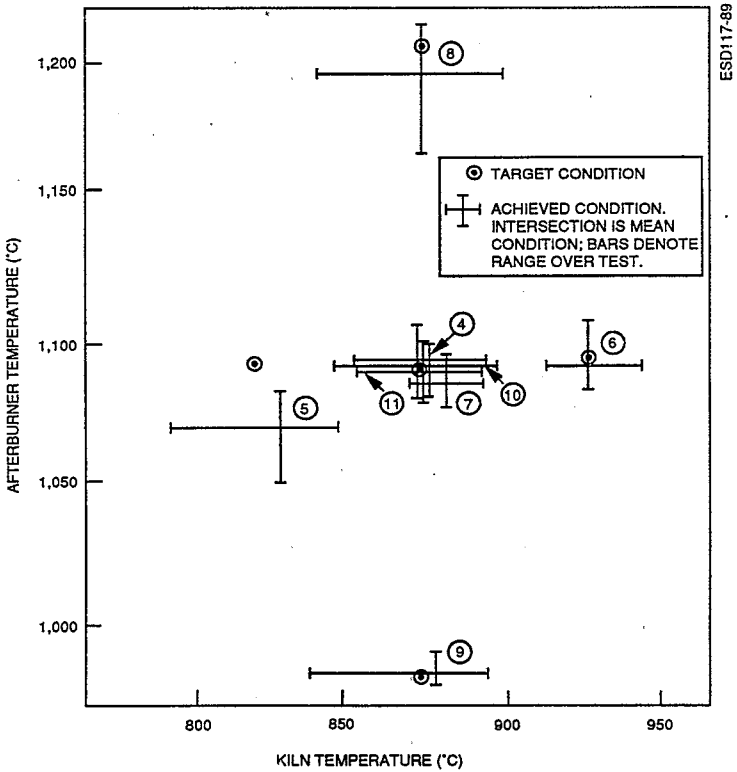
Most metal vaporized at some point in the incinerator will ultimately condense when the flue gas is cooled to its scrubber exit temperature of about 75°C. Condensation occurs via fume formation or condensation onto available flue gas particulate. Fume formation results in very fine particulate. Condensation onto available particulate results in concentrating the metal in fine particulate, since condensation is a per unit of surface area event and the surface-area-to-mass ratio is increased in fine particulate. Both mechanisms tend to concentrate volatilized metal in fine particulate. Since venturi scrubbers collect coarse particulate more efficiently than they do fine particulate, a poorer efficiency in collecting volatile metals is expected.

This same mechanism may explain the poor collection efficiency observed for arsenic and, perhaps, copper. The above discussion noted that arsenic was observed to be relatively refractory based on its high kiln ash fraction. However, any amount of arsenic carried in entrained flyash out of the kiln and into the afterburner would experience the higher afterburner temperatures (980° to 1200°C in tests performed). Thus, further opportunity to volatilize in the afterburner exists. If the predominant arsenic species had a volatility temperature above test kiln temperature (825° to 930°C) but below afterburner temperature, then volatilization in the afterburner may have occurred, leading to the poor scrubber collection efficiency for the small amount of arsenic carried into the afterburner. Similarly, entrained copper (volatility temperatures of 1116°C) may have volatilized in the afterburner, leading to the poor scrubber collection efficiency that was observed. If this were the case, the good collection efficiencies for barium could remain unexplained, however.

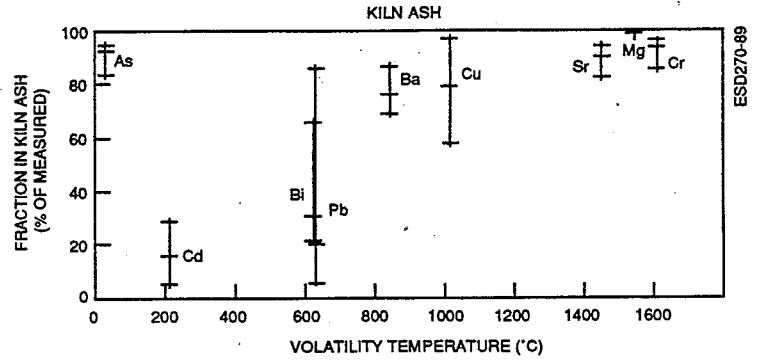
**Table 3. POHC Concentrations in Clay/Organic Liquid Feed**

Test	Test Date	Weight % in mixture			
		Toluene	Tetrachloro-ethylene	Chloro-benzene	Chlorine Content*
<b>Mixture 1</b>					
Target Composition		28.6	0	0	0
<b>Measured Composition</b>					
1	9/29/88	27.9	0	0	0
2	9/28/88	27.9	0	0	0
4	9/14/88	23.2	0	0	0
<b>Mixture 2</b>					
Target Composition		21.7	3.4	3.4	4
<b>Measured Composition</b>					
5	8/25/88	16.7	3.0	3.6	3.7
6	9/16/88	20.5	3.6	3.5	4.2
7	8/30/88	19.7	3.2	3.2	3.8
8	9/07/88	17.1	3.1	3.0	3.6
9	9/09/88	16.5	2.9	2.9	3.4
10	9/20/88	22.5	3.9	3.8	4.6
<b>Mixture 3</b>					
Target Composition		14.9	6.9	6.9	8
<b>Measured Composition</b>					
3	9/26/88	15.9	7.5	6.7	8.5
11	9/22/88	14.6	7.1	6.9	8.3

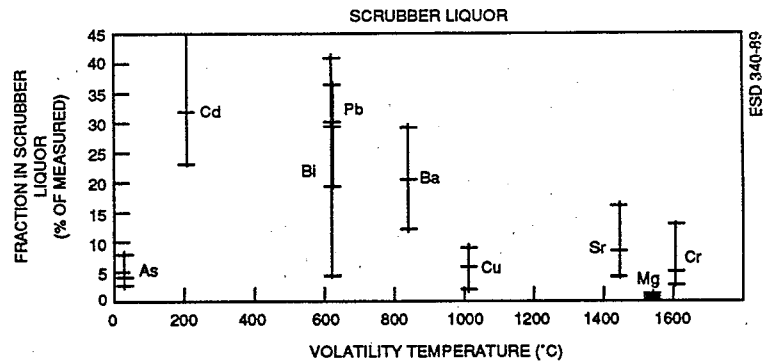
\*Based on measured tetrachloroethylene and chlorobenzene concentrations.



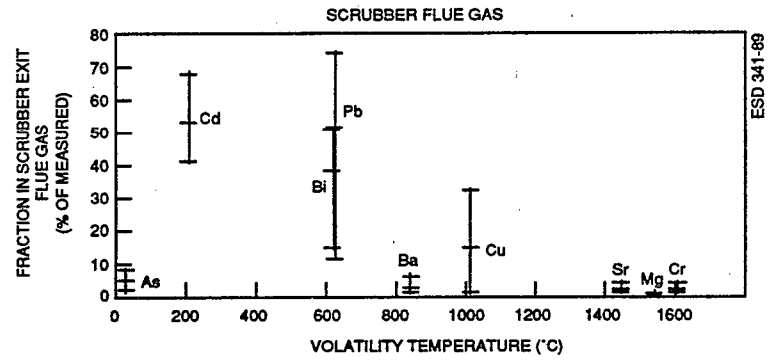
**Figure 2. Actual versus target operating temperatures for parametric trace metal tests.**



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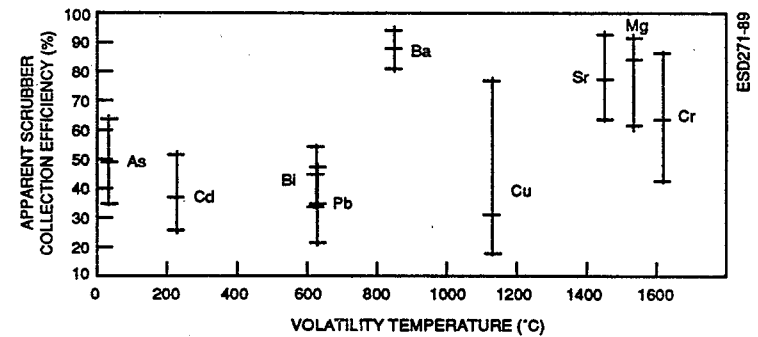


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**Figure 3. Distribution of metals in discharge streams.**



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**Figure 4. Apparent venturi/packed column scrubber efficiencies for trace metals.**

## Effect of Inclinerator Operating Conditions

Within the tested range, kiln temperature had a minor effect on the discharge distributions of arsenic, cadmium, and lead. Of the three metals, the effect was most pronounced, though still minor, for cadmium.

Within the tested range, afterburner temperature had little or no effect on discharge distributions of the nonvolatile metals. Increasing afterburner temperature caused a slightly increased fraction of the three volatile metals (cadmium, lead, and bismuth) in the flue gas and a corresponding decreased fraction in the scrubber liquor. The most pronounced effect was for lead.

Varying the chlorine in the waste had little to no effect on the distribution of arsenic, barium, chromium, strontium, or magnesium. However, the increase in volatility for the volatile metals cadmium, bismuth, and lead, in addition to that for copper, was substantial. The most pronounced effect was for lead. This observation is consistent with expectations since metal chlorides (possible with chlorine in the feed) are typically more volatile than are the base metal or metal oxides. This is especially the case for lead. With no chlorine present, lead metal is the most volatile lead species, with a volatility temperature of 627°C. With chlorine present, the formation of the significantly more volatile  $PbCl_2$ , with a volatility temperature of -15°C, is possible.

### Particle Size Distribution

Figure 5 shows that the afterburner exit particle size distributions for all tests were roughly log normal. The absence of chlorine in the waste appears to shift the particles to a larger size distribution. This is consistent with the expectation that presence of chlorine increases the volatility of the inorganic constituents in the feed. In such a case, condensation of volatilized inorganic compounds would tend to produce finer particles.

### Metal Particle Size Distribution

Trace metal contents in four size fractions in afterburner exit particulate (nominally <2, 2 to 4, 4 to 10, and >10  $\mu m$ ) were analyzed. Figure 6a shows the average fractions of arsenic, barium, cadmium, chromium, and lead that were distributed over the four size ranges. Similar results for the four nonhazardous constituent metals (bismuth, copper, magnesium, and strontium) are shown in Figure 6b.

It appears that the more volatile metals bismuth and barium tend to concentrate on

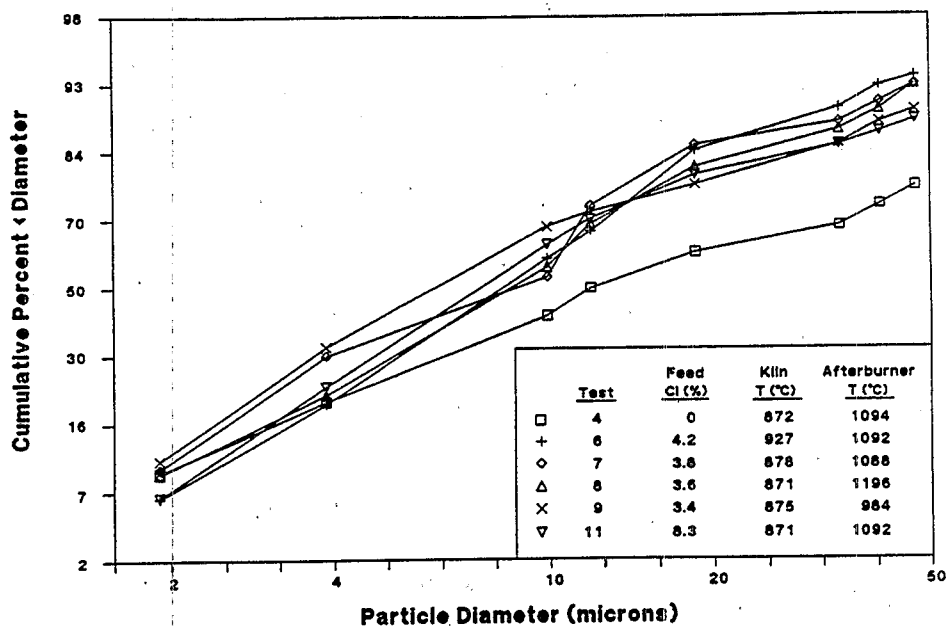


Figure 5. Afterburner exit flue gas size distributions for the parametric trace metal tests.

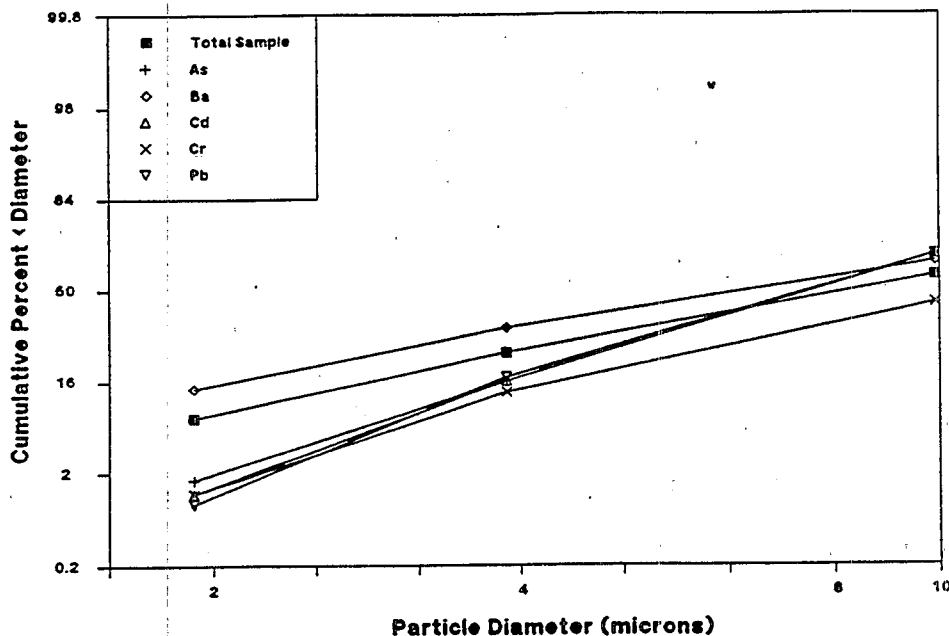


Figure 6a. Hazardous constituent trace metal size distributions in afterburner exit flue gas particulate for the parametric trace metal tests.

the finer particles. The relatively nonvolatile metals chromium, copper, magnesium, and strontium tend to concentrate on the larger particles. This observation is consistent with the volatilization/concentration mechanism discussed previously.

### Chromium Valence State Distributions

Chromium discharge distributions for the focused chromium valence state tests, ex-

pressed as fractions of total measured chromium, are tabulated in Table 4. In these tests as well, chromium clearly remained predominantly in the kiln ash (greater than 80% of total). The scrubber exit flue gas and blowdown liquor streams combined accounted for less than 5% of the discharged chromium with no feed chlorine. With chlorine in the feed, the flue gas chromium fraction doubled to about 4%. Similarly, the scrubber blowdown liquor chromium fraction increased to about 11%.

Table 5 summarizes the fraction of the total chromium in feed and discharge streams analyzed as being Cr(+6). As shown, the feed was 52% Cr(+6) for the test with Cr(+6) spiked into the feed and was analyzed as 2% Cr(+6) for the tests with Cr(+3) spiked into the feed. For all tests, the kiln ash chromium was composed of negligible amounts of Cr(+6).

With no chlorine in the feed, the scrubber exit flue gas Cr(+6) fraction was the same (12% to 16%) regardless of whether Cr(+6) was present in the feed. In contrast, when the feed contained chlorine, roughly half the scrubber exit flue gas chromium was Cr(+6). This would be expected if some of the entrained particulate chromium from the kiln vaporized in the hotter afterburner and reacted with the flue gas chlorine to form chromyl chloride ( $\text{CrO}_2\text{Cl}_2$ ), a relatively stable compound with chromium as Cr(+6).

The scrubber liquor Cr(+6) fraction for the test with Cr(+6) in the feed was significantly higher than for the other two tests with only Cr(+3) in the feed. This is as expected if some of the chromium in the scrubber inlet flue gas was present as soluble Cr(+6) species ( $\text{CrO}_4^{2-}$  and  $\text{Cr}_2\text{O}_7^{2-}$ ).

## Conclusions

- The observed metal volatilities, based upon normalized discharge distribution data, generally agreed with theoretical predictions based on volatility temperature. A notable exception was arsenic, which is theoretically the most volatile metal; it exhibited one of the lowest observed volatilities.
- Cadmium, bismuth, and lead were relatively volatile, with an average of less than 32% of the discharge metal accounted for by the kiln ash. Barium, copper, strontium, chromium, magnesium, and arsenic were more refractory, with greater than 75% of the metal discharge accounted for by the kiln ash.
- Apparent venturi/packed column scrubber collection efficiencies decreased as metal volatility increased.

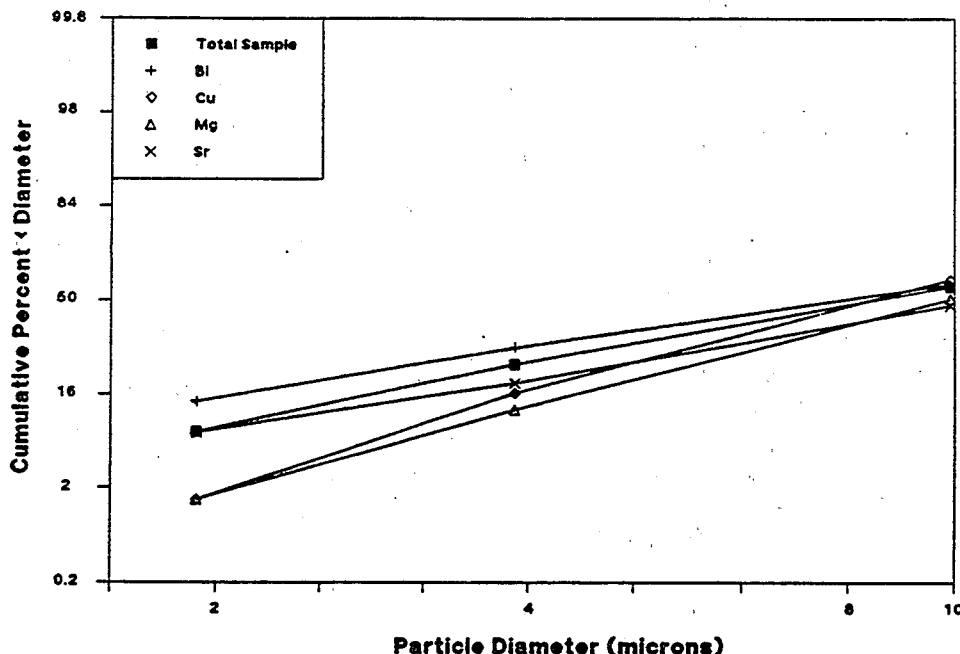


Figure 6b. Nonhazardous trace metal size distributions in afterburner exit flue gas particulate for the parametric trace metal tests.

Table 4. Total Chromium Discharge Distributions for the Chromium Valence State Test Series

	Total Cr Fraction (% of measured)		
	Test 1 Cr(+6) feed, no Cl	Test 2 Cr(+3) feed, no Cl	Test 3 Cr(+3) feed, 8.5% feed Cl
Kiln ash	95.5	95.2	84.4
Scrubber exit flue gas	1.3	1.8	4.2
Scrubber liquor	3.2	3.0	11.4
Total	100.0	100.0	100.0
Apparent scrubber Cr removal efficiency	71	63	73

Table 5. Hexavalent Chromium Fractions for the Chromium Valence State Test Series

	Cr(+6)/total Cr(%)		
	Test 1 Cr(+6) feed, no Cl	Test 2 Cr(+3) feed, no Cl	Test 3 Cr(+3) feed, 8.5% feed Cl
Composite feed	52	2	2
Kiln ash	0.3	0.2	0.1
Scrubber exit flue gas	12	16	48
Scrubber liquor	57	21	28

- Increasing feed chlorine content measurably increased the volatility of the volatile metals (cadmium, lead, and bismuth) and of copper (less volatile).
- Consistent with expectation, increasing kiln temperature tended to slightly decrease the fraction of volatile metal accounted for by the kiln ash.
- Discharge distributions of the non-volatile metals were generally unaf-

ected by variations in the test variables over the range tested.

- Particle size distributions for the afterburner exit flue gas were roughly log-normal; the presence of chlorine appeared to shift the particles to a finer distribution.
- In the scrubber exit flue gas, chromium existed predominantly in the trivalent form regardless of valence state in the feed, provided the feed contained no

chlorine; its hexavalent fraction increased in the test where chlorine was present in the feed.

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*The complete report, consists of two volumes entitled "The Fate of Trace Metals in a Rotary Kiln Incinerator with a Venturi/Packed Column Scrubber:"*

*Volume I (Order No. PB90-263864 /AS; Cost: \$23.00 subject to change) discusses the results of the technical data.*

*Volume II Order No. PB90-263872/AS; Cost: \$31.00 subject to change) consists of the appendices.*

*Both volumes of this report will be available only from:*

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*The EPA Project Officer can be contacted at:*

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