OPERATIONS AND RESEARCH AT THE U.S. EPA INCINERATION RESEARCH FACILITY: ANNUAL REPORT FOR FY93

By

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatibie balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This document reviews the accomplishments at the Incineration Research Facility (IRF) in Jefferson, Arkansas, during Fiscal Year 1993. In the 12-month period, two major test programs were completed at the facility. The major EPA program supported through test activities was the Superfund site remediation program within the Office of Emergency and Remedial Response (OERR) as administered by OERR and EPA Region 3. In addition, a third major test program was completed in support of the Department of Energy's efforts to install and permit a mixed-waste incineration system at the Savannah River Plant. The report outlines all efforts completed or ongoing at the facility during FY93.

ABSTRACT

The U.S. Environmental Protection Agency's Incineration Research Facility (IRF) in Jefferson, Arkansas, is an experimental facility that houses a pilot-scale rotary kiln incineration system (RKS) and the associated waste handling, emission control, process control, and safety equipment; as well as onsite laboratory facilities.

During fiscal year 1993, two major test programs were completed at the IRF: an evaluation of rotary kiln incinerator operation at low to moderate temperatures, and a series of tests in which simulated mixed wastes were incinerated to support the Westinghouse Savannah River Company.

Results of a pilot-scale test program previously completed, a parametric evaluation of the fate of trace metals fed to a rotary kiln incinerator equipped with a Calvert Flux-Force/ Condensation scrubber system, were reported during FY93.

Detailed plans were developed for four test programs to be completed in FY94: an evaluation of the incinerability of waste and contaminated soil from the M. W. Manufacturing Superfund site; an evaluation of a pulse combustion burner technology under the Superfund Innovative Technology Evaluation (SITE) program; a program demonstrating that U.S. and Russian Federation environmental regulations can be complied with during the incineration of liquid ballistic missile propellant components; and an evaluation of candidate additives as trace metal sorbents for incineration applications.

Finally, a fabric filter air pollution control system, including flue gas reheat, was incorporated into the RKS.

This report summarizes all efforts completed or ongoing at the IRF during FY93.

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SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) Incineration Research Facility (IRF) in Jefferson, Arkansas, is an experimental facility that currently houses a pilot-scale rotary kiln incineration system (RKS) and its associated waste handling, emission control, process control, and safety equipment, and a bench-scale thermal treatment unit (TTU) for performing thermal treatability studies on a smaller scale. The IRF also has onsite laboratory facilities for waste characterization and analysis of process performance samples.

The objective of research projects conducted at the IRF have been and continue to be as follows:

- To develop technical information on the performance capabilities of the hazardous waste incineration process to assist EPA Regional Offices and state environmental agencies in the review, assessment, and issuance of reasonable and responsible permits for regulated hazardous waste incineration facilities, and to assist waste generators and incinerator operators in the preparation of permit applications

- To develop incinerator system performance data for regulated hazardous wastes to support current Resource Conservation and Recovery Act (RCRA) incinerator regulations and performance standards, and to provide a sound technical basis for any necessary future standards

- To promote an understanding of the hazardous waste incineration process and develop methods to predict the performance of incinerators of varying scale and design for the major classes of incinerable hazardous wastes as a function of key process operating variables

- To develop methods of improving reliability and control of the incineration process, including the use of destruction and removal efficiency (DRE) surrogates

- To provide a means of conducting specialized test burns (particularly for high-hazard and special waste materials such as Superfund site wastes) in support of specific Regional Office permitting or enforcement actions and Regional Office or private party Superfund site remediation efforts

- To test the performance of new and advanced incinerator components and subsystems, and emission control devices

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Fiscal year 1993 (FY93, October 1, 1992 through September 30, 1993) saw the continuation of routine incineration testing efforts at the IRF. During the year, two major programs were completed and plans for an additional four test programs developed.

The major EPA program supported through test activities in FY93 was the Superfund site remediation program with the Office of Emergency and Remedial Response (OERR). A major test program to evaluate rotary kiln incinerator operation at low to moderate temperatures in decontaminating soils contaminated with organic constituents was completed.

FY93 also saw the initiation, completion, and reporting of the first major test program funded by a source other than EPA. This program, a series of tests feeding simulated mixed waste, was performed for the Westinghouse Savannah River Company (WSRC), the operating contractor for the Department of Energy (DOE) Savannah River Plant and Savannah River Laboratory.

In addition, the results of a major series of tests to evaluate the fate of trace metals fed to a rotary kiln incinerator equipped with a Calvert Flux-Force/Condensation scrubber system, completed in FY91, but with significant analytical effort extending through FY92, were assembled and reported in FY93. The test planning documents (test plan outline, test plan, and/or Quality Assurance Project Plan) for three major series of incineration tests and one series of tests in the thermal treatment unit (TTU), all to be performed in FY94, were completed.

Finally, a major enhancement to facility capabilities was completed in FY93. Specifically, a flue gas reheat and fabric filter air pollution control system (APCS) was installed for use on the RKS.

Activities completed during FY93 are discussed in more detail in the following sections. Section 2 discusses the results of the Calvert scrubber trace metal tests. Section 3 discusses the low to moderate temperature kiln operation tests. Section 4 discusses the results of the WSRC simulated mixed waste tests. Section 5 discusses the detailed test plan for the RKS test program to evaluate the incinerability of fluff waste and contaminated soil from the M. W. Manufacturing Superfund site in Danville, Pennsylvania. Section 6 covers the upcoming Superfund Innovative Technology Evaluation (SITE) of a pulse combustion burner technology. Section 7 discusses the upcoming program to demonstrate that U.S. and Russian Federation environmental regulations can be complied with during the incineration of liquid ballistic missile propellant components. Section 8 outlines the detailed plans for a series of tests in the TTU at the facility to evaluate the effectiveness of candidate additives as trace metal sorbents. Section 9 discusses the fabric filter APCS installed on the RKS. Section 10 discusses external communication activities associated with the facility and its operation. Finally, Section 11 presents an outline of plans for activities to be completed in FY94 other than those discussed in Sections 5 through 8.

SECTION 2

FATE OF TRACE METALS IN THE ROTARY KILN INCINERATION SYSTEM
WITH A CALVERT FLUX-FORCE/CONDENSATION SCRUBBER

During FY88, a research program to develop data on the partitioning of trace metals among the discharges from hazardous waste incinerators was initiated at the IRF. Over the succeeding 4 years, three series of parametric tests were performed to quantify the distribution of trace metals among the discharge streams of the IRF RKS, and to assess the effects of system operation and feed composition on these distributions. Although certain details of the test program design differed from series to series, the major differences between the test series were the primary APCSs used for particulate and acid gas control. In the first series, completed in FY88, a venturi scrubber/packed-column scrubber was used as the primary APCS.[1] In the second series, completed in FY89, a single stage ionizing wet scrubber was used.[2]

The third series of parametric trace metal partitioning tests investigated the use of a Calvert Flux-Force/Condensation scrubber system for air pollution control. This series of tests was completed during FY91. However, the trace metal analyses of the extensive number of test program samples collected were not completely reported until mid-FY92. In addition, initial evaluation of the original trace metal analysis data raised several questions regarding reported concentrations. Consequently, several test program samples were reanalyzed. Reanalysis data were received near the close of FY92. Thus, detailed data evaluation and reporting became FY93 efforts; the results of these evaluations are summarized in this section.

The objectives of the third series of parametric trace metal tests were to identify:

- The partitioning of metals among the kiln ash, the scrubber liquor, and the flue gas discharges

- The effects of kiln exit gas temperature and waste feed chlorine content on metal partitioning

- The efficiency of the Calvert scrubber in collecting flue gas metals

- The effects of scrubber pressure drop on metal collection efficiencies

The test series to address these objectives consisted of 11 parametric tests. Two additional baseline tests were also performed with no metals fed to determine the extent of hysteresis in the RKS caused by test-to-test carryover of metals. Results of the test program are discussed in the subsections that follow.

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2.1   TEST PROGRAM

All tests were conducted in the IRF RKS. The RKS as it was configured for these tests is illustrated in Figure 1. Figure 2 is a schematic of the Calvert scrubber pilot plant installed on the RKS for this test program.

2.1.1   Synthetic Waste Mixture

The synthetic waste contained a mixture of organic liquids added to an attapulgite clay absorbent material.   This attapulgite clay material was comprised of hydrated magnesium aluminum silicate, free silica, dolomite, and calcite. Trace metals were incorporated by spiking an aqueous mixture of the metals of interest onto the clay/organic-liquid material as it was fed to the rotary kiln via a screw feeder.

The organic-liquid base consisted of toluene, with varying amounts of tetrachloroethene and chlorobenzene added to provide a range of chlorine contents. Synthetic waste chlorine content was varied from 0 to nominally 3.4 percent. The analyzed organic fractions for the three waste feed mixtures are given in Table 1. .Table 2 summarizes the average metal concentrations in the combined waste feed over the 11 parametric tests.

2.1.2   Test Conditions

The test variables were kiln exit gas temperature, chlorine content of the synthetic waste feed, and scrubber pressure drop. Eleven specific combinations of these variables were selected as test points. In addition, two baseline tests were conducted in which the clay/organic mixture was fed, but the metals spike solution was not. Average achieved values for the three variables for all 13 tests are summarized in Table 3. One of the baseline tests was conducted several days before the test series began to establish baseline conditions for metals present in the incineration system. The second baseline test was performed 2 days after the test series was completed. The target conditions for the two baseline tests were the same as test condition 8. .

All tests were performed at the same nominal afterburner exit flue gas O_2 (9 percent), afterburner exit gas temperature (1,093°C [2,000°F]), and synthetic waste feedrate (63.5 kg/hr [140 lb/hr]), of which 14 kg/hr (30 lb/hr) was the organic-liquid mixture. For all tests, the solids residence time in the kiln was about 1 hour. Average kiln exit flue gas O_2 concentrations ranged from 10.6 to 17.7 percent.

2.2   TEST RESULTS

2.2.1   Average Trace Metal Discharge Distributions

Figure 3 shows the amount of each test metal, except mercury, found in each discharge stream, as a fraction of the amount of metal fed. Figure 4 is a corresponding illustration of the amount of test metal found in each discharge stream as a fraction of the total measured in the three discharge streams: kiln ash, scrubber exit flue gas, and scrubber liquor. In the figures, the tick marks at each end of the vertical line for each metal represent the range in the fraction accounted for by each discharge stream over the 11 parametric tests. The average fraction over all 11 tests is noted by the midrange tick mark. Metal discharge distribution data in the figures

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ESD 159-91

ATMOSPHERE

STACK

ID FAN

DEMISTER

HEPA FILTER

CARBON BED ADSORBER

REDUNDANT AIR POLLUTION CONTROL SYSTEM

CALVERT SCRUBBER SYSTEM

ID FAN

SINGLE-STAGE IONIZING WET SCRUBBER

PACKED COLUMN SCRUBBER

SCRUBBER LIQUOR RECIRCULATION

SCRUBBER LIQUOR RECIRCULATION

VENTURI SCRUBBER

SCRUBBER LIQUOR RECIRCULATION

MODULAR PRIMARY AIR POLLUTION CONTROL DEVICES

SOLIDS FEEDER

MAIN BURNER

AIR

NATURAL GAS, LIQUID FEED

AFTERBURNER

ROTARY KILN

ASH BIN

QUENCH

AFTERBURNER

AIR

NATURAL GAS, LIQUID FEED

TRANSFER DUCT

ROTARY KILN INCINERATOR

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

5

ESD 151-91
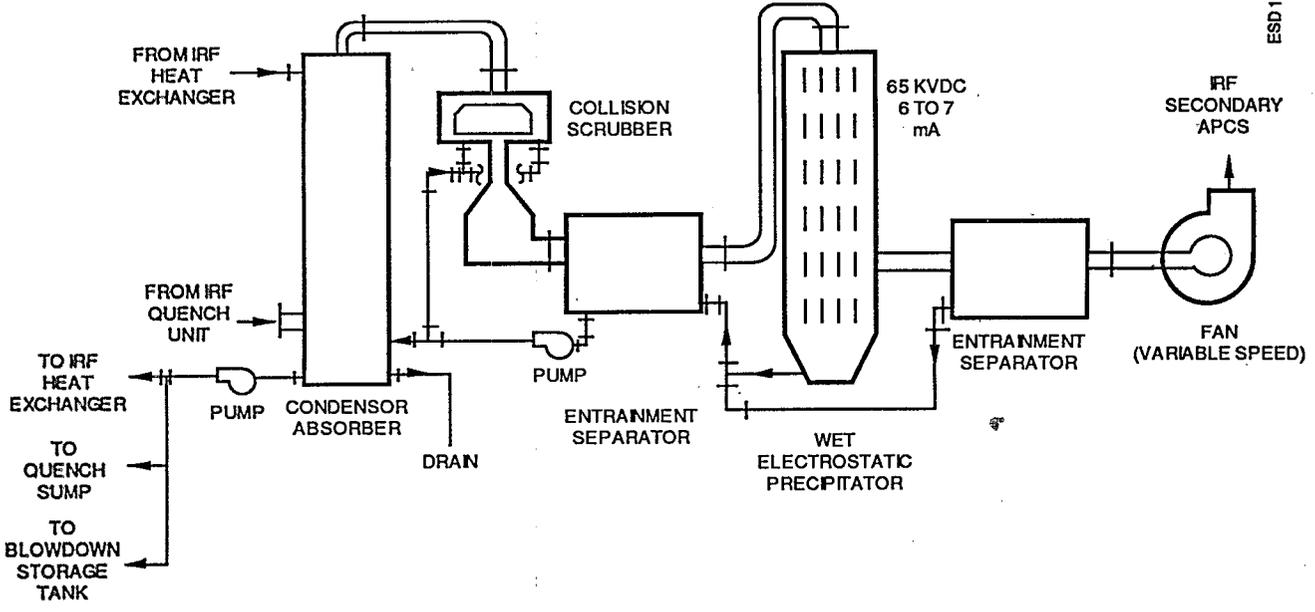
Figure 2. Schematic of the Calvert flux-force/condensation scrubber system.

TABLE 1. AVERAGE ORGANIC CONCENTRATIONS IN THE
WASTE FEED

	Weight % in mixture		
Test	Toluene	Tetrachloroethene	Chlorobenzene
1 through 3	20.2	0	0
4 through 6	18.3	0.6	0.6
7 through 11	16.2	2.7	2.7

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TABLE 2. AVERAGE INTEGRATED FEED METAL CONCENTRATIONS

Metal	Concentration, mg/kg
Arsenic	34
Barium	465
Bismuth	371
Cadmium	20
Chromium	283
Copper	347
Lead	74
Magnesium	34,500
Strontium	388
Mercury	4

TABLE 3. AVERAGE ACHIEVED VALUES FOR THE TEST VARIABLES

Test	Date	Kiln exit gas temperature, °C (°F)	Feed mixture chlorine content, %	Calvert scrubber pressure drop, kPa (in WC)
Baseline	5/29/91	831 (1,528)	2.8	12.4 (50)
1	6/5/91	541 (1,006)	0	12.9 (52)
2	6/6/91	819 (1,507)	0	12.4 (50)
3	6/13/91	909 (1,669)	0	12.4 (50)
4	6/18/91	555 (1,031)	0.6	12.4 (50)
5	6/19/91	842 (1,547)	0.6	12.4 (50)
6	6/21/91	919 (1,686)	0.8	12.4 (50)
7	6/25/91	543 (1,010)	3.6	12.4 (50)
8	6/28/91	817 (1,502)	3.4	12.4 (50)
9	7/9/91	944 (1,731)	3.1	12.2 (49)
10	7/11/91	829 (1,524)	2.3	8.2 (33)
11	7/16/91	827 (1,521)	3.4	16.9 (68)
Repeat baseline	7/18/91	834 (1,534)	2.3	12.4 (50)
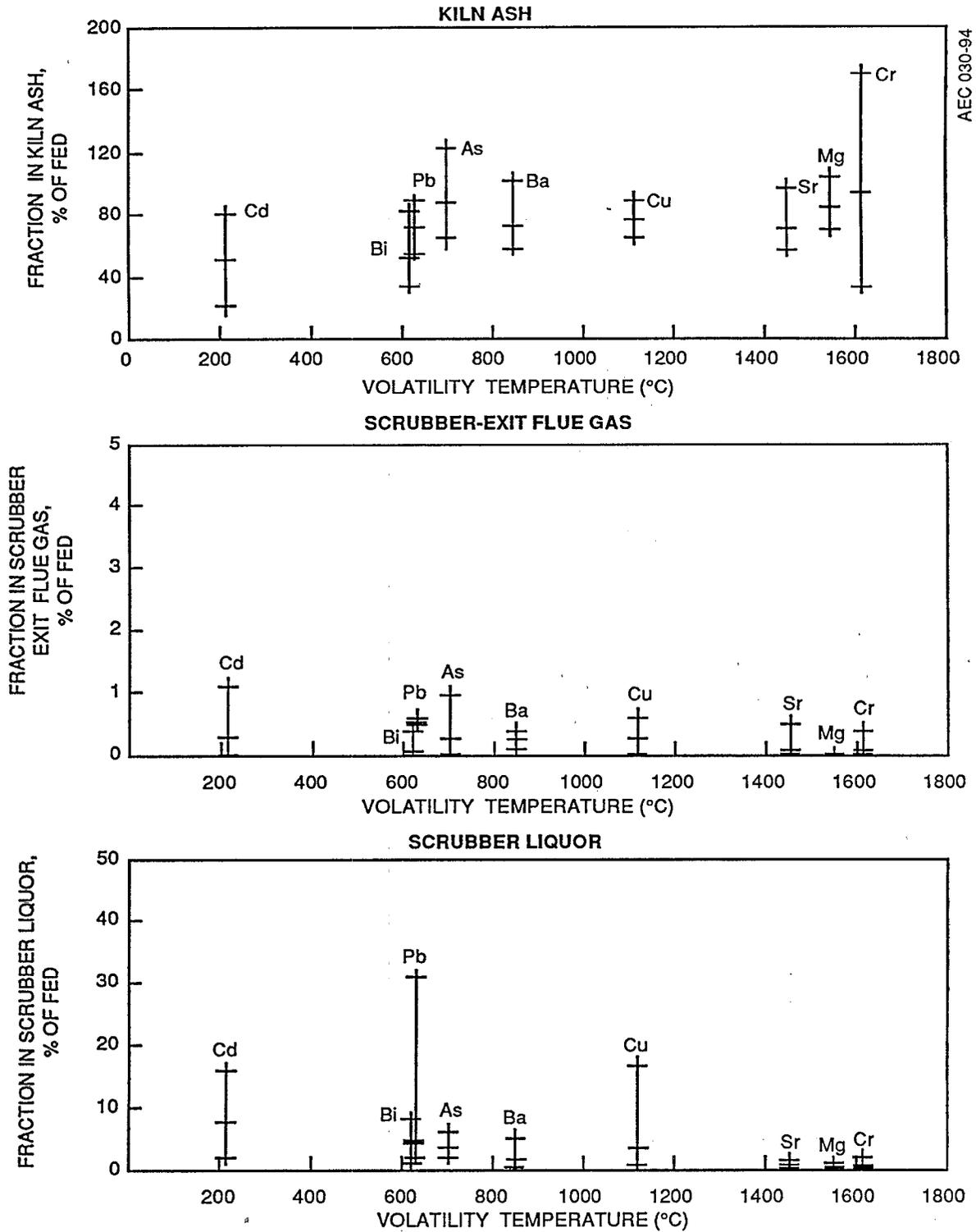
Figure 3. Distributions of metals in the discharge streams expressed as a fraction of the metal fed.
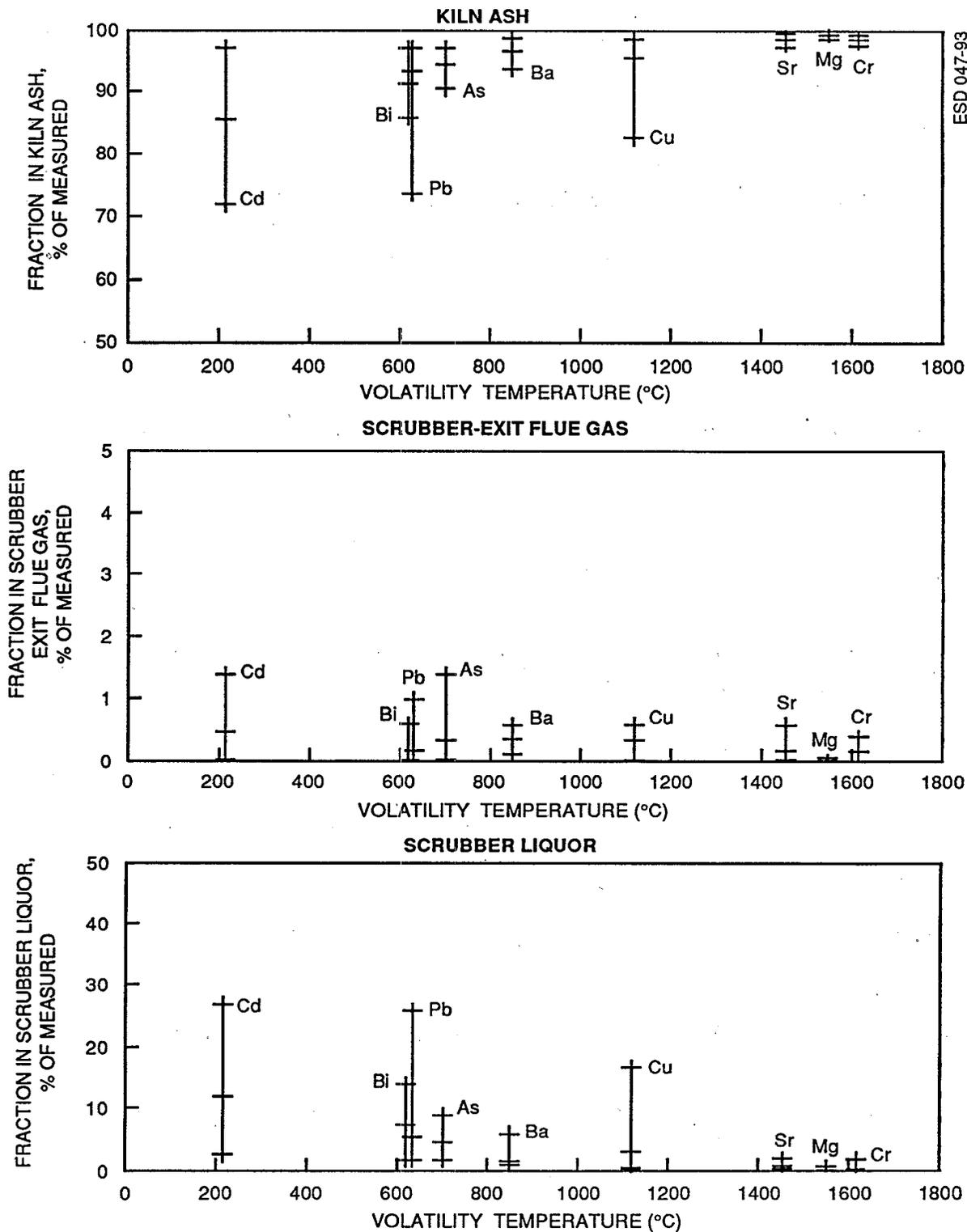
Figure 4. Normalized distributions of metals in the discharge streams.

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are plotted versus the volatility temperature for each metal, based on the metal's elemental and oxide forms. The volatility temperature[3] is the temperature at which the effective vapor pressure of the metal is 10^{-6} atm. The effective vapor pressure is the combined equilibrium vapor pressures of all species containing the metal, reflecting the quantity of metal that would vaporize under a given set of conditions. A vapor pressure of 10^{-6} atm was selected because it represents a measurable amount of vaporization. The lower the volatility temperature, the more volatile the metal is expected to be.

Figures 3 and 4 represent two ways of presenting metal partitioning data. The first way, illustrated in Figure 3, presents metal partitioning to discharge streams as fractions of the amount of metal fed to the incinerator. The second way, illustrated in Figure 4, presents discharge distributions normalized to the total amount of metal measured in the sum of the three incinerator discharges — the kiln ash, the scrubber liquor, and the scrubber exit flue gas.

Both methods of presenting metal discharge distributions are useful in the process of data interpretation. Expressing distributions as a percent of the metal fed provides a more accurate representation of individual discharge stream fractions if there are metal losses in the incineration system that are not quantified. However, this method introduces a source of test-to-test data variability caused by less than perfect mass balance closure.

The use of normalized distributions attempts to correct for this source of data variability. Mass balance closure varied from test to test in this program, as it has in all past experience in measuring trace metal discharges from combustion sources. Thus, variations in metal discharge distributions expressed as a percent of the metal fed are affected by both actual variations due to changes in test variables, and by individual test mass balance closure. Variations in normalized distributions more closely reflect those due to changes in test variables because variable mass balance closure is removed by the normalization. In discussing metal partitioning, it is important to present metal distributions as both a fraction of the metal fed and normalized to the total amount measured. The greatest credence is placed on conclusions supported by both methods of presentation.

In all tests, mercury concentrations in the kiln ash were below a detection limit of 0.1 mg/kg. The volatile behavior of mercury was expected based on mercury's high vapor pressure and low volatility temperature of 14°C (57°F). The normalized data in Figure 4 show that the other test metals were relatively refractory. On average, kiln ash fractions accounted for greater than 86 percent of each of the metals except for mercury; the lowest measured normalized kiln ash fraction was 72 percent, for cadmium. In addition, Figure 4 shows a gradual increase in kiln ash fraction with increasing volatility temperature, an expected observation. The less volatile a metal is, as reflected in its higher volatility temperature, the less likely it is to volatilize in the kiln and be carried out of the kiln in the vapor phase in the combustion flue gas. Thus, it will more likely be retained in the kiln ash discharge.

2.2.2 Effects of Incinerator Operating Conditions on Metal Distributions

The effect of incinerator operating conditions and feed chlorine content can be seen via plots such as those shown for cadmium in Figures 5 through 8. Figures 5 and 6 show the variation in cadmium distribution with varying kiln temperature at each of the three feed chlorine contents tested. Figures 7 and 8 show the variation in cadmium distributions with

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VARIABLE: KILN EXIT TEMPERATURE
CADMIUM, NO CHLORINE

CADMIUM, 0.7% CHLORINE

CADMIUM, 3.4% CHLORINE
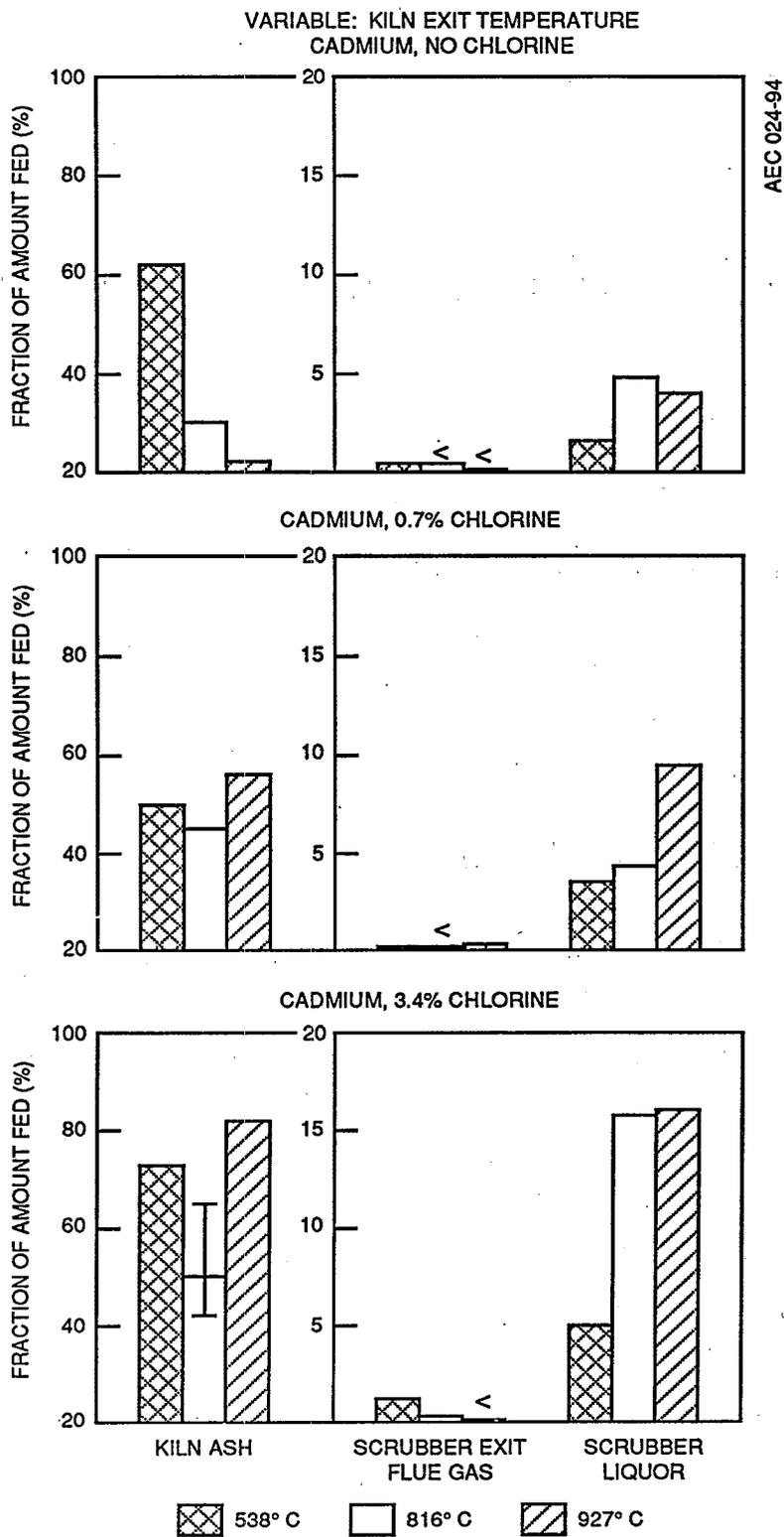
Figure 5. Cadmium distributions expressed as a fraction of cadmium
fed, showing variations with kiln exit temperature at
constant waste feed chlorine content.

11

VARIABLE: KILN EXIT TEMPERATURE
CADMIUM, NO CHLORINE

CADMIUM, 0.7% CHLORINE

CADMIUM, 3.4% CHLORINE
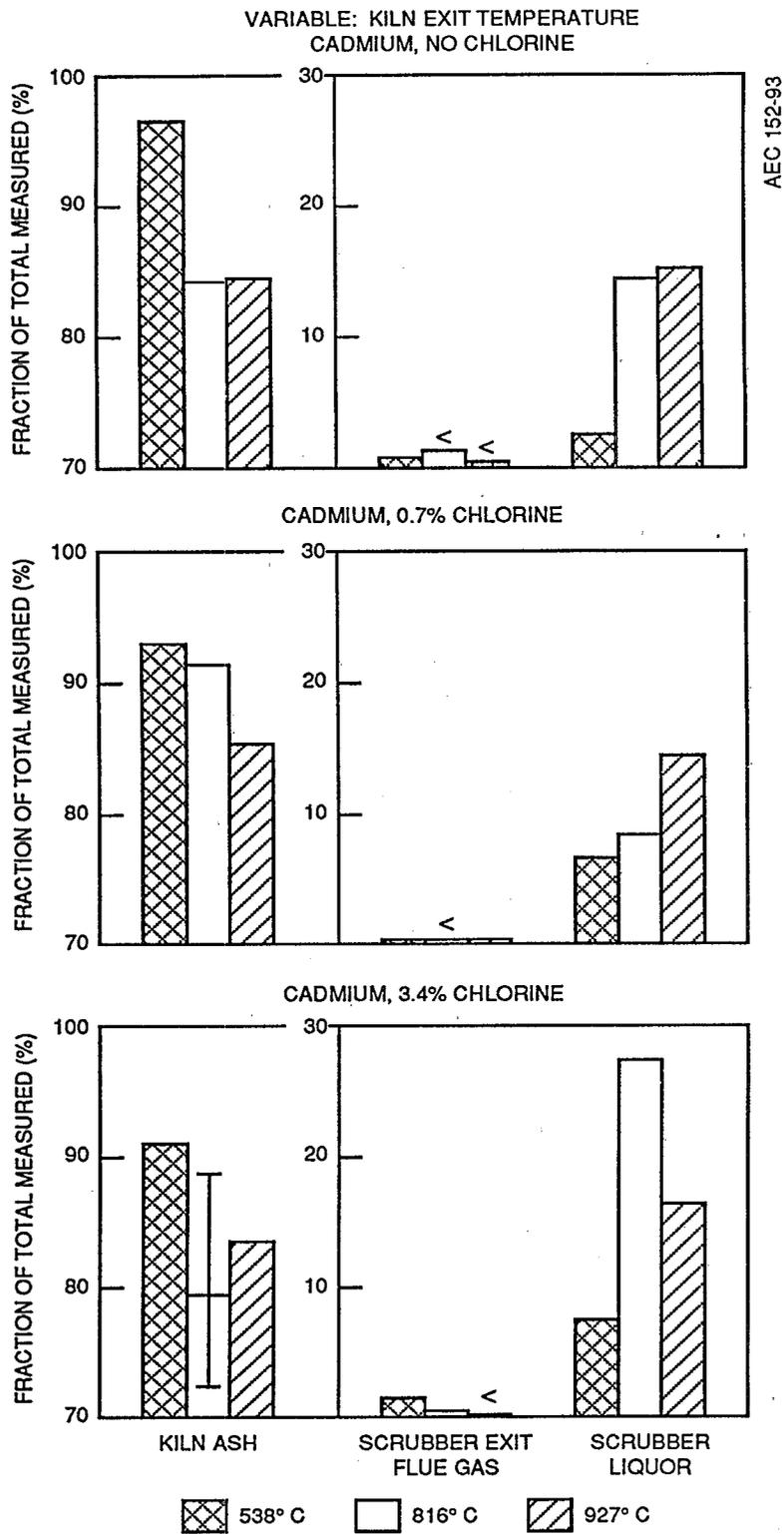
Figure 6. Normalized cadmium distributions, showing variations with kiln exit temperature at constant waste feed chlorine content.

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VARIABLE: WASTE FEED CHLORINE CONTENT
CADMIUM, 538°C KILN EXIT TEMPERATURE
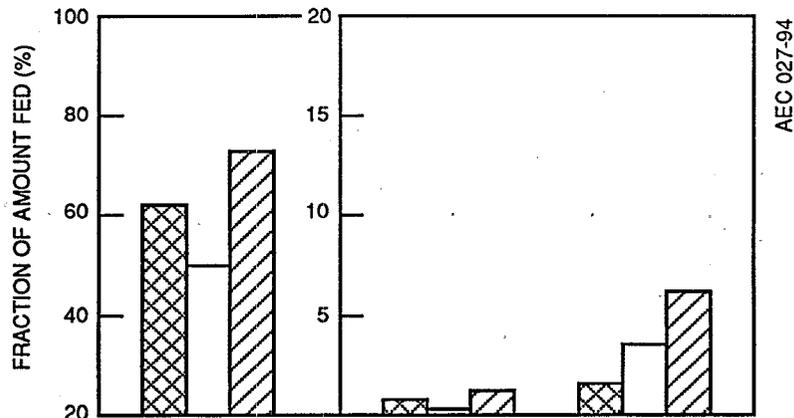
AEC 027-94

CADMIUM, 816°C KILN EXIT TEMPERATURE
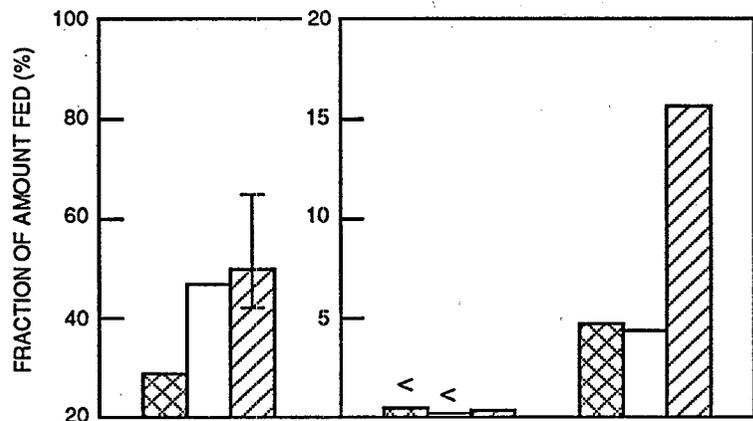
CADMIUM, 927°C KILN EXIT TEMPERATURE

KILN ASH   SCRUBBER EXIT   SCRUBBER
            FLUE GAS   LIQUOR

0%   0.7%   3.4%
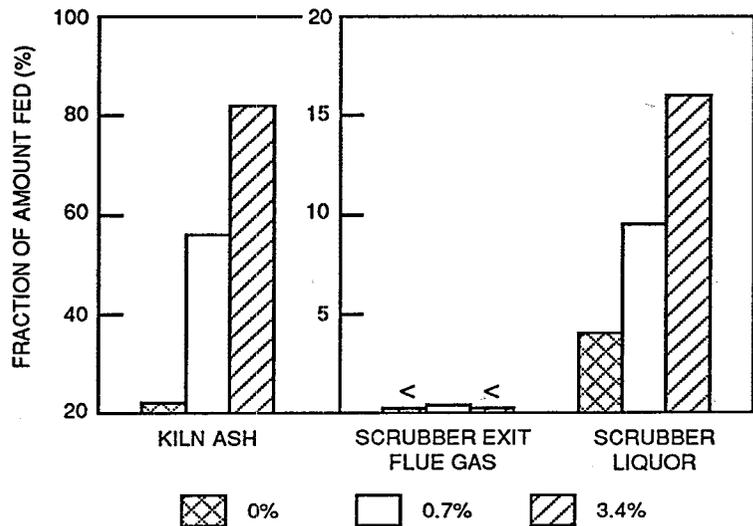
**Figure 7. Cadmium distributions expressed as a fraction of the
cadmium fed, showing variations with waste feed
chlorine content at constant kiln exit temperature.**

13
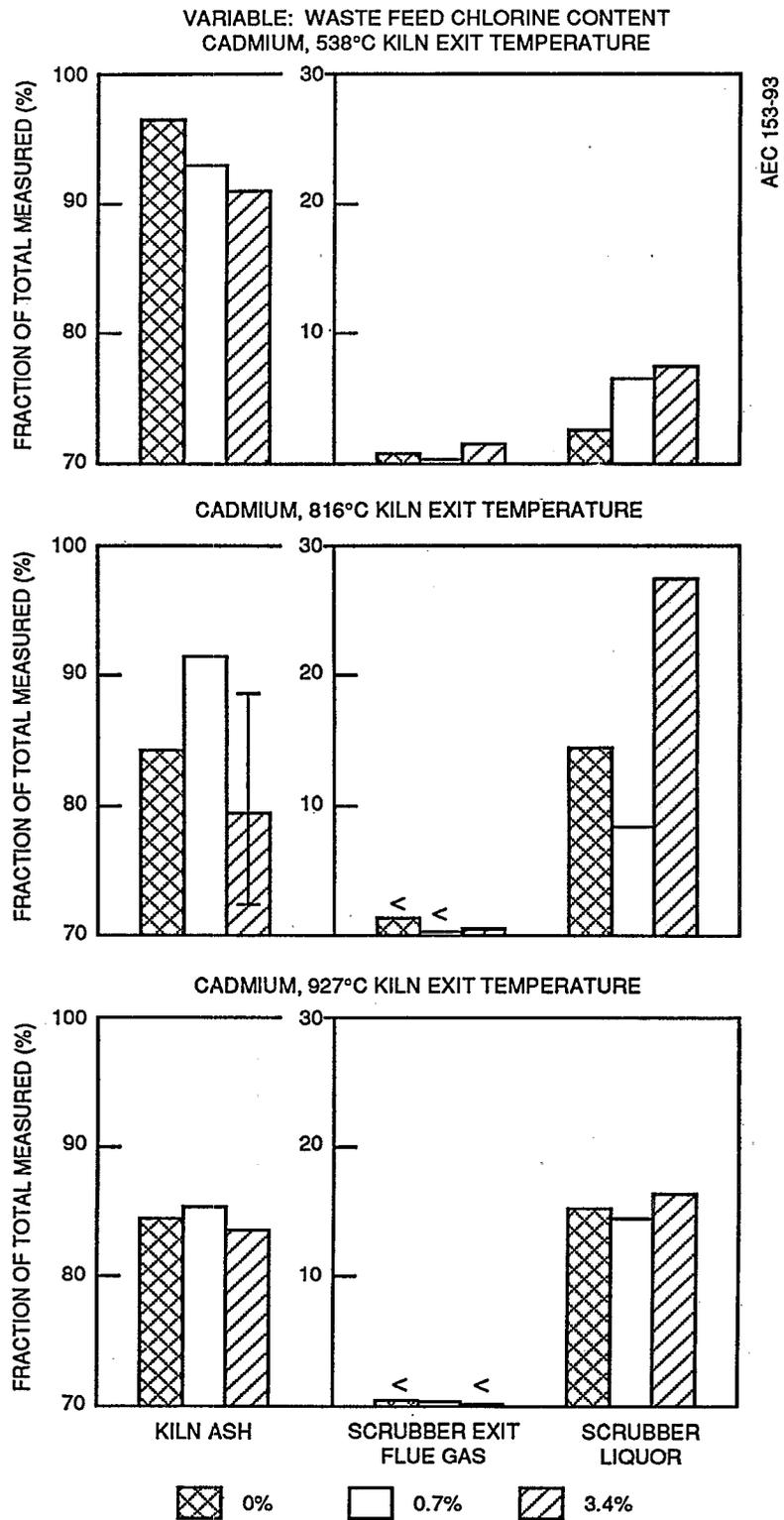
Figure 8. Normalized cadmium distributions, showing variations with waste feed chlorine content at constant kiln exit temperature.

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varying feed chlorine content at each of the three kiln exit gas temperatures tested. Figure 5 and 7 use distribution fractions as a percent of cadmium fed. Figures 6 and 8 use normalized distribution fractions as discussed in Section 2.2.1.

All four figures show an indication of a range in kiln ash fraction for the 3.4-percent chlorine feed tested at the 816°C (1,500°F) kiln exit gas temperature. Three tests with this feed at this nominal kiln exit gas temperature were performed while the Calvert scrubber system pressure drop was varied. However, because changes in the scrubber system pressure drop should not affect metals partitioning to the kiln ash, these three tests represent replicates for evaluating data variability for metals partitioning to the kiln ash. Kiln ash partitioning values for these three tests have been averaged and plotted as a single bar. The observed range for partitioning to the kiln ash for these three tests is shown as an indicator of data variability.

In many cases, cadmium was not detected in the scrubber exit flue gas. The "<" indications above the bars for the corresponding scrubber exit flue gas fractions are used to highlight this occurrence. The height of the bar in these cases is the distribution fraction corresponding to the detection limit flue gas concentration. Also note that two scales are shown in each distribution plot; one (usually 70 to 100 percent) applies to the kiln ash fractions, and the other (usually 0 to 30 percent) applies to the scrubber exit flue gas and scrubber liquor fractions.

The normalized data in Figure 6 show a weak increase in cadmium volatility with increased kiln exit gas temperature for all three feed chlorine contents, whereas the percent-of-fed data in Figure 5 confirm this only for the chlorine-free feed. The data in Figures 7 and 8 suggest that feed chlorine content did not affect cadmium volatility within the range of data variability experienced. The normalized data in Figures 10 and 14 show that the observed volatilities of copper and lead were not affected by kiln exit-gas temperature at 0 and 0.7 percent chlorine content in the feed. For a 3.4-percent feed chlorine content, these figures show that both metals exhibited increased volatility with increasing kiln temperature. However, the percent-of-fed data in Figures 9 and 13 do not confirm this observation. The normalized data in Figures 12 and 16 show that the volatilities of copper and lead also apparently increased with increasing feed chlorine content. The percent-of-fed data in Figure 11 suggest the same for copper at the two lower kiln exit gas temperatures. However, the percent-of-fed data in Figure 15 do not confirm the observation for lead.

In all cases, each of these metals remained relatively refractory and were found primarily in the kiln ash for all test conditions. In addition, there was no clear relationship between the partitioning of arsenic, barium, bismuth, chromium, magnesium, mercury, or strontium and the test variables over the ranges tested.

2.2.3 Scrubber Collection Efficiencies

The apparent scrubber collection efficiency for flue gas metals was determined for each test. The apparent scrubber efficiency represents the ratio of the metal fraction measured in the scrubber liquor to the sum of the metal fractions measured in the scrubber liquor and scrubber exit flue gas. Figure 17 summarizes the efficiency data. The bar for each metal represents the range of apparent scrubber collection efficiencies over the 11 tests, with the overall average for the 11 tests noted by the midrange tick mark. Mercury recovery from scrubber liquor samples

VARIABLE: KILN EXIT TEMPERATURE
COPPER, NO CHLORINE

AEC 029-94

COPPER, 0.7% CHLORINE

COPPER, 3.4% CHLORINE

KILN ASH   SCRUBBER EXIT   SCRUBBER
              FLUE GAS   LIQUOR

538° C   816° C   927° C
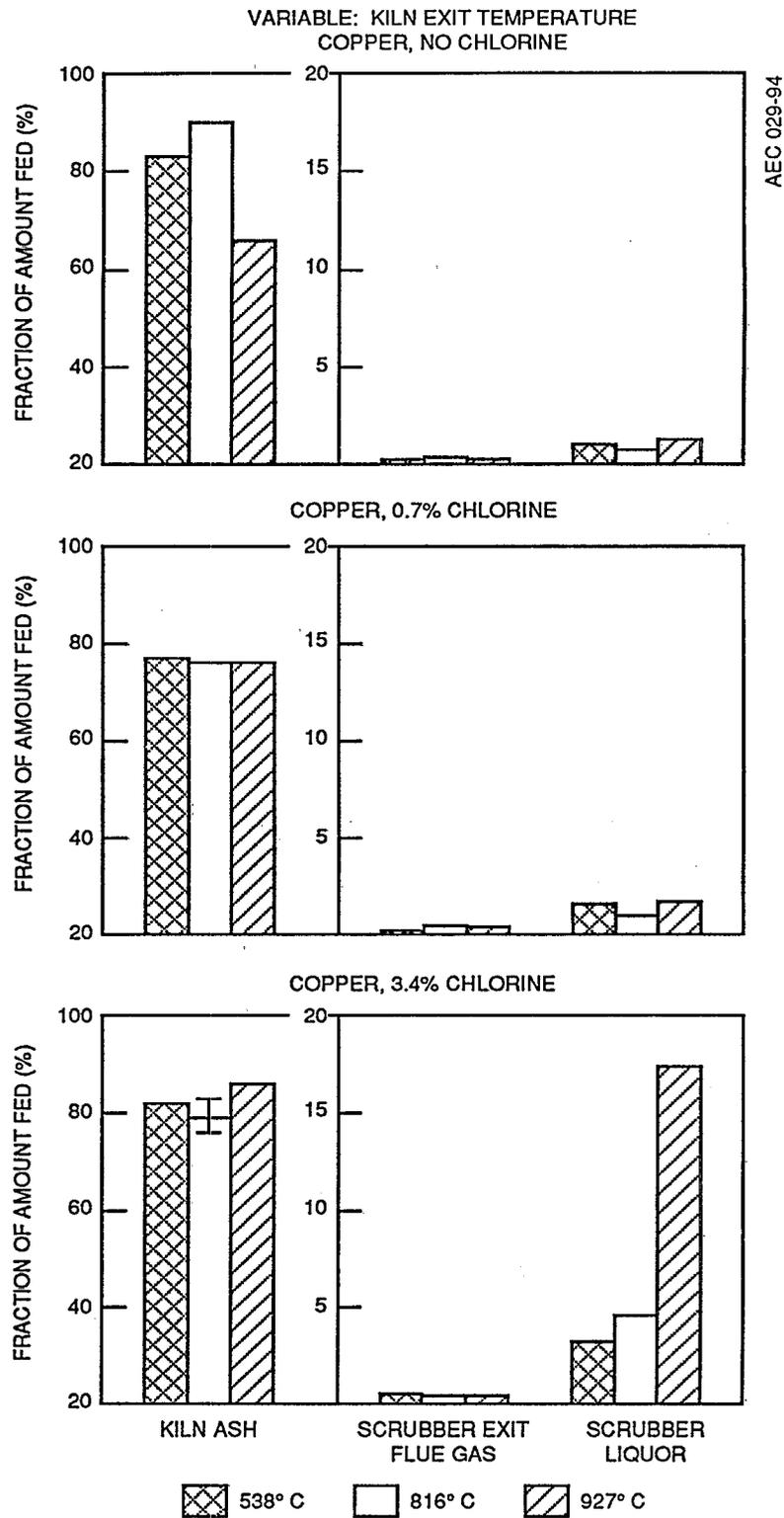
**Figure 9. Copper distributions expressed as a fraction of the copper
fed, showing variations with kiln exit temperature at
constant waste feed chlorine content.**

VARIABLE: KILN EXIT TEMPERATURE
COPPER, NO CHLORINE

AEC 157-93

COPPER, 0.7% CHLORINE

COPPER, 3.4% CHLORINE

KILN ASH   SCRUBBER EXIT   SCRUBBER
                     FLUE GAS   LIQUOR

538° C   816° C   927° C
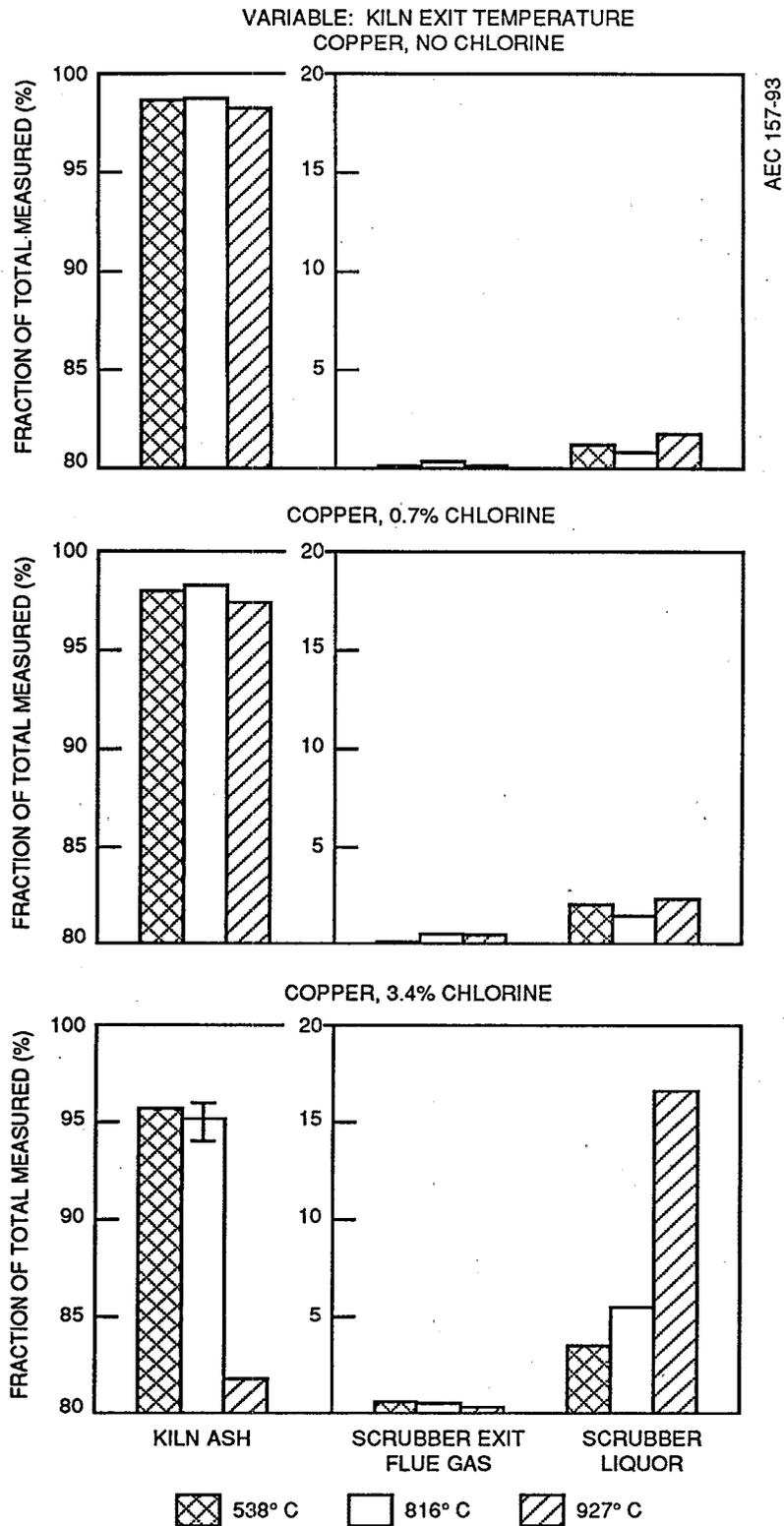
Figure 10. Normalized copper distributions, showing variations with kiln
exit temperature at constant waste feed chlorine content.

17

VARIABLE: WASTE FEED CHLORINE CONTENT
COPPER, 538°C KILN EXIT TEMPERATURE

AEC 028-94

COPPER, 816°C KILN EXIT TEMPERATURE

COPPER, 927°C KILN EXIT TEMPERATURE

KILN ASH   SCRUBBER EXIT   SCRUBBER
                    FLUE GAS   LIQUOR

0%   0.7%   3.4%
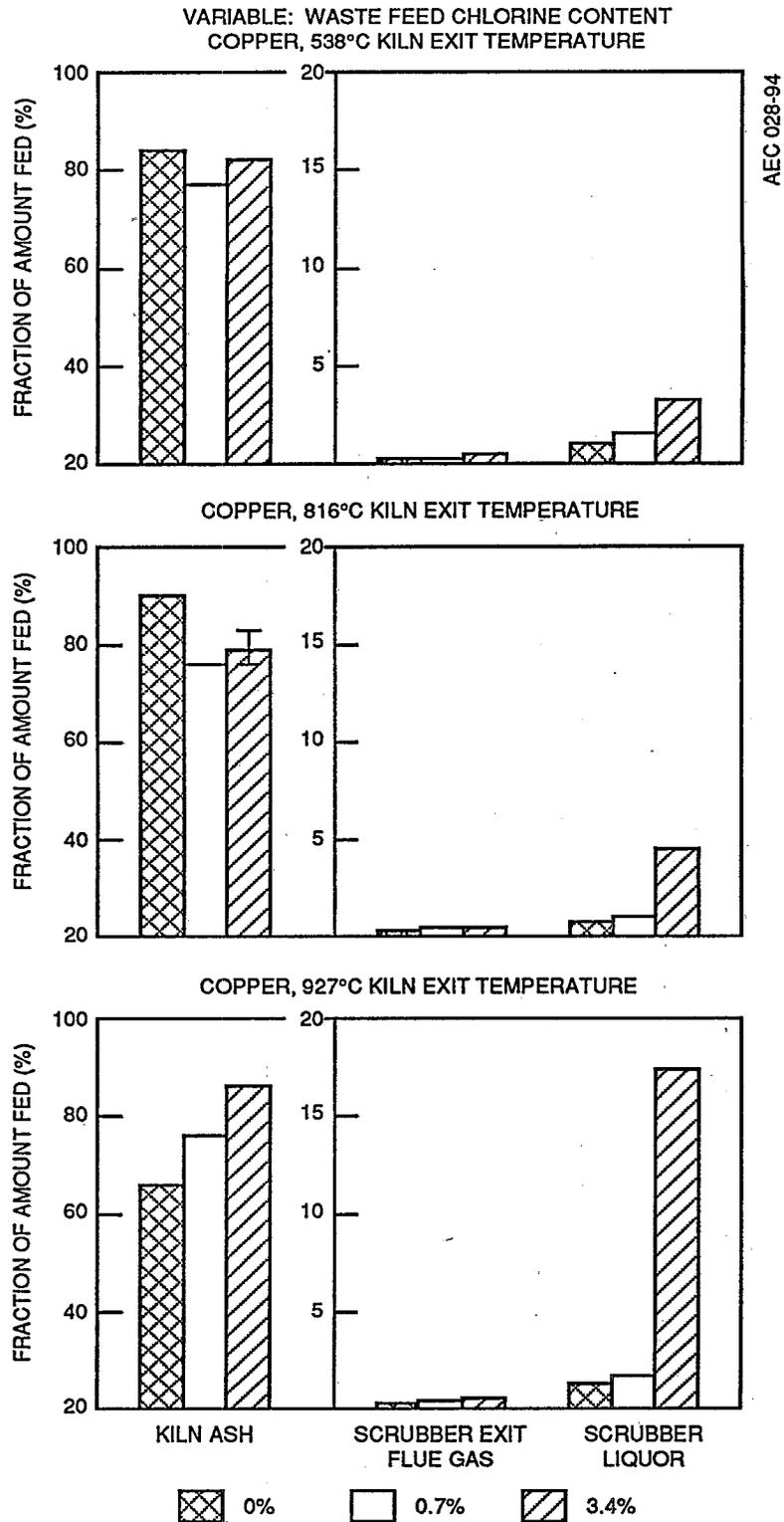
**Figure 11. Copper distributions expressed as a fraction of the copper
fed, showing variations with waste feed chlorine content at
constant kiln exit temperature.**

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VARIABLE: WASTE FEED CHLORINE CONTENT
COPPER, 538°C KILN EXIT TEMPERATURE

AEC 156-93

COPPER, 816°C KILN EXIT TEMPERATURE

COPPER, 927°C KILN EXIT TEMPERATURE
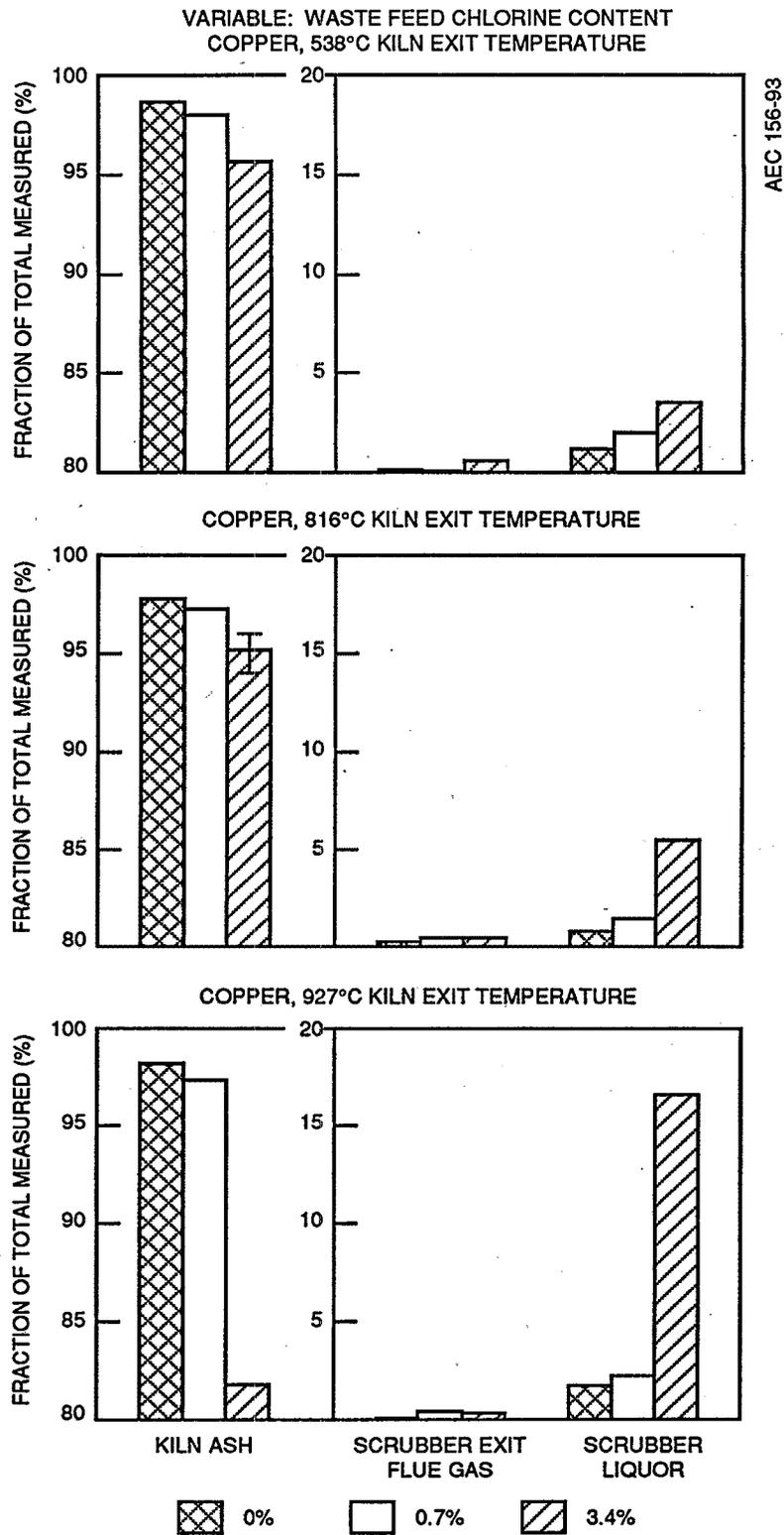
Figure 12. Normalized copper distributions, showing variations with waste
feed chlorine content at constant kiln exit temperature.

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VARIABLE: KILN EXIT TEMPERATURE
LEAD, NO CHLORINE

AEC 026-94

LEAD, 0.7% CHLORINE

LEAD, 3.4% CHLORINE

KILN ASH   SCRUBBER EXIT   SCRUBBER
            FLUE GAS   LIQUOR

538° C   816° C   927° C
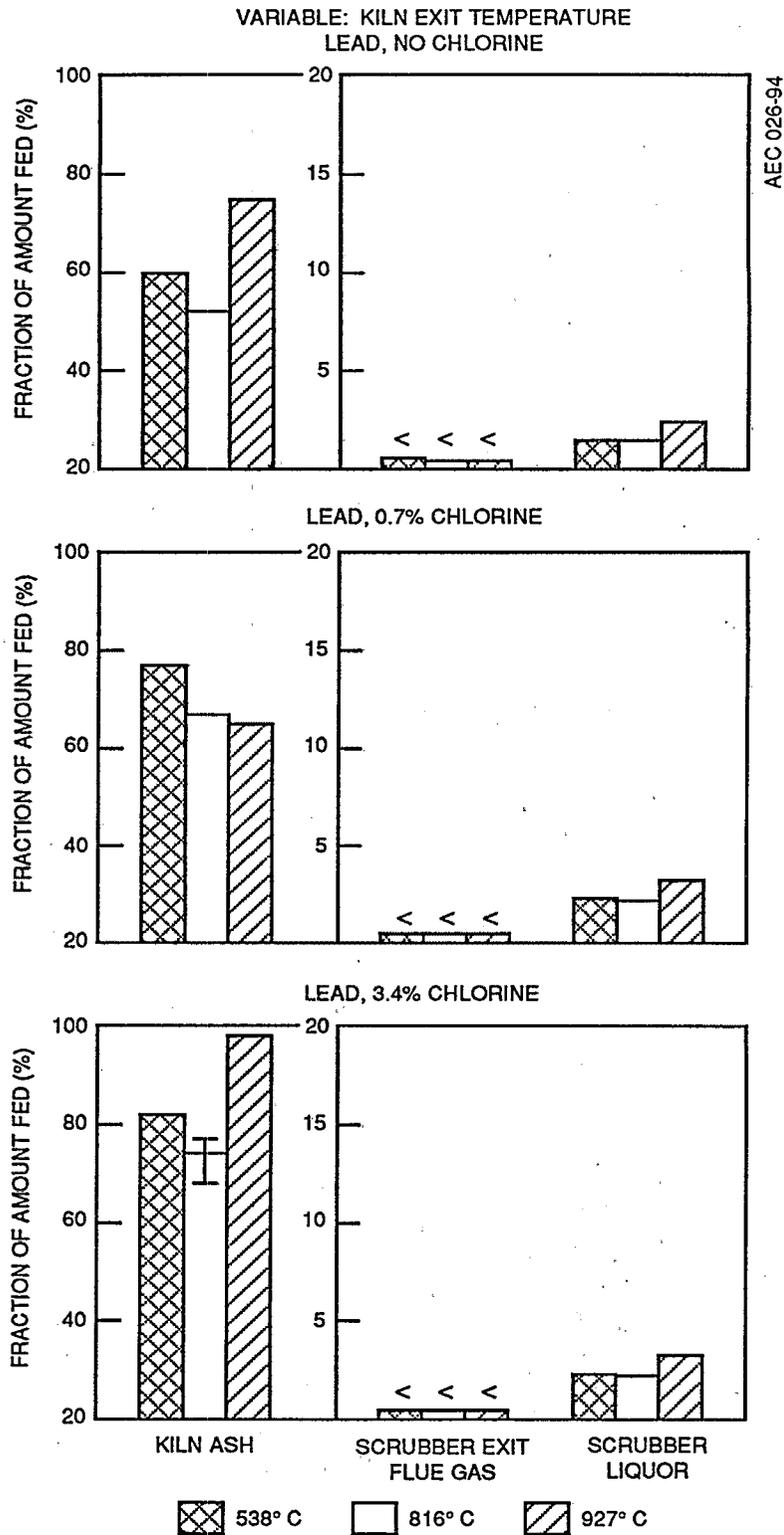
Figure 13. Lead distributions expressed as a fraction of the lead fed, showing variations with kiln exit temperature at constant waste feed chlorine content.

20
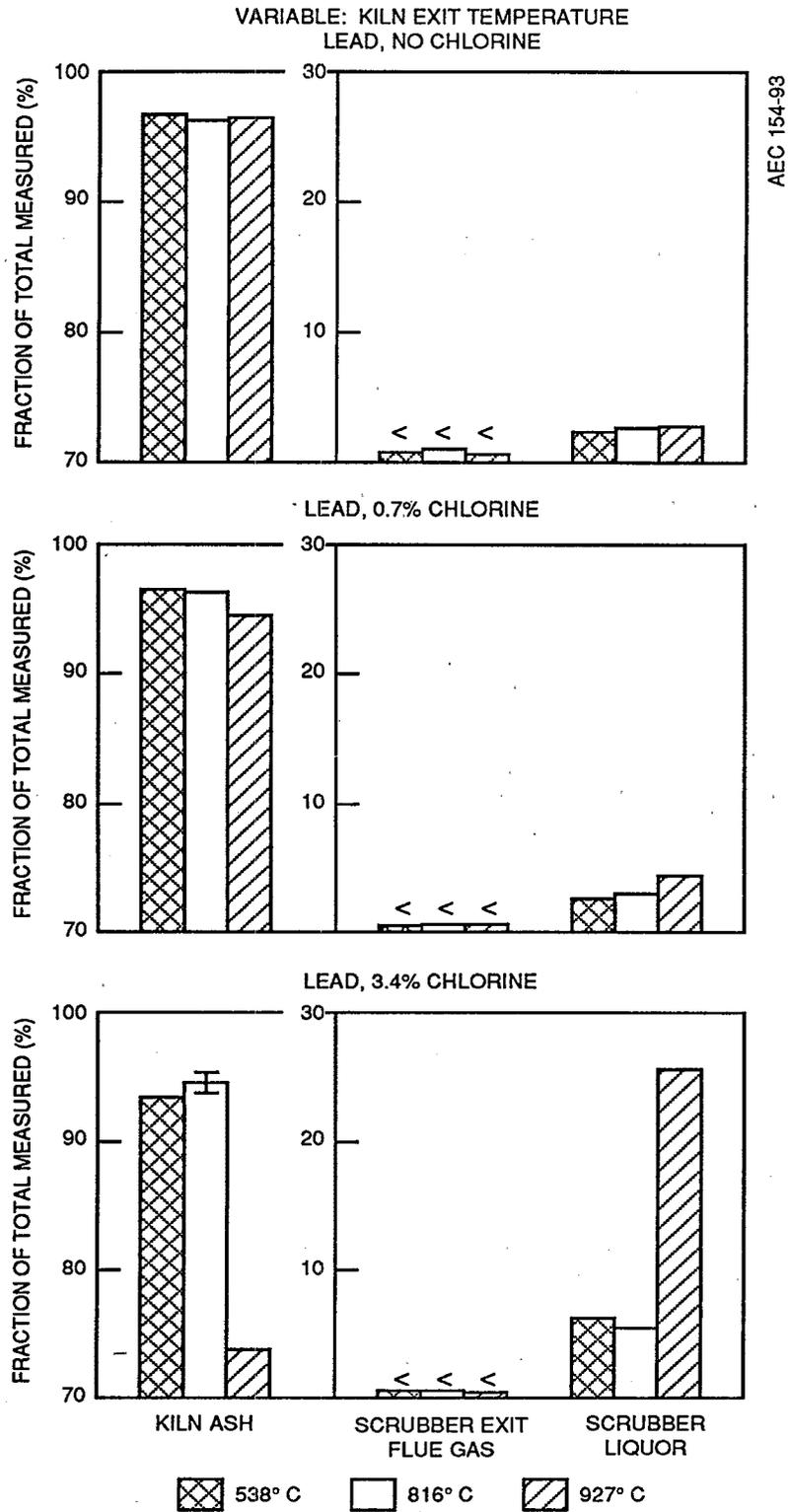
Figure 14. Normalized lead distributions, showing variations with kiln exit temperature at constant waste feed chlorine content.

21
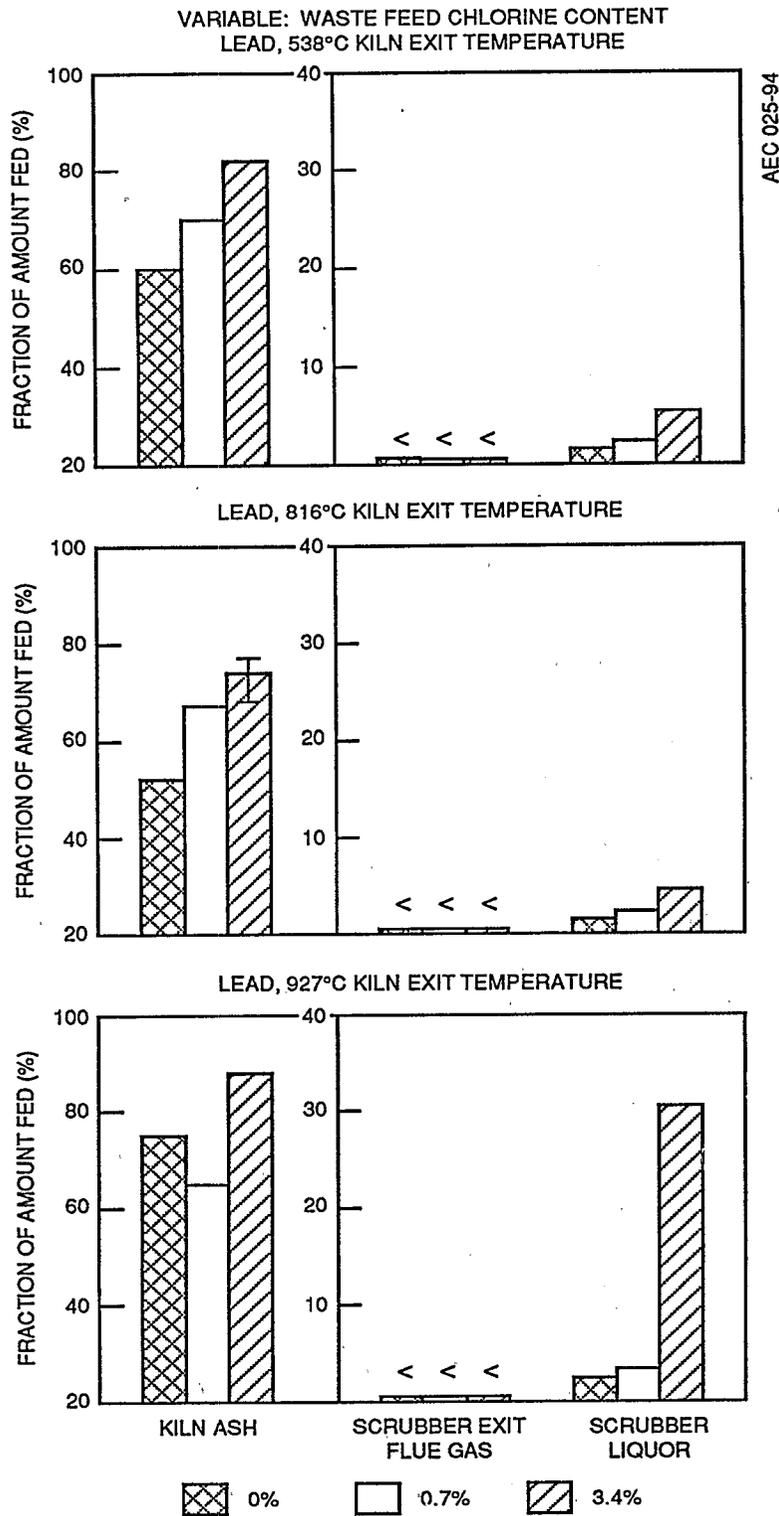
Figure 15. Lead distributions expressed as a fraction of the lead fed, showing variations with waste feed chlorine content at constant kiln exit temperature.

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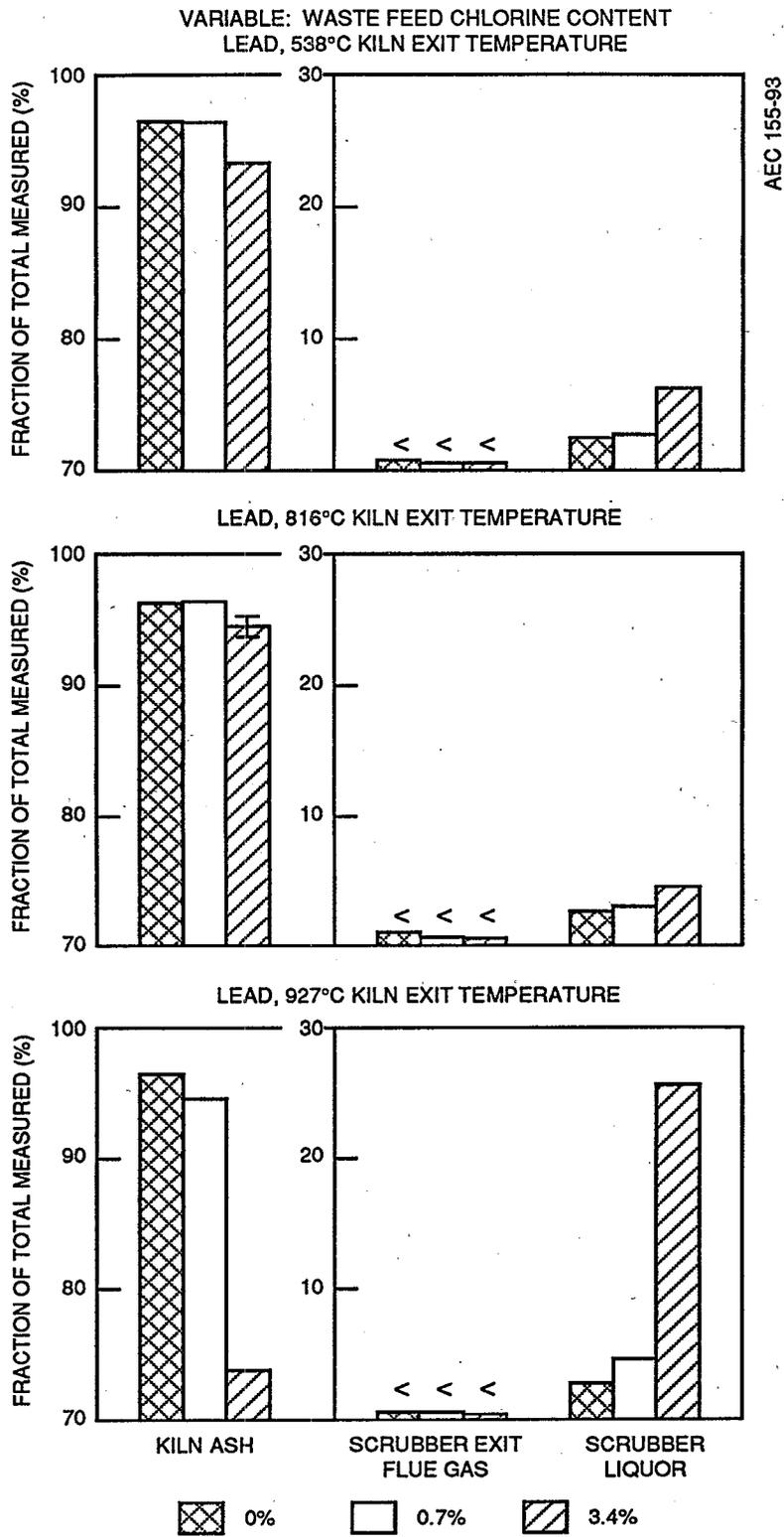
Figure 16. Normalized lead distributions, showing variations with waste feed chlorine content at constant kiln exit temperature.

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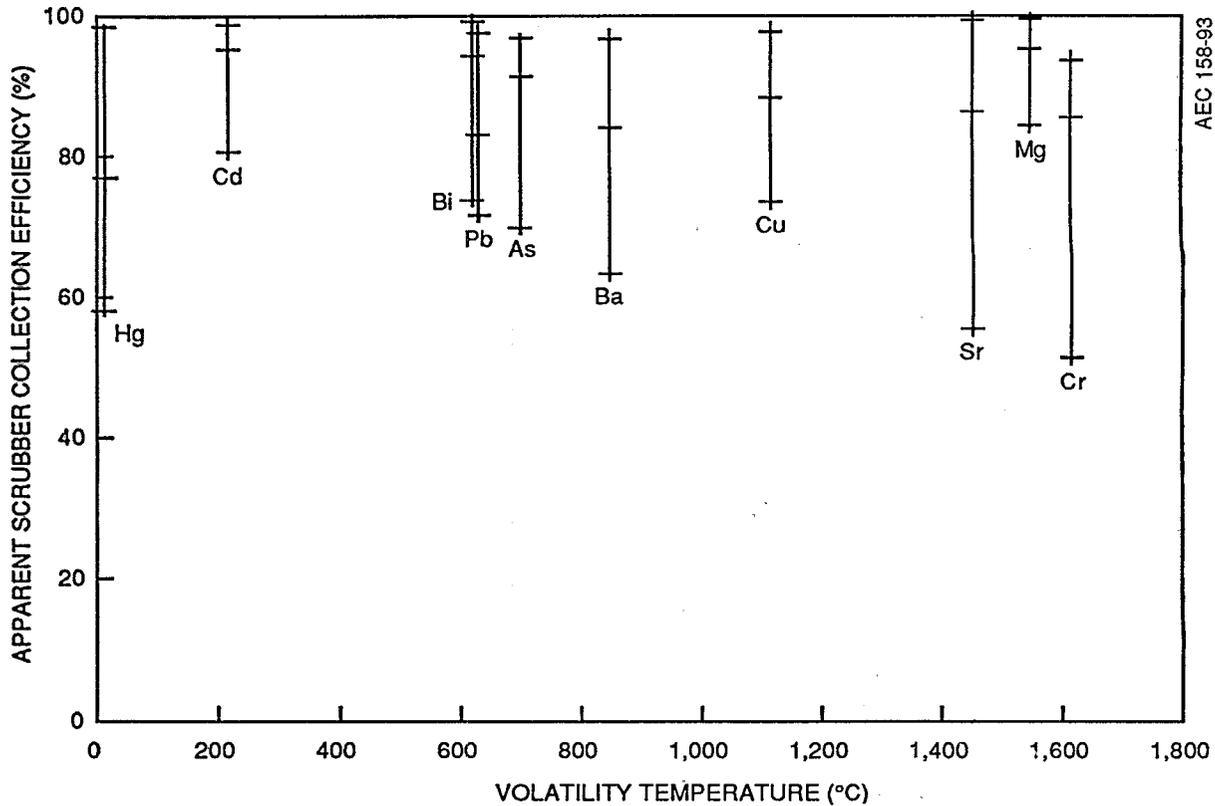
Figure 17. Apparent Calvert scrubber collection efficiencies for metals.

was poor for the tests without chlorine. For this reason, the mercury scrubber collection efficiencies shown in Figure 17 are based on flue gas measurements, which, for mercury alone, are thought to be more representative of the actual system performance.

Average metal collection efficiencies shown in Figure 17 ranged from 78 to 96 percent; the overall average for all metals was 90 percent. Individual scrubber collection efficiencies for each test ranged from 52 to greater than 99.7 percent. Figure 17 shows that there was no clear relationship between apparent scrubber collection efficiency and metal volatility temperature. There was also no clear relationship between the test variables and scrubber collection efficiency.

The observed scrubber collection efficiencies are somewhat lower than expected based on past experience with this scrubber system. However, the average concentration of the metals in the scrubber inlet flue gas ranged from 23 to 580 μg/dscm. For any APCS, there will likely be a contribution to the scrubber exit metals concentrations due to metals penetration that is relatively insensitive to inlet metal concentrations. Therefore, the removal efficiency of an APCS will likely be lower when inlet concentrations are lower than the efficiency will be when inlet concentrations are higher. Scrubber inlet metals concentrations were relatively low for these tests. Higher removal efficiencies might have been measured had inlet loadings been higher.

A relationship between scrubber pressure drop and removal efficiency would also be more likely at higher inlet loadings.

2.3   CONCLUSIONS

Test program conclusions include the following:

- All of the metals were relatively nonvolatile except mercury. On average, kiln ash fractions accounted for greater than 86 percent of each of the metals except for mercury; the lowest measured normalized kiln ash fraction was for cadmium, at 72 percent. As expected, mercury was very volatile and was not found in the kiln ash sample of any test.

- On average, the relative volatilities of the metals observed agreed with the order predicted by metal volatility temperatures

- There was no clear relationship between the partitioning of arsenic, barium, bismuth, chromium, magnesium, mercury, or strontium and the test variables over the ranges used

- Cadmium volatility may have showed a weak increase with increasing kiln exit gas temperature; feed chlorine content did not affect cadmium volatility within the range of data variability experienced

- The observed volatilities of copper and lead were not affected by kiln exit gas temperature at 0- and 0.7-percent chlorine content in the feed. For a 3.4-percent feed chlorine content, both metals exhibited increased volatility with increasing kiln exit gas temperature based on normalized data. Percent-of-fed data do not confirm this observation, however. The volatilities of copper and lead also increased with increasing feed chlorine content based on normalized data. This trend is not apparent in the percent-of-fed data for lead, however.

- There was no clear evidence of hysteresis in the RKS caused by test-to-test carryover of any of the metals

- The average scrubber collection efficiencies for metals ranged from 78 to 96 percent. The overall average collection efficiency for all metals was 90 percent. That scrubber efficiencies were lower than expected is likely due to the low metal concentrations at the scrubber inlet. No clear variation in scrubber collection efficiency with variations in the test variables was observed. The lack of a relationship between scrubber pressure drop and scrubber collection efficiency is most likely due, in part, to the low metal concentrations at the scrubber inlet.

Test results outlined above were reported in the following report:

- Fournier, D. J., Jr., and L. R. Waterland, "The Fate of Trace Metals in a Rotary Kiln Incinerator with a Calvert Flux-Force/Condensation Scrubber System," draft, January 1993.

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SECTION 3

EVALUATION OF ROTARY KILN INCINERATOR OPERATION
AT LOW TO MODERATE TEMPERATURES

As part of the EPA's efforts to remediate Superfund sites, several remediation technologies can be candidates for consideration. One of the more frequently used technologies to decontaminate soils contaminated with organic hazardous constituents is incineration. High-temperature incineration, while usually effective in destroying organic compounds, may not be necessary for some soils that need treatment, such as soils contaminated with volatile organic compounds (VOCs). Also, in soils contaminated with toxic trace metals, high-temperature incineration may increase the volatilization of some metals into the combustion flue gas. The presence of elevated levels of volatile trace metals in the flue gas can pose increased challenges to an APCS.

Another thermal treatment technology, thermal desorption, may be an attractive alternative to incineration. When successful in decontaminating soils to the necessary degree, thermal desorption treatment of soils offers the benefits of lower fuel consumption; avoidance of slag formation; and less tendency to volatilize certain toxic metals such as lead and cadmium into the effluent gas discharge, thereby decreasing the demands on an APCS to control metal emissions.

Most conventional rotary kiln incinerators can be easily operated at temperatures below those typically employed for incineration treatment. Thus, the following question arises: how effective is the treatment of contaminated soils by a rotary kiln incinerator operated at the low to moderate temperatures associated with the thermal desorption processes?

To address this question, a series of tests was conducted in the IRF RKS with the kiln of the RKS operated at low to moderate temperatures The test program consisted of 12 tests under 11 different kiln operating conditions; one test condition was tested in duplicate.

The objective of the test program was to study the global effects of five parameters believed to be of primary importance in the effectiveness of soil decontamination and the fate of contaminant metals in the treatment of contaminated soil in an incinerator operated at the low to moderate temperatures associated with thermal desorption processes. These parameters were soil moisture content, treatment temperature, treatment time, solids bed depth, and degree of solids agitation.

The results obtained from the test program were intended to yield the following information:

- The relationship between compound vapor pressure characteristics (boiling point) and the extent of decontamination for each organic contaminant

- How peak solids bed temperature affects the extent of decontamination

- The differences in organic constituent decontamination effectiveness for solids beds of different depths, when the same peak solids bed temperatures are reached

- How the presence and the amount of moisture affect organic constituent decontamination effectiveness

- The relationship between treatment time and temperature and organic constituent decontamination effectiveness

- The distribution of trace metals in process discharges when a metal-contaminated soil is treated by thermal desorption

- Whether thermal desorption treatment conditions affect a metal's leachability from the treated soil

The test program to address these issues was performed during late December 1992, and January and early February 1993. The RKS was configured as shown in Figure 1, with the exception that the Calvert scrubber system indicated in the figure was not in place. The venturi/packed-column scrubber system shown in the figure served as the primary APCS for these tests.

3.1   TEST PROGRAM

3.1.1   Test Contaminated Soil

Original plans for the test program were to prepare a contaminated soil mixture by combining a mixture of organic contaminants and an aqueous trace metal solution with a local topsoil obtained from a garden supply vendor. After preparation of this synthetic contaminated soil mixture, requisite quantities of water were to be added to achieve one of the two target moisture contents selected for this test program variable. Prepared contaminated soils were to be continuously fed to the RKS kiln over a test's duration using either a screw feeder for free flowing (lower moisture content) soil or a progressive cavity pump for sludge-like (higher moisture content) soil. However, initial attempts to feed unsupplemented local topsoils with target moisture contents ran into problems.

Attempts to feed several local soil types adjusted to the low target moisture content of 10 percent were unsuccessful due to problems with soil bridging in the feed hopper supplying the screw feeder. Even the use of an oversized screw and the placement of bridge breakers in the feed hopper did not prevent bridge formation problems. Mixing soil with up to 30 percent sand was similarly unsuccessful.

A different set of problems was experienced in the feeding of soil with the initial high target moisture content of 30 percent with a progressive cavity pump. Pumping this high moisture content material into the kiln was not a problem. However, once heated in the kiln,

the dried soil caked and adhered to the kiln refractory wall and would not flow along the kiln axis to the kiln discharge end.

After many trials, soil mixtures containing equal weights of local topsoil and attapulgite clay absorbent material, with mixture moisture contents of 10 and 20 percent, were found to be feedable when the screw feeder with bridge breakers and the oversized screw was used. Thus, these mixtures became the two moisture content bases for the subsequent tests.

Synthetic contaminated soil mixtures for the actual tests were prepared as follows. The local topsoil was delivered to the IRF in quantity by a dump truck. Delivered soil was placed on a polyethylene-liner-covered area outside of the IRF building. This soil pile was mixed for 1 hour or longer with a tractor bucket that was dragged in an alternate perpendicular (crisscross) pattern. After mixing, the soil was transferred into the IRF building and spread onto polyethylene-liner-covered floor space to air dry for 36 hours or more.

The soil/clay absorbent mixtures were prepared in two 3.5-ft^3 (100-L) cement mixers via the addition of weighed quantities of each mixture component into a mixer. The organic contaminants were added to the soil/clay mixtures as a combined organic solution. Trace metal contaminants were added in an aqueous solution. After the organic and trace metal solutions were added, additional water (if needed) was added to adjust the contaminated soil mixtures to the desired moisture content. The final soil mixtures were tumbled to uniform appearance, then transferred to 55-gal (208-L) drums that were then sealed. Contaminated soil mixtures were allowed to age between 7 and 14 days before use in a test.

The organic compounds included in the test feed materials were n-hexane, octane, benzene, toluene, tetrachloroethene, chlorobenzene, naphthalene, anthracene, and pyrene. This set of compounds includes common volatile organic solvent contaminants (benzene, toluene, tetrachloroethene, and chlorobenzene), common gasoline constituent contaminants (n-hexane, octane, and benzene), and common semivolatile organic contaminants associated with coal tar or manufactured gas plant materials (naphthalene, anthracene, and pyrene). Compound boiling points ranged from 69° to 156°C. Table 4 summarizes the organic mixture composition used to spike the test mixtures. The organic contaminant mixture was added to the soil/clay mixtures in the ratio of 0.02 kg organic liquid to 1.00 kg final soil mixture. Resulting contaminated soil organic constituent concentrations are also noted in Table 4.

Contaminant trace metals were added to the soil/clay absorbent feed materials as a concentrated aqueous solution. The trace metals added and their concentrations are summarized in Table 5. All metal constituents were added as soluble nitrate salts except arsenic, which was added as As_2O_3 dissolved into the acid nitrate spike solution. The metals spike solution was added to the soil/clay mixtures in the ratio of 0.05 kg spike solution per kg of final contaminated soil mixture. Resulting contaminated soil trace metal concentrations, neglecting native soil/clay metal concentrations, are also noted in Table 5.

3.1.2 Test Conditions

As noted above, the test program consisted of 12 tests under 11 different combinations of the test variables, with one test performed in duplicate. The test parameters were soil moisture content, treatment temperature, treatment time, solids bed depth, and degree of solids

TABLE 4. ORGANIC CONSTITUENTS IN THE SYNTHETIC CONTAMINATED SOIL

Compound	Molecular weight	Specific gravity	Melting point, °C	Boiling point, °C	Organic liquid mixture composition, wt %	Concentration in soil at an organic liquid fraction of 2%, mg/kg
n-Hexane	86.2	0.66	-94	69	15	3,000
Benzene	78.1	0.88	6	80	15	3,000
Toluene	92.7	0.87	-95	111	15	3,000
Tetrachloroethene	165.9	1.62	-22	121	24	4,800
n-Octane	114.2	0.70	-57	126	15	3,000
Chlorobenzene	112.6	1.11	50	132	10	2,000
Naphthalene	128.2	1.16	80	218	3	600
Phenanthrene	178.2	1.18	100	340	2	400
Pyrene	202.2	1.27	156	404	1	200

TABLE 5. TRACE METAL CONSTITUENTS IN THE SYNTHETIC CONTAMINATED SOIL

| Metal | Aqueous spike solution | | | Resulting soil feed metal concentration[b], mg/kg |
	Metal concentration, g/L	Compound	Compound concentration[a], g/L	
Arsenic	0.50	As_2O_3	0.67	25
Barium	4.0	$Ba(NO_3)_2$	7.61	200
Cadmium	0.20	$Cd(NO_3)_2 \cdot 4H_2O$	0.55	10
Chromium	0.50	$Cr(NO_3)_3 \cdot 9H_2O$	3.8	25
Lead	0.80	$Pb(NO_3)_2$	1.28	40
Mercury	0.20	$Hg(NO_3)_2$	0.32	10

[a]Sufficient HNO_3 added to maintain lead arsenate compounds in solution.
[b]Negligible soil metal concentrations and a ratio of 0.05 kg of spike solution per kg of organic/soil/spike solution mixture assumed.

agitation. Soil moisture content was directly varied, at 10 and 20 percent, respectively. Changes in the other test parameters were caused by changing the RKS operating conditions. The operating conditions varied from test condition to test condition were kiln exit gas temperature, contaminated soil feedrate, and kiln rotation rate. Three kiln exit gas temperatures were tested, 320°, 480°, and 650°C (600°, 900°, and 1,200°F). Two feedrates were tested, 70 and 210 kg/hr (150 and 470 lb/hr). Three rotation rates were tested, 0.2, 0.5, and 1.5 rpm.

Kiln exit gas temperature primarily affected peak solids bed temperature. Peak solids bed temperatures corresponding to the above kiln exit gas temperatures were about 120°, 260°, and 430°C (250°, 500°, and 800°F), respectively. Kiln rotation rate affected both degree of agitation and solids residence time in the kiln, or maximum treatment time. Total kiln solids residence times corresponding to the above rotation rates were 60, 40, and 30 minutes, respectively. The combination of feedrate and kiln rotation rate affected solids bed depth.

Total treatment times were varied by varying kiln rotation rates, as noted above. However, to allow the evaluation of treatment effectiveness at multiple, partial treatment times for each test condition, samples of the solids bed material were taken at four axial locations along the kiln for each test in addition to a solids discharge sample. These additional samples corresponded to four different treatment times at each test condition.

A summary of the target test operating conditions and soil moisture contents for each of the specified 12 tests is given in Table 6. The "center point" of the test matrix is represented by Test 2, with soil feedrate at 70 kg/hr (150 lb/hr), kiln exit gas temperature of 480°C (900°F),

TABLE 6. TARGET TEST CONDITIONS

Test	Kiln exit gas temperature, °C (°F)	Expected peak solids bed temperature, °C (°F)	Kiln rotation rate, rpm	Soil feedrate, kg/hr (lb/hr)	Soil moisture content, %
1	320 (600)	120 (250)	0.2	70 (150)	10
2	480 (900)	270 (520)	0.2	70 (150)	10
3	650 (1,200)	430 (800)	0.2	70 (150)	10
4	320 (600)	120 (250)	0.2	70 (150)	20
5	480 (900)	270 (520)	0.2	70 (150)	20
6	650 (1,200)	430 (800)	0.2	70 (150)	20
7	480 (900)	270 (520)	0.5	70 (150)	10
8	480 (900)	270 (520)	0.5	70 (150)	20
9	480 (900)	270 (520)	1.5	70 (150)	20
10	480 (900)	270 (520)	0.2	210 (470)	10
11	480 (900)	270 (520)	0.2	210 (470)	20
12	480 (900)	270 (520)	0.2	70 (150)	10

kiln rotation rate of 0.2 rpm, and soil moisture content of 10 percent. This test condition was tested in duplicate (Test 12). From this "center point," kiln temperature was varied (Tests 1 and 3), soil moisture content was varied (Test 5), kiln rotation rate was varied (Test 7), and soil feedrate was varied (Test 10). Additional test combinations were performed for the high moisture soil at the base feedrate and rotation rate (Tests 4 and 6), at the high feedrate and base rotation rate (Test 11), and at the base feedrate and increased rotation rate (Test 8). The highest rotation rate was tested at high feedrate with the high moisture soil (Test 9).

For all tests, the afterburner was operated at 1,090°C (2,000°F) to ensure satisfactory burnout of all volatilized organic compounds. The scrubber system was operated under its nominal design conditions to achieve typical scrubber performance. The scrubber was operated at near total recycle, so there was minimum blowdown. The synthetic contaminated soil was fed continuously until all flue gas sampling was completed. Treated soil was continuously removed from the kiln ash hopper via an ash auger transfer system, and deposited in initially clean 55-gal (208-L) drums. After the completion of each test (all flue gas sampling completed) the system continued to operate at the specified test conditions, without soil feed, until all treated soil was cleared from the kiln. The weight of treated soil collected was monitored continuously throughout the test; the resulting data allowed the calculation of total kiln solids residence times.

A summary of the actual test conditions in effect for each test is given in Table 7. As shown, average kiln exit gas temperature targets were closely met for all tests. Solids bed temperatures were measured at four locations along the kiln axis — 0.6, 1.1, 1.5, and 2.0 m (2.0, 3.5, 5.0, and 6.5 ft) from the kiln feed face. Measurements were made with a specially-fabricated probe that allowed the immersing of four thermocouples in the solids bed at the respective axial locations. Solids bed temperatures measured for the tests are also given in Table 7.

3.1.3 Sampling and Analysis

For all tests, the sampling protocol consisted of:

- Obtaining a composite sample of the contaminated soil feed material mixture

- Obtaining composite samples of the treated soil in the kiln chamber at four axial locations corresponding to the solids bed temperature measurements — 0.6, 1.1, 1.5, and 2.0 m (2.0, 3.5, 5.5, and 8.6 ft) from the kiln feed face

- Obtaining a composite sample of the treated soil discharge from the discharge collection drum

- Obtaining composite pre-test and post-test scrubber liquor samples

- Sampling flue gas for trace metals using an EPA multiple metals train at the venturi/packed-column scrubber exit

- Sampling flue gas for mercury using a Method 101A train at the venturi/packed-column scrubber exit

- Continuously monitoring O_2, CO, and total unburned hydrocarbon (TUHC) levels in the kiln exit flue gas

- Continuously monitoring O_2 in the afterburner exit flue gas

- Continuously monitoring O_2 and CO_2 downstream of the venturi/packed-column scrubber

- Continuously monitoring O_2 and CO in the stack downstream of the secondary APCS (carbon bed/HEPA filter)

- Sampling the stack gas for particulate, and HCl, and Cl_2 using Method 50

As noted in Section 3.1.1, contaminated soil feed was prepared, placed into 55-gal (208-L) drums, and allowed to age between 7 and 14 days prior to use in a test. Just prior to a test, the drums of soil to support the test were opened and sampled. Drum contents were then transferred to the screw feed hopper for feeding.

Four composite kiln solids bed samples were also collected for each test. One sample was collected using a custom-fabricated quartz scoop at each of the four axial locations where

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TABLE 7. ACTUAL TEST OPERATING CONDITIONS

Test Date	1 1/29/93	2 2/2/93	3 2/4/93	4 1/27/93	5 12/4/92	6 12/16/92	7 1/6/93	8 12/9/92	9 2/11/93	10 1/15/93	11 1/19/93	12 1/21/93
Average soil feedrate, kg/hr (lb/hr)	68 (149)	70 (155)	67 (147)	69 (153)	73 (160)	71 (157)	67 (148)	78 (171)	66 (145)	215 (473)	214 (471)	67 (148)
Kiln exit gas temperature												
Range, °C (°F)	305-331 (501-627)	474-492 (885-918)	641-658 (1,185-1,216)	301-330 (524-626)	463-499 (866-930)	633-660 (1,171-1,220)	471-494 (880-921)	467-501 (873-935)	471-492 (880-918)	287-508 (548-946)	464-500 (867-932)	471-493 (879-919)
Average, °C (°F)	317 (603)	482 (900)	648 (1,199)	316 (601)	482 (900)	648 (1,199)	482 (900)	480 (896)	482 (900)	481 (897)	482 (900)	482 (900)
Kiln rotation rate, rpm	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.5	1.5	0.2	0.2	0.2
Total kiln solids residence time, min	58	67	70	64	61	54	60	29	27	36	42	63
Average solids bed temperature at "x" m ("x" ft) from feed face, °C (°F)												
0.6 (2.0)	86 (186)	123 (253)	267 (512)	69 (156)	113 (235)	122 (251)	144 (292)	179 (355)	172 (341)	130 (266)	107 (224)	144 (291)
1.1 (3.5)	109 (228)	182 (359)	393 (740)	88 (191)	204 (399)	319 (606)	204 (400)	215 (419)	194 (382)	161 (321)	132 (269)	211 (412)
1.5 (5.0)	115 (239)	228 (443)	434 (814)	98 (208)	260 (500)	401 (753)	249 (481)	239 (462)	245 (473)	175 (347)	149 (300)	257 (495)
2.0 (6.5)	123 (254)	227 (440)	451 (844)	123 (254)	182 (359)	356 (672)	241 (465)	231 (448)	277 (531)	253 (487)	239 (463)	244 (471)

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solids bed temperature was measured. Each of these samples represented a different treatment time under the set of other test conditions established for each test. A sample of the final treated soil discharge was also collected from the discharge collection drum after the completion of each test.

Test program samples were analyzed as follows. Unspiked soil/clay absorbent mixture, each test's feed mixture, and all treated soil samples were analyzed for the spiked volatile and semivolatile organic contaminants and the spiked trace metals. A composite of the Test 1, 2, and 3 soil feed, and the final treated soil discharge samples for each of these tests, were analyzed for polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs) by Method 8290.

Toxicity characteristic leaching procedure (TCLP) leachates of two composite soil feed samples and of all treated soil samples were prepared and analyzed for the test trace metals. Specifically, leachates were digested by EPA Method 3010 and analyzed for barium, cadmium, chromium, and lead by inductively coupled argon plasma (ICAP) spectroscopy by Method 6010; leachates were digested and analyzed for arsenic by Method 7060; and leachates were digested and analyzed for mercury by Method 7470.

All pre-test and post-test scrubber liquor samples were analyzed for the test trace metals by the same methods employed for the TCLP leachate samples. In addition, one composite pre-test scrubber liquor and all post-test scrubber liquor samples were analyzed for the spiked volatile and semivolatile organic soil contaminants.

Finally, all multiple metals train samples were analyzed for the non-mercury test trace metals, and the Method 101A sampling train samples were analyzed for mercury.

3.2 CURRENT STATUS

As noted in Section 3.1.2, the testing portion of this program was completed in February 1993. However, due to the large number of samples collected, the organic analysis results were not completely reported until May. In addition, the trace metal analysis results were not completely reported until mid-August. Evaluation of the very large quantity of test data collected in the program was underway at the close of FY93. The test report will be completed in FY94.

SECTION 4

INCINERATION OF SIMULATED MIXED WASTE

The Savannah River Laboratory (SRL) is providing technical support for the design and eventual operation of the Consolidated Incineration Facility (CIF), a rotary kiln incineration system to be installed at the Savannah River Plant to treat hazardous and combustible low-level mixed waste. As a key part of this technical support, SRL (D. Burns, Coordinator) requested that a series of pilot-scale incineration tests be performed at the IRF to supply data to support final equipment specifications for CIF subsystems, to guide trial burn planning efforts, and to supply kiln ash samples for solidification/stabilization experiments. These tests were performed under contract to SRL within the third-party use provisions of the IRF operations contract.

In this series of tests, simulated waste feeds representing typical Savannah River Plant low-level mixed waste were incinerated in the IRF RKS. Three simulated waste types were tested in a 22-test program in which waste type, waste density, waste feedrate, solids residence time in the kiln, and incineration temperatures were varied. The objectives of the test program were to:

- Measure the incineration system flue gas particulate load and size distribution upstream of any APCS, as a function of the test variables

- Collect sufficient kiln bottom ash and flue gas particulate upstream of the APCS for further characterization by SRL, as a function of the test variables

- Measure waste volume and mass reduction as a function of the test variables

- In a limited set of three tests with simulated waste spiked with organic hazardous constituents and hazardous constituent trace metals:

  - Measure organic constituent DREs as a function of the test variables

  - Evaluate the fate of the trace metals with respect to their distribution among incinerator discharge streams as a function of the test variables

Results of the test program are discussed in the subsections that follow.

4.1   TEST PROGRAM

As noted above, all tests were performed in the RKS. For the tests, the RKS was configured as shown in Figure 1 with the exception that the Calvert scrubber system was not in

place. Sections 4.1.1 through 4.1.3 discuss the simulated mixed wastes tested, the matrix of incinerator operating conditions tested, and the sampling and analysis matrix completed.

4.1.1 Test Waste Description

Three simulated waste feed mixtures were incinerated in different tests during the program. The three waste types were:

- Design waste mix A, which contained, by weight, 30 percent white copier paper, 15 percent newsprint type yellow paper, 10 percent polyvinylchloride (PVC) scraps, 25 percent polyethylene (PE) bags, and 20 percent latex gloves

- Spiked design waste mix E, which consisted of waste type A spiked with hazardous constituent trace metals and organic constituents. The organic constituents, considered as the principal organic hazardous constituents (POHCs) requiring demonstration that incineration achieved 99.99 percent DRE, were hexachloroethane and hexachlorobenzene. Each POHC was added at a concentration of 0.6 percent by weight of the waste A base. In addition, hazardous constituent trace metals were spiked into this waste mixture. The metals spiking compounds and spiking levels are shown in Table 8.

- Design waste mix B, a high-ash waste that consisted of 100 percent copier paper

TABLE 8. HAZARDOUS CONSTITUENT METALS SPIKED IN WASTE E

Metal	Spiking compound	Metal concentration in simulated waste, mg metal/kg feed
Antimony	Antimony potassium tartrate $[K(SbO)C_4H_4O_6 \cdot \frac{1}{2} H_2O]$	730
Barium	Barium acetate $[Ba(CH_3COO)_2]$	10,000
Chromium	Chromium nitrate, 9-hydrate $[Cr(NO_3)_3 \cdot 9 H_2O]$	550
Lead	Lead nitrate $[Pb(NO_3)_2]$	9,000
Mercury	Mercuric nitrate, monohydrate $[Hg(NO_3)_2 \cdot H_2O]$	590
Thallium	Thallium acetate $[Tl(CH_3 COO)]$	730

The bulk raw waste materials (the two types of paper, PVC, PE, and gloves) were delivered to the IRF by SRL. Waste blending, spiking (for waste E feed), and packaging for feeding to the RKS were performed at the IRF. The waste was packaged into 1.5-gal (5.7-L) cubical cardboard boxes with length, width, and height of 7 in. (17.8 cm). These boxes were fed into the RKS via the ram feed system. Three target densities of waste type A were tested: 3, 6, and 9 lb/ft^3 (48, 96, and 144 g/L). An industrial shredder was used to shred the paper and PVC. In packing the waste A boxes, each box was first lined with a PE bag, then packed sequentially with each item, and then sealed with paper tape backed with water-soluble glue. The PE bag liner was not used for the waste B boxes, and only one waste B density, 9 lb/ft^3 (144 g/L), was tested.

Waste E boxes required the addition of the POHCs and spike metals. These boxes were packaged with the required density of waste A, which was then spiked with the POHCs and metals. Each POHC was preweighed into plastic test tubes that were emptied into each box. The metals were added as aqueous solutions. The PE bag liners were then sealed with a plastic tie and the boxes sealed with paper tape.

4.1.2 Test Conditions

The test program variables were waste type (A, B, and E), waste feed density, waste feedrate, kiln and afterburner temperatures, and kiln solids residence time. Table 9 summarizes the matrix of target test conditions. The primary waste feedrate settings desired by SRL for the test program variable were in terms of the volumetric heat release rate from the waste (kW/m^3 [Btu/hr/ft^3]). Given that the volume of the RKS is 1.9 m^3 (67.2 ft^3), required waste heat input rates (kW [Btu/hr]) can be specified. Knowledge of the heating values of the waste components allowed the specification of corresponding waste weight feedrates (kg/hr [lb/hr]) as shown in Table 9.

The waste feeding procedure involved placing the entire quantity of feed for a test on a weigh scale and manually loading each box onto the ram feeder. The ram feeder's operation was remotely controlled to deliver each box into the kiln at the specified feedrate.

For all tests, the scrubber system was operated at its nominal design operating conditions, listed in Table 10. The scrubber system was operated as close to complete recirculation (minimum blowdown) as possible for all tests in order to maximize the total solids content for each waste type. The same scrubber liquor was recirculated in all tests for a given waste type.

A total of 765 gal (2,900 L) of scrubber liquor with a solids content of 1 percent was collected from 17 waste A tests. From the waste B tests, a total scrubber liquor volume of 265 gal (1,000 L) with a 1 percent solids content was collected. The total scrubber liquor volume collected from the waste A tests and the total from the waste B tests were shipped separately to SRL for further characterization. Scrubber liquor from waste E tests was disposed of.

Ash from each test was initially collected in 20-gal (76-L) drums in the kiln ash pit and, after cooling, transferred to 5-gal (19-L) plastic drums. In addition, some amount of flyash was deposited in the afterburner, and in the entry and observation hatches to the kiln. Ash from the

TABLE 9. TARGET TEST CONDITIONS

Test	Waste type	Waste density, g/L (lb/ft²)	Exit flue gas temperature, °C (°F)		Charge regimen		Waste feedrate			Kiln solids residence time, min
			Kiln	Afterburner	Weight waste base/box[a], kg (lb)	Boxes per hr	kg/hr (lb/hr)	kW (kBtu/hr)	kW/m³ (kBtu/hr/ft³)	
1	A	48 (3)	760 (1,400)	870 (1,600)	0.27 (0.6)	48	13.1 (28.8)	93 (317)	49 (4.7)	30
2	A	48 (3)	760 (1,400)	870 (1,600)	0.27 (0.6)	90	24.6 (54.0)	174 (595)	91 (8.8)	60
3	A	48 (3)	1,000 (1,830)	1,100 (2,010)	0.27 (0.6)	90	24.6 (54.0)	174 (595)	91 (8.8)	30
4	A	48 (3)	1,000 (1,830)	1,100 (2,010)	0.27 (0.6)	48	13.1 (28.8)	93 (317)	49 (4.7)	60
5	A	144 (9)	760 (1,400)	870 (1,600)	0.82 (1.8)	16	13.1 (28.8)	93 (317)	49 (4.7)	30
6	A	144 (9)	760 (1,400)	870 (1,600)	0.82 (1.8)	30	24.6 (54.0)	174 (595)	91 (8.8)	60
7	E	144 (9)	1,000 (1,830)	1,100 (2,010)	0.82 (1.8)	30	24.6 (54.0)	174 (595)	91 (8.8)	30
8	A	144 (9)	1,000 (1,830)	1,100 (2,010)	0.82 (1.8)	16	13.1 (28.8)	93 (317)	49 (4.7)	60
9	A	96 (6)	1,000 (1,830)	1,100 (2,010)	0.55 (1.2)	45	24.6 (54.0)	174 (595)	91 (8.8)	60
10	E	96 (6)	760 (1,400)	870 (1,600)	0.55 (1.2)	45	24.6 (54.0)	174 (595)	91 (8.8)	30
11	A	96 (6)	760 (1,400)	870 (1,600)	0.55 (1.2)	24	13.1 (28.8)	93 (317)	49 (4.7)	60
12	A	96 (6)	1,000 (1,830)	1,100 (2,010)	0.55 (1.2)	24	13.1 (28.8)	93 (317)	49 (4.7)	30
13	A	144 (9)	1,000 (1,830)	1,100 (2,010)	0.82 (1.8)	24	19.6 (43.2)	139 (476)	73 (7.1)	45
14	E	144 (9)	870 (1,600)	1,090 (2,000)	0.82 (1.8)	30	24.6 (54.0)	174 (595)	91 (8.8)	45
15	A	144 (9)	870 (1,600)	1,090 (2,000)	0.82 (1.8)	24	19.6 (43.2)	139 (476)	73 (7.1)	60
16	A	144 (9)	760 (1,400)	870 (1,600)	0.82 (1.8)	24	19.6 (43.2)	139 (476)	73 (7.1)	30
17	A	144 (9)	760 (1,400)	870 (1,600)	0.27 (0.6)	72	19.6 (43.2)	139 (476)	73 (7.1)	60
18	A	48 (3)	870 (1,600)	1,090 (2,000)	0.27 (0.6)	90	24.6 (54.0)	174 (595)	91 (8.8)	30
19	A	48 (3)	1,000 (1,830)	1,100 (2,010)	0.27 (0.6)	48	13.1 (28.8)	93 (317)	49 (4.7)	45
20	A	144 (9)	760 (1,400)	870 (1,600)	0.82 (1.8)	16	13.1 (28.8)	93 (317)	49 (4.7)	45
21	B	144 (9)	1,000 (1,830)	1,100 (2,010)	0.82 (1.8)	36	29.5 (64.8)	78 (267)	41 (4.0)	30
22	B	144 (9)	1,000 (1,830)	1,100 (2,010)	0.82 (1.8)	36	29.5 (64.8)	78 (267)	41 (4.0)	60

[a]Excludes the POHC and trace metal spike for waste E.

TABLE 10. APCS OPERATING CONDITIONS

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)
Scrubber blowdown rate	0 L/min (0 gpm) or minimum operable

afterburner was recovered whenever the kiln and the afterburner were shut down and sufficiently cool between tests.

On any given test day the RKS was brought to steady operation at the desired test condition, firing natural gas only. Waste feed was then initiated. Flue gas sampling was started only after at least 1 hour of steady operation in which waste feeding had occurred.

Table 11 summarizes the actual RKS operating conditions for each test, along with the respective test targets. As indicated in the table, actual test waste feedrates were within 6 percent of target for all except three tests. Even for these three, actual waste feedrates were still within 9 percent of target. Target kiln solids residence times were always achieved.

Average kiln exit gas temperatures achieved were within 14°C (25°F) of target temperatures for all but three tests. For Test 6, the average kiln exit gas temperature, at 825°C (1,517°F), was 65°C (117°F) higher than the 760°C (1,400°F) target. As noted in Table 11, the target kiln exit gas O_2 level was 10 percent for all tests. The attempt to maintain a near target flue gas O_2 level at the kiln exit for the high waste A feedrate specified for Test 6 resulted in higher than target kiln exit gas temperatures. At the specified heat input rate for Test 6, gas temperatures could not be held as low as 760°C (1,400°F) without the addition of cooling air in excess of that associated with an exit gas O_2 of 11 percent. For subsequent tests, the SRL Coordinator agreed that maintaining target kiln gas temperatures was more important than achieving target flue gas O_2 levels. Thus, for subsequent tests, the low kiln exit gas temperature target, 760°F (1,400°F), was more nearly achieved for low waste feedrate (13.1 kg/hr[28.8 lb/hr]) conditions at the expense of needing excess air resulting in 12.5 to 13 percent O_2 in the exit flue gas. The next low kiln temperature, high waste A feedrate (24.6 kg/hr [54.0 lb/hr]) test, Test 2, still had an average kiln exit gas temperature of 54°C (97°F) higher than the target, even though excess air corresponding to an exit gas O_2 of 14 percent was allowed. The two tests at low kiln temperature for the intermediate waste A feedrate (19.6 kg/hr [43.2 lb/hr]) were associated with the next two largest differences between average test kiln exit gas temperature and test target. For these two tests, Tests 16 and 17, actual average kiln exit gas temperatures were 23° and 13°C (41° and 24°F) higher, respectively, than the kiln exit gas temperature target. This occurred despite allowing excess air levels corresponding to kiln exit gas O_2 concentrations of 12.1 percent to be introduced.

TABLE 11. ACTUAL TEST CONDITIONS

Test	1	2	3	4	5	6	7	8	9	10	11
Date	5/6/93	4/27/93	4/13/93	5/19/93	3/31/93	3/30/93	6/8/93	4/1/93	5/13/93	6/3/93	5/11/93
Waste feedrate, kg/hr (lb/hr)											
Target	13.1 (28.8)	24.6 (54.0)	24.6 (54.0)	13.1 (28.8)	13.1 (28.8)	24.6 (54.0)	37.3 (82.0)	13.1 (28.8)	24.6 (54.0)	37.3 (82.0)	13.1 (28.8)
Actual average	12.1 (26.6)	25.4 (56.0)	25.5 (56.1)	13.6 (30.0)	13.7 (30.2)	23.7 (52.1)	35.3 (77.7)	13.9 (30.5)	25.0 (54.9)	36.2 (79.6)	13.6 (30.0)
Kiln exit gas temperature, °C (°F)											
Target	760 (1,400)	760 (1,400)	999 (1,830)	999 (1,830)	760 (1,400)	760 (1,400)	999 (1,830)	999 (1,830)	999 (1,830)	760 (1,400)	760 (1,400)
Actual: Average	766 (1,410)	814 (1,497)	998 (1,829)	1,003 (1,837)	773 (1,423)	825 (1,517)	1,000 (1,832)	995 (1,823)	1,007 (1,844)	767 (1,413)	769 (1,417)
Range	717-823 (1,323-1,513)	598-883 (1,108-1,622)	943-1,033 (1,730-1,891)	959-1,034 (1,758-1,894)	733-821 (1,352-1,510)	706-907 (1,302-1,664)	917-1,048 (1,683-1,919)	950-1,042 (1,742-1,908)	959-1,042 (1,759-1,908)	674-811 (1,245-1,492)	736-810 (1,357-1,490)
O_2, %											
Target	10	10	10	10	10	10	10	10	10	10	10
Actual average	12.5	12.4	10.5	9.8	13.4	11.1	9.0	9.9	10.0	12.2	12.6
Afterburner exit gas temperature, °C (°F)											
Target	871 (1,600)	871 (1,600)	1,099 (2,010)	1,099 (2,010)	871 (1,600)	871 (1,600)	1,099 (2,010)	1,099 (2,010)	1,099 (2,010)	871 (1,600)	871 (1,600)
Actual: Average	874 (1,605)	873 (1,603)	1,102 (2,015)	1,102 (2,015)	874 (1,605)	874 (1,605)	1,103 (2,017)	1,102 (2,015)	1,101 (2,014)	874 (1,605)	873 (1,604)
Range	868-882 (1,590-1,619)	867-892 (1,593-1,638)	1,096-1,109 (2,004-2,029)	1,096-1,107 (2,004-2,024)	664-882 (1,588-1,619)	864-886 (1,587-1,627)	1,095-1,110 (2,003-2,030)	1,095-1,107 (2,003-2,024)	1,093-1,108 (1,999-2,027)	860-883 (1,580-1,621)	867-881 (1,592-1,618)
O_2, %											
Target	9	9	9	9	9	9	9	9	9	9	9
Actual average	11.2	14.0	12.8	8.9	13.6	11.1	8.7	8.6	8.7	11.1	11.5
Kiln solids residence time, min											
Target	30	60	30	60	30	60	30	60	60	30	60
Estimated actual	30	60	30	60	30	60	30	60	60	30	60

(continued)

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TABLE 11. (continued)

Test	12	13	14	15	16	17	18	19	20	21	22
Date	5/18/93	4/28/93	6/10/93	5/27/93	5/5/93	4/7/93	5/25/93	4/29/93	4/6/93	3/24/93	3/25/93
Waste feedrate, kg/hr (lb/hr)											
Target	13.1 (28.8)	19.6 (43.2)	37.3 (82.0)	19.6 (43.2)	19.6 (43.2)	19.6 (43.2)	24.6 (54.0)	13.1 (28.8)	13.1 (28.8)	29.5 (64.8)	29.5 (64.8)
Actual average	13.4 (29.4)	20.4 (44.9)	35.1 (77.3)	20.1 (44.2)	19.5 (42.8)	18.0 (39.5)	25.6 (56.3)	13.8 (30.3)	14.3 (31.4)	29.6 (65.1)	30.2 (66.5)
Kiln exit gas temperature, °C (°F)											
Target	999 (1,830)	999 (1,830)	871 (1,600)	871 (1,600)	760 (1,400)	760 (1,400)	871 (1,600)	999 (1,830)	760 (1,400)	999 (1,830)	999 (1,830)
Actual: Average	1,006 (1,843)	1,003 (1,838)	874 (1,605)	878 (1,612)	783 (1,441)	747 (1,376)	890 (1,616)	1,004 (1,840)	759 (1,398)	997 (1,827)	997 (1,827)
Range	977-1,037 (1,790-1,898)	954-1,049 (1,749-1,921)	822-915 (1,511-1,679)	842-917 (1,547-1,682)	739-833 (1,362-1,532)	566-860 (1,051-1,580)	837-916 (1,539-1,681)	970-1,032 (1,778-1,890)	656-829 (1,212-1,524)	987-1,028 (1,773-1,883)	978-1,021 (1,788-1,869)
O₂, %											
Target	10	10	10	10	10	10	10	10	10	10	10
Actual average	11.0	11.1	11.0	11.9	12.1	12.9	10.0	10.8	12.9	9.2	10.1
Afterburner exit gas temperature, °C (°F)											
Target	1,099 (2,010)	1,099 (2,010)	1,093 (2,000)	1,093 (2,000)	871 (1,600)	871 (1,600)	1,093 (2,000)	1,099 (2,010)	871 (1,600)	1,099 (2,010)	1,099 (2,010)
Actual: Average	1,101 (2,014)	1,103 (2,017)	1,098 (2,008)	1,097 (2,006)	874 (1,605)	874 (1,605)	1,097 (2,006)	1,102 (2,015)	873 (1,604)	1,102 (2,015)	1,102 (2,015)
Range	1,094-1,106 (2,001-2,022)	1,096-1,109 (2,005-2,028)	1,087-1,104 (1,988-2,020)	1,089-1,105 (1,992-2,021)	865-883 (1,589-1,621)	856-901 (1,572-1,654)	1,090-1,102 (1,994-2,016)	1,096-1,107 (2,001-2,024)	864-886 (1,587-1,626)	1,094-1,108 (2,002-2,026)	1,095-1,107 (2,003-2,024)
O₂, %											
Target	9	9	9	9	9	9	9	9	9	9	9
Actual average	8.3	8.7	9.1	8.8	13.1	13.0	8.4	12.3	12.6	8.3	8.5
Kiln solids residence time, min											
Target	30	45	45	60	30	60	30	45	45	30	60
Estimated actual	30	45	45	60	30	60	30	45	45	30	60

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Average actual afterburner exit gas temperatures were uniformly within 5°C (8°F) of the target for all tests. However, for many tests, additional excess cooling air was needed so that the exit gas O_2 levels were often as high as 14 percent compared to the test program target of 9 percent.

Table 12 summarizes the solids bed temperatures measured at four locations along the kiln axis. These locations were 0.6, 1.1, 1.5, and 2.0 m (2.0, 3.5, 5.0, and 6.5 ft) from the feed face of the kiln. The solids bed temperature measurement system discussed in Section 3.1.2 was used to make the bed temperature measurements. The data in Table 12 show that the highest solids bed temperature always occurred at either the 0.6 m (2.0 ft) or 1.1 m (3.5 ft) distance from the feed face. These locations were where visual observation showed that the most vigorous waste combustion occurred after waste charge ignition.

As noted above, kiln ash was collected in a 20-gal (76-L) drum placed in the kiln ash discharge pit. However, some of the flyash entrained in kiln exit combustion gas dropped out in the horizontal afterburner of the RKS or in hatches between the kiln and afterburner. The afterburner and hatches were not cleaned after each test. Instead, they were usually cleaned at the beginning of a test week while the incinerator was cool, before the start of heating up the incinerator for the week's tests. Table 13 summarizes the weight of kiln ash collected in the collection drum during each test, and collected from the afterburner and hatches after groups of tests.

4.1.3   Sampling and Analysis

The sampling protocol followed to satisfy the test plan objectives entailed:

- Collecting and shipping all kiln bottom ash from each test to SRL

- Collecting and shipping all composite scrubber liquor from the test series with waste A and waste B to SRL

- Continuously measuring O_2 levels at the kiln exit; O_2, CO, CO_2, NO_x, and TUHC levels at the afterburner exit; O_2, CO_2, and NO_x levels at the scrubber exit; and O_2 and CO at the stack

- Sampling the flue gas in triplicate for each test at the afterburner exit for particulate loading using Method 5, and for particle size distribution using an Andersen cascade impactor train

- Sampling the flue gas in triplicate for each test at the afterburner exit to obtain gram-sized particulate samples, using a modified Method 17 train

- Sampling the flue gas in triplicate for Tests 7, 10, and 14 at the afterburner exit for trace metals, using the EPA multiple metals train

- Sampling the flue gas for Tests 7, 10, 14, and 18 at the afterburner exit for the test POHCs, using Method 0010

TABLE 12. SOLIDS BED TEMPERATURES

		Temperature, °C (°F)			
		Solids bed at a distance of "x" m ("x" ft) from the kiln feed face			
Test	Kiln exit gas	0.6 m (2.0 ft)	1.1 m (3.5 ft)	1.5 m (5.0 ft)	2.0 m (6.5 ft)
1	766 (1,410)	885 (1,625)	779 (1,434)	717 (1,323)	691 (1,275)
2	814 (1,497)	887 (1,628)	867 (1,596)	777 (1,431)	746 (1,375)
3	998 (1,829)	986 (1,807)	1,094 (2,001)	1,003 (1,837)	975 (1,787)
4	1,003 (1,837)	1,091 (1,996)	1,086 (1,987)	1,030 (1,886)	937 (1,718)
5	773 (1,423)	851 (1,564)	801 (1,474)	742 (1,368)	701 (1,293)
6	825 (1,517)	832 (1,530)	919 (1,687)	808 (1,487)	760 (1,400)
7	1,000 (1,832)	842 (1,547)	1,133 (2,072)	1,000 (1,832)	977 (1,791)
8	995 (1,823)	968 (1,775)	1,003 (1,838)	967 (1,773)	947 (1,736)
9	1,007 (1,844)	1,098 (2,009)	1,131 (2,067)	1,046 (1,915)	971 (1,780)
10	767 (1,413)	679 (1,255)	879 (1,614)	717 (1,322)	696 (1,285)
11	769 (1,417)	864 (1,588)	765 (1,409)	714 (1,317)	667 (1,232)
12	1,006 (1,843)	1,053 (1,927)	1,047 (1,916)	1,009 (1,849)	928 (1,703)
13	1,003 (1,838)	989 (1,813)	1,087 (1,988)	997 (1,826)	972 (1,782)
14	874 (1,606)	726 (1,339)	1,037 (1,898)	863 (1,585)	828 (1,522)
15	878 (1,612)	794 (1,462)	994 (1,822)	856 (1,573)	813 (1,496)
16	783 (1,441)	875 (1,607)	829 (1,525)	753 (1,387)	717 (1,322)
17	747 (1,376)	916 (1,681)	829 (1,524)	729 (1,345)	698 (1,288)
18	880 (1,616)	853 (1,569)	1,030 (1,886)	890 (1,634)	866 (1,590)
19	1,004 (1,840)	1,072 (1,961)	1,048 (1,919)	993 (1,819)	971 (1,779)
20	759 (1,398)	856 (1,573)	779 (1,434)	704 (1,300)	694 (1,281)
21	997 (1,827)	881 (1,617)	980 (1,796)	922 (1,691)	920 (1,688)
22	997 (1,827)	857 (1,574)	1,007 (1,844)	936 (1,716)	941 (1,726)

TABLE 13. COLLECTED ASH WEIGHTS

Test	Date	Waste type	Ash collected, kg (lb)		
			Collection drum	Afterburner and hatches	Total per test group
21	3/24/93	B	5.0 (11.0)		
22	3/25/93	B	5.9 (13.0)		
After Test 22				11.4 (25.0)	22.3 (49.0)
Total Waste B					22.3 (49.0)
6	3/30/93	A	3.0 (6.5)		
5	3/31/93	A	1.1 (2.5)		
8	4/1/93	A	1.4 (3.0)		
After Test 8				5.5 (12.0)	10.9 (24.0)
20	4/6/93	A	1.4 (3.0)		
17	4/7/93	A	3.2 (7.0)		
After Test 17				2.5 (5.5)	7.1 (15.5)
3	4/13/93	A	2.5 (5.5)		
2	4/27/93	A	2.5 (5.5)		
13	4/28/93	A	1.1 (2.5)		
19	4/29/93	A	1.4 (3.0)		
After Test 19				4.8 (10.5)	12.3 (27.0)
16	5/5/93	A	1.8 (4.0)		
1	5/6/93	A	1.6 (3.5)		
After Test 1				3.4 (7.5)	6.8 (15.0)
11	5/11/93	A	0.9 (2.0)		
9	5/13/93	A	2.3 (5.0)		
After Test 9				2.7 (6.0)	5.9 (13.0)
12	5/18/93	A	0.9 (2.0)		
4	5/19/93	A	1.1 (2.5)		
After Test 4				2.7 (6.0)	4.7 (10.5)
18	5/25/93	A	2.7 (6.0)		
15	5/27/93	A	1.4 (3.0)		
After Test 15				3.2 (7.0)	7.3 (16.0)
Total Waste A					55.0 (121.0)
10	6/3/93	E	5.0 (11.0)		
After Test 10				1.6 (3.5)	6.6 (14.5)
7	6/8/93	E	1.8 (4.0)		
14	6/10/93	E	2.0 (4.5)		
After Test 14				8.9 (19.5)	12.7 (28.0)
Total Waste E					19.3 (42.5)

- Sampling the flue gas for Tests 7, 10, 14, and 18 at the scrubber system exit duct for PCDD/PCDFs, using Method 23

- Sampling the flue gas for Tests 7, 10, and 14 at the stack downstream of the secondary APCS for particulate and HCl, using Method 5

A kiln ash sample from each test was analyzed for total carbon using ASTM Method D-3178. Kiln ash samples from Tests 7, 10, 14, and 18 were analyzed for total chlorine content. The Method 0010 train samples were Soxhlet extracted (EPA Method 3540) and analyzed for the test POHCs by Method 8270.

The front half (filter plus probe wash) and back half (impinger contents) of the multiple metals train were analyzed separately for the spiked trace metals. Microwave multi-acid (HF plus HNO_3) digestion was used to prepare the front half, and conventional digestion to prepare the back half. Digestates were analyzed by ICAP spectroscopy in accordance with Method 6010 for all test trace metals except mercury, which was determined by cold vapor atomic absorption spectroscopy (CVAAS) according to Method 7470. Kiln ash samples for Tests 7, 10, and 14 were also analyzed for the spiked metals by microwave multi-acid digestion followed by ICAP, and for mercury using CVAAS by Method 7471.

The Method 23 train samples from the scrubber exit were extracted and analyzed by Method 8290 for total tetra- through octa-chlorinated PCDDs and PCDFs, with specific quantitation for all 2,3,7,8-chlorine-substituted tetra- through octa-chlorinated isomers.

Stack gas particulate load was determined by desiccating the Method 5 train filter and probe wash. The stack gas HCl levels were determined by analyzing the combined impinger solutions from the train according to Method 9057.

The composite scrubber liquor sample from the waste E tests was subjected to TCLP extraction and analyzed for trace metals and the test POHCs before disposal.

4.2   TEST RESULTS

Table 14 summarizes the particulate levels measured in the afterburner exit flue gas for all tests. Average levels (over three Method 5 runs for a test) ranged from 175 to 743 mg/dscm corrected to 7 percent O_2. The general, though not universal, trend is that the higher afterburner exit particulate levels are associated with the higher waste feedrates for waste A.

Two POHCs, hexachlorobenzene and hexachloroethane, were spiked into the waste feed for three tests, Tests 7, 10, and 14, in order that the achieved DREs could be measured. The spiked waste became waste E. Afterburner exit flue gas concentrations and emission rates of these POHCs were measured for the three tests. In addition, afterburner exit flue gas concentrations of the two POHCs were also measured for Test 18 to establish a background flue gas concentration for a test in which no spiking was performed. Measured flue gas concentrations and corresponding DREs are summarized in Table 15. As shown, neither POHC was detected in the afterburner exit flue gas of any test at detection limits of about 0.6 µg/dscm for hexachlorobenzene and 1.3 to 1.4 µg/dscm for hexachloroethane. Corresponding DREs

TABLE 14. AFTERBURNER EXIT PARTICULATE LOAD

Test	Waste type	Waste density g/L	(lb/ft²)	Target feedrate kg/hr	(lb/hr)	Average temperatures, °C (°F) Kiln exit gas	Afterburner exit gas	Particulate load, mg/dscm at 7% O₂ Train 1	Train 2	Train 3	Average
1	A	48	(3)	13.1	(28.8)	766 (1,410)	874 (1,605)	224	203	255	227
2	A	48	(3)	24.6	(54.0)	814 (1,497)	873 (1,603)	700	708	598	669
3	A	48	(3)	24.6	(54.0)	998 (1,829)	1,102 (2,015)	735	715	779	743
4	A	48	(3)	13.1	(28.8)	1,003 (1,837)	1,102 (2,015)	186	175	205	189
5	A	144	(9)	13.1	(28.8)	773 (1,423)	874 (1,605)	359	264	477	367
6	A	144	(9)	24.6	(54.0)	825 (1,517)	874 (1,605)	652	706	697	685
8	A	144	(9)	13.1	(28.8)	995 (1,823)	1,102 (2,015)	161	191	172	175
9	A	96	(6)	24.6	(54.0)	1,007 (1,844)	1,101 (2,014)	418	382	419	406
11	A	96	(6)	13.1	(28.8)	769 (1,417)	873 (1,604)	202	199	244	215
12	A	96	(6)	13.1	(28.8)	1,006 (1,843)	1,101 (2,014)	186	181	252	206
13	A	144	(9)	19.6	(43.2)	1,003 (1,838)	1,103 (2,017)	259	245	259	254
15	A	144	(9)	24.6	(54.0)	878 (1,612)	1,097 (2,006)	244	239	300	261
16	A	144	(9)	19.6	(43.2)	783 (1,441)	874 (1,605)	448	440	712	533
17	A	48	(3)	19.6	(43.2)	747 (1,376)	874 (1,605)	496	509	216	407
18	A	48	(3)	19.6	(43.2)	880 (1,616)	1,097 (2,006)	418	315	287	340
19	A	48	(3)	13.1	(28.8)	1,004 (1,840)	1,102 (2,015)	387	340	350	359
20	A	144	(9)	13.1	(28.8)	759 (1,398)	873 (1,604)	256	298	402	315
7	E	144	(9)	37.3	(82.0)	1,000 (1,832)	1,103 (2,017)	597	438	632	556
10	E	96	(6)	37.3	(82.0)	767 (1,413)	874 (1,605)	803	719	670	731
14	E	144	(9)	37.3	(82.0)	874 (1,605)	1,098 (2,008)	520	469	505	498
21	B	144	(9)	29.5	(64.8)	997 (1,827)	1,102 (2,015)	268	107	207	193
22	B	144	(9)	29.5	(64.8)	997 (1,827)	1,102 (2,015)	308	85	245	213

TABLE 15. POHC DREs

Test	Average temperature, °C (°F)		Afterburner exit flue gas			
	Kiln exit flue gas	Afterburner exit flue gas	Concentration, µg/dscm		DRE, %	
			Hexachlorobenzene	Hexachloroethane	Hexachlorobenzene	Hexachloroethane
7	1,000 (1,832)	1,103 (2,017)	<0.64	<1.38	>99.99925	>99.9984
10	767 (1,413)	874 (1,605)	<0.59	<1.26	>99.99948	>99.9989
14	874 (1,605)	1,098 (2,008)	<0.63	<1.35	>99.99925	>99.9984
18	880 (1,616)	1,097 (2,006)	<0.62	<1.32	—[a]	—

[a] — = POHC not fed, no DRE appropriate.

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achieved for the three POHC-spiked tests were greater than 99.99925 percent for hexachlorobenzene and greater than 99.9984 for hexachloroethane.

Levels of PCDDs/PCDFs were measured in the scrubber exit flue gas for the same four tests for which afterburner exit flue gas POHC concentrations were measured. PCDD/PCDF results are summarized in Table 16. As shown in the table, the highest PCDD/PCDF emission levels were measured in Test 18, the one test of the four for which no hexachlorobenzene or hexachloroethane was spiked. All total PCDD/PCDF concentrations were less than the recent EPA guidance level of 30 ng/dscm, and all 2,3,7,8-TCDD toxicity equivalent levels were less than to slightly higher than the European Community (EC) guidance level of 0.1 ng/m^3.

Table 17 summarizes the trace metal data from the three tests for which simulated waste was spiked with metals. The data in the table show that the kiln ash antimony, barium, and chromium concentrations were greater than the corresponding waste feed concentrations. This would be expected for metals not volatilized to a significant extent into the kiln combustion gas because a given weight of waste feed produces a smaller weight of kiln ash. In contrast, kiln ash lead concentrations were lower, and mercury and thallium concentrations much lower, than the corresponding waste feed concentrations. This suggests that some, perhaps most, of the feed quantity of these three metals was volatilized under test conditions and was carried out of the kiln in the combustion flue gas.

This point is further illustrated by Table 18. This table summarizes the fractional distributions of the amount of metal fed for each test among the two incineration system discharge streams sampled, the kiln ash and the afterburner exit flue gas. Afterburner exit flue gas distributions are based on the average concentrations for each test given in Table 17. It bears noting that the three metals sampling train concentration measurements for each test gave quite comparable results for each metal.

Two sets of metal distributions are given in Table 18. The first set, comprising the upper half of the table, represents the fraction of the metal fed in the spiked waste accounted for by the respective discharge. This set of distributions also notes the total fraction of metal fed measured in the two discharges. This total fraction represents the degree of mass balance closure achieved for each metal. The second set of distributions, comprising the bottom half of the table, represents fractions normalized to the total amount of each metal measured in the two discharge streams analyzed. These normalized values represent fractions that would have resulted had mass balance closure been 100 percent. Note that the sum of the normalized fractions is, indeed, 100 percent.

Focusing on the percent-of-fed distributions, the data in the upper half of Table 18 show that metal mass balance closures ranged from 18 to 130 percent, with an average closure of 59 percent and median of 39 to 56 percent. That most closures achieved are less than 100 percent is expected because of flyash settling and accumulation in the horizontal afterburner. As noted above, the accumulated ash in the afterburner was removed after Test 10 and after the combination of Tests 7 and 14. This ash was assumed to have the same metal concentrations as bottom ash, and a proportional contribution to the bottom ash factions was included in the distributions in Table 18. However, it is possible that not all of the ash that accumulated in the afterburner was recovered. This would likely have been the case if some ash fusion occurred leading to an accumulation of slag in the afterburner. Because slag is difficult to remove, it is

TABLE 16. FLUE GAS PCDD/PCDF ANALYSIS RESULTS

Analyte	Afterburner exit flue gas concentration, ng/dscm			
	Test 7	Test 10	Test 14	Test 18
2,3,7,8-TCDD	<0.004	<0.003	<0.006	<0.001
1,2,3,7,8-PeCDD	<0.025	<0.009	<0.013	<0.015
1,2,3,4,7,8-HxCDD	<0.019	<0.006	<0.009	0.012
1,2,3,6,7,8-HxCDD	<0.013	0.003	0.006	0.009
1,2,3,7,8,9-HxCDD	0.013	0.006	<0.006	0.015
1,2,3,4,6,7,8-HpCDD	0.047	0.031	0.051	0.078
OCDD	0.138	0.097	0.102	0.330
2,3,7,8-TCDF	0.119	0.034	0.074	0.126
1,2,3,7,8-PeCDF	<0.019	0.014	0.013	0.033
2,3,4,7,8-PeCDF	0.075	0.023	0.058	0.099
1,2,3,4,7,8-HxCDF	0.103	0.031	0.074	0.121
1,2,3,6,7,8-HxCDF	0.038	0.011	0.023	0.048
2,3,4,6,7,8-HxCDF	0.081	0.028	0.070	0.108
1,2,3,7,8,9-HxCDF	<0.015	0.003	<0.009	<0.009
1,2,3,4,6,7,8-HpCDF	0.084	0.037	0.080	0.014
1,2,3,4,7,8,9-HpCDF	0.028	0.020	0.023	0.048
OCDF	0.144	0.094	0.141	0.332
Total TCDD	0.030	0.006	0.013	0.015
Total PeCDD	0.081	0.020	0.022	0.069
Total HxCDD	0.041	0.020	0.040	0.045
Total HpCDD	0.059	0.031	0.096	0.145
Total TCDF	0.210	0.123	0.289	0.393
Total PeCDF	0.312	0.088	0.282	0.785
Total HxCDF	0.344	0.120	0.273	0.513
Total HpCDF	0.097	0.094	0.180	0.332
Total PCDD/PCDF	1.46	0.69	1.44	2.96
2,3,7,8-TCDD toxicity equivalents	0.097	0.033	0.064	0.116

TABLE 17. TRACE METAL CONCENTRATIONS IN FEED AND DISCHARGE SAMPLES

Concentration	Antimony	Barium	Chromium	Lead	Mercury	Thallium
Simulated waste feed, mg/kg	730	10,000	550	9,000	590	730
Test 7						
Kiln ash, mg/kg	4,160	61,100	2,200	67.1	0.03	0.1
Afterburner exit flue gas, mg/dscm						
Train 1	2.86	8.5	0.57	44.8	5.10	9.3
Train 2	4.29	14.2	0.29	49.1	8.61	10.5
Train 3	3.93	7.9	1.41	54.7	7.82	11.3
Average	3.69	10.2	0.76	49.4	7.18	10.4
Test 10						
Kiln ash, mg/kg	1,540	46,200	3,050	14.6	0.04	0.1
Afterburner exit flue gas, mg/dscm						
Train 1	2.71	2.45	0.29	94.7	10.6	13.1
Train 2	2.35	3.00	0.51	58.6	10.3	11.8
Train 3	2.21	2.62	0.48	53.8	10.3	11.2
Average	2.42	2.69	0.43	69.0	10.4	12.0
Test 14						
Kiln ash, mg/kg	6,990	29,900	1,690	1,620	0.1	0.1
Afterburner exit flue gas, mg/dscm						
Train 1	4.31	5.75	0.32	75.9	8.54	14.7
Train 2	4.63	5.48	0.32	72.9	8.05	14.4
Train 3	3.62	7.29	0.68	65.5	9.43	11.7
Average	4.19	6.17	0.44	71.4	8.67	13.6

TABLE 18. TRACE METAL DISTRIBUTIONS

Discharge stream	Antimony	Barium	Chromium	Lead	Mercury	Thallium
	Distribution, % of metal fed					
Test 7, kiln temperature: 1,000°C (1,832°F)						
Kiln ash	29	31	20	<0.04	<0.01	<0.01
Afterburner exit flue gas	36	7	10	39	85	100
Total	65	38	30	39	85	100
Test 10, kiln temperature: 767°C (1,413°F)						
Kiln ash	10	21	25	<0.01	<0.01	<0.01
Afterburner exit flue gas	16	2	5	32	94	82
Total	26	23	30	32	34	82
Test 14, kiln temperature: 874°C (1,605°F)						
Kiln ash	45	14	14	0.8	<0.01	<0.01
Afterburner exit flue gas	40	4	6	55.2	102	130
Total	85	18	20	56	102	130
	Distribution, % of metal measured					
Test 7, kiln temperature: 1,000°C (1,832°F)						
Kiln ash	45	81	68	0.1	<0.01	<0.01
Afterburner exit flue gas	55	19	32	99.9	100	100
Test 10, kiln temperature: 767°C (1,413°F)						
Kiln ash	37	93	84	<0.01	<0.01	<0.01
Afterburner exit flue gas	63	7	16	100	100	100
Test 14, kiln temperature: 874°C (1,605°F)						
Kiln ash	53	77	72	1.5	<0.01	<0.01
Afterburner exit flue gas	47	23	28	98.5	100	100

possible that not all the metal accumulated in the afterburner was recovered. In addition, the assumption that the afterburner accumulation has the same composition as bottom ash may not be true. Metal volatilization, and subsequent condensation on available flyash, may have led to metal enrichment of the flyash.

Mass balance closures achieved for mercury and thallium were quite good, at 85 to 130 percent. Essentially all of the mercury and thallium fed was accounted for in the afterburner exit flue gas. This confirms the expectation that these very volatile metals are vaporized in the kiln and carried out in the vapor phase through the higher temperature afterburner. These metals would not be expected to be present in any unrecovered afterburner accumulation. Thus, this route of possible loss would not have affected mass balance closure for these metals. Mass balance closures for barium, chromium, and lead were uniformly in the 20 to 40 percent range. Closures for antimony were better, at 26 to 85 percent.

Focusing on the normalized distribution data in the bottom half of Table 18 gives a clearer picture of metal partitioning in the tests. This clearer picture occurs because variable mass balance closure is removed as a source of test-to-test data variability. Highly variable and less than perfect mass balance closure has been the universal experience in attempts to measure metal partitioning in combustion sources. Because this variable and less than perfect mass balance closure is invariably experienced, the use of normalized distributions represents a best attempt to quantify metal partitioning phenomena.

The normalized distributions in Table 18 show that, in addition to mercury and thallium, lead exhibited quite volatile behavior in all three conditions tested. Essentially all, greater than 98.5 percent, of the lead discharged from the RKS was accounted for in the afterburner exit flue gas. At most only 1.5 percent was accounted for in the kiln ash at the intermediate kiln temperature tested, 874°C (1,605°F). Barium and chromium were relatively nonvolatile under the conditions tested; 77 to 93 percent of the barium and 68 to 84 percent of the chromium discharged remained with the kiln ash. The remaining fractions accounted for in the afterburner exit flue gas most likely represent the amount of metal contained in entrained flyash. Antimony exhibited intermediate volatility behavior, and was relatively evenly distributed between the two discharges. The variations in kiln (and afterburner) temperatures tested appear not to have affected any metal's partitioning tendencies.

4.3 CONCLUSIONS

Test program conclusions include the following:

- Afterburner exit flue gas particulate levels ranged from 175 to 743 mg/dscm corrected to 7 percent O_2. In general, higher particulate levels were associated with higher waste feedrates.

- Greater than 99.9984 percent POHC (hexachlorobenzene and hexachloroethane) DREs were achieved as measured in the afterburner exit flue gas under the three operating conditions in which POHC-spiked waste was tested. Neither POHC was found above method detection limits for any test in which flue gas was sampled for POHCs.

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- Scrubber exit flue gas total PCDD/PCDF levels ranged from 0.69 to 2.96 ng/dscm, well below a recent EPA guidance level of 30 ng/dscm. 2,3,7,8-TCDD toxicity equivalent levels were 0.033 to 0.116 ng/dscm, just at or below the EC directive level of 0.1 ng/m^3. The highest PCDD/PCDF levels occurred in a test in which no POHCs were spiked into the feed. Lower levels were measured in the tests with POHC-spiked feed.

- Lead, mercury, and thallium exhibited quite volatile behavior over the range of kiln temperatures tested — exit gas at 767°, 874°, and 1,000°C (1,413°, 1,605°, and 1,832°F). Essentially all of the discharged amount of each metal was found in the afterburner exit flue gas, and essentially none in the kiln discharge.

- Barium and chromium exhibited relatively nonvolatile behavior, with 77 to 93 percent of the barium and 68 to 84 percent of the chromium discharged in the kiln ash. The 7 to 19 percent of the barium and 16 to 32 percent of the chromium accounted for in the afterburner exit flue gas most likely represents respective amounts in entrained flyash.

- Antimony exhibited intermediate volatility behavior, being relatively evenly distributed between the two discharge streams analyzed

SECTION 5

TESTING OF FLUFF WASTE AND CONTAMINATED SOIL
FROM THE M. W. MANUFACTURING SUPERFUND SITE

One of the IRF's primary missions is to support Regional Offices in evaluations of the potential of incineration as a treatment option for wastes and other contaminated materials at Superfund sites. One priority site is the M. W. Manufacturing site in Danville, Pennsylvania. EPA Region III (B. Khona, Remedial Project Manager) and the U.S. Army Corps of Engineers (USACE) (H. Santiago, Project Manager) requested that a pilot-scale test program be conducted at the IRF to support evaluations of the suitability of incineration as a treatment technology for wastes and contaminated soil at the site. FY93 efforts in support of this test program are discussed in this section.

5.1   BACKGROUND

The M. W. Manufacturing site began operation in 1966. M. W. Manufacturing Corporation reclaimed copper from scrap wire using both mechanical and chemical processes. Reclamation activities began in 1969 and continued until 1972 when M. W. Manufacturing filed for bankruptcy. Warehouse 81, Inc., acquired the site in 1976 and began mechanical recovery operations from the existing waste piles onsite. The mechanical recovery operations generated large volumes of waste material, termed fluff. The chemical recovery processes used by M. W. Manufacturing also led to site contamination.

The fluff waste produced by the mechanical stripping process consists of fibrous insulation material mixed with plastic. Phthalate esters, copper, and lead are the major contaminants in this material. The chemical recovery process used by M. W. Manufacturing was a two-step process. The first step involved the use of a hot oil bath to melt the plastic insulation away from the metal in the scrap wire. Residual oils were removed from the separated copper in the second step through the use of chlorinated solvents, including trichloroethene and tetrachloroethene. Thus, these solvents are waste and soil contaminants at the site.

The June 1990 record of decision (ROD) document for the site identified five wastes and contaminated materials for remedial treatment:

- Fluff waste piles

- Organic- and trace-metals-contaminated surface soils

- Organic- and trace-metals-contaminated subsurface soils

- Lagoon water

- Contents of drums and tanks

Onsite incineration was identified as the selected treatment for the fluff and the soil. The remedy includes possible stabilization of the incineration ash prior to landfill disposal.

In subsequent efforts, a series of treatability studies was completed to aid in the selection of incineration system design and operating variables. Initially a set of muffle furnace tests was performed using site wastes. The test results suggested that effective organic decontamination and destruction could be achieved at incineration temperatures of 871° and 982°C (1,600° and 1,800°F) and perhaps at as low as 760°C (1,400°F). The residual ash from the muffle furnace tests of both fluff waste and a blend of fluff and site soil exhibited the toxicity characteristic for lead.

The findings of the muffle furnace tests were used to guide a series of small pilot-scale tests. These small pilot-scale batch-mode tests were performed to further aid in the selection of the best set of incinerator operating parameters. The small pilot-scale tests confirmed that 871°C (1,600°F) appeared to be the optimum incineration temperature. However, these tests raised several issues, including the following:

- PCDDs/PCDFs were apparently formed during the incineration of both fluff waste and a fluff/soil mixture. However, this observation may have been an artifact of the system's design and operating mode, which used only air quenching of combustion gas to the 360° to 475°C (680° to 887°F) range. Rapid quenching of flue gas to temperatures below 90°C (200°F) using water may prevent PCDD/PCDF formation.

- Trace metal mass balance closures were poor for all tests

- The fabric filter (baghouse) collection efficiencies for both particulate and metals were 90 to 94 percent, below the expected 98 percent

To extend the data base on the incineration characteristics of the fluff waste and contaminated site soil, Region III requested that pilot-scale testing on a larger scale, more in keeping with the size of incinerator envisioned for use at the site, be performed. Testing at this larger scale would provide flue gas emission and ash residue characteristics data that will better reflect expected actual conditions during the site remediation. Thus, a series of large pilot-scale incineration tests at the IRF was designed to supply these data. The specific data quality objectives (DQOs) of the IRF tests were defined as follows:

- Verify that the fluff waste and the contaminated soil at the site can be incinerated in compliance with the hazardous waste incinerator performance standards and permit requirements of:

  — 99.99 percent principal organic hazardous constituent (POHC) DRE

- HCl emissions less than 1 percent of the APCS inlet flowrate or 1.8 kg/hr, whichever is greater

- CO emissions of less than 100 ppm at 7 percent O_2, 1-hour rolling average

and the recently announced performance guidance of:

- Particulate emissions of less than 34 mg/dscm (0.015 gr/dscf) corrected to 7 percent O_2

- Total tetra- through octa-PCDD/PCDF emissions of less than 30 ng/dscm corrected to 7 percent O_2

● Measure the effectiveness of incineration treatment in decontaminating fluff and soil of their organic contaminants and evaluate whether incineration temperature affects the effectiveness of fluff decontamination

● Measure the distribution of the contaminant trace metals in the fluff and the contaminated soil among the incineration system discharge streams

● Determine whether the bottom ash residue and the APCS discharges from the incineration of fluff and contaminated soil will be toxicity characteristic (TC) hazardous wastes

● Determine whether the bottom ash residue from the incineration of contaminated soil meets the cleanup levels for soil given in the ROD

5.2   TEST PROGRAM

5.2.1   Waste Description

Data on the contaminant concentrations in the fluff waste and the surface and subsurface soil, taken from the ROD, are summarized in Table 19. Only contaminants present at an average concentration of 1 mg/kg or greater in one or more contaminated site matrix are listed in the table. The data in Table 19 show that the major site contaminants are the two phthalate esters, bis (2-ethylhexyl) phthalate (BEHP) and di-n-octyl phthalate (DNOP). Thus, these compounds would be considered the POHCs in the site wastes. In addition, Region III was interested in establishing that tetrachloroethene is effectively destroyed by incineration, so tetrachloroethene was also defined to be a POHC. Site wastes were also highly contaminated with copper and lead, and with lesser, though still significant amounts of antimony, barium, chromium, nickel, and zinc. PCB-1254 was also reported in the ROD to be present at an average of 9.4 mg/kg in the fluff. Site soil PCB levels were significantly lower.

Samples of the fluff waste and surface and subsurface soil were sent to the IRF for characterization analyses. Results of the analyses are summarized in Table 20. Presuming that the characterization samples analyzed typify the test materials to be received for testing in this test program, the soil material for testing will have contaminant concentrations in the range reported in the ROD for site soils. Contaminant concentrations in the fluff material for testing

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TABLE 19. M. W. MANUFACTURING SITE WASTE CONTAMINANTS FROM THE ROD

	Concentration, mg/kg						
	Fluff		Surface soil		Maximum average subsurface soil		
Contaminant	Range over 17 samples	Average	Range over 21 samples	Average	Range	Average	Depth, ft
Volatile Organic Constituents							
2-Butanone	2.8-6.4	1.6	—[a]	—	up to 3.9	0.78	16-18
Tetrachloroethene	0.72-18.0	4.4	0.023-67	10	0.001-1,600[b]	56	4-6
Trichloroethene	—	—	0.002-21	1.0	0.002-2.6	2.7	12-14
1,1,2-Trichloroethane	—	—	0.003-2.8	0.28	up to 5.4	1.1	16-18
1,2-Dichloroethene	—	—	0.002-10	0.49	0.004-0.58	0.04	8-10
Methylene chloride	up to 7.7	0.45	up to 0.83	0.04	—	—	—
Semivolatile Organic Constituents							
Bis(2-ethylhexyl)phthalate	72,000-230,000	149,000	3.9-3,000	836	0.30-30,000[b]	1,480	12-14
Di-n-octyl phthalate	1,800-13,000	4,400	0.2-140	37	0.038-150	7,850	0-2
Di-n-butyl phthalate	—	—	0.48	0.02	0.036-130	3.9	0-2
PCB-1254	0.90-18.1	9.4	0.061-3.7	0.21	0.077-1.0	0.043	0-2
Trace Metals							
Antinomy	80-143	65	62-118	16	—	—	—
Barium	20-232	93	22-107	74	47-218	107	0-2
Cadmium	0.65-4.4	2.4	1.2-12	2.0	1-13	1	0-2
Chromium	24-59	40	7.1-59	27	14-70	20	0-14
Copper	5,910-130,000	50,000	742-171,000	21,600	24-38,900	1,850	12-14
Lead	1,600-3,600	2,400	32-9,770	1,450	7-741	160	16-18
Nickel	4.1-15	5.6	8.5-40	22	42-50	46	6-8
Silver	1.6-5.7	1.8	8.6	0.4	—	—	—
Zinc	135-2,580	620	55-787	240	56-319	144	6-8

[a]— = not reported.
[b]Maximum value in range represents an estimated value above minimum detection limit but below lowest calibration standard ("J" flag).

TABLE 20. M. W. MANUFACTURING SITE CHARACTERIZATION SAMPLE ANALYSIS RESULTS

	Sample		
Parameter	Fluff	Surface soil	Subsurface soil
Characterization			
Moisture, %	7.7	18	9.8
Ash, %			
at 550°C	41	77	89
at 900°C	14	76	90
Heating value, MJ/kg	6.50	0.07	Will not burn
(Btu/lb)	(2,800)	(30)	
Volatile organic constituents, mg/kg			
Tetrachloroethene	146	69	18
1,1,2-Trichloroethane	4.8	1.5	ND[a]
Semivolatile organic constituents, mg/kg			
BEHP	124,000	47.6	4.62
DNOP	17,800	1.95	ND
Trace metals, mg/kg			
Antimony	230	51	<5
Barium	64	60	78
Cadmium	3.5	<0.2	0.93
Chromium	57	30	21
Copper	31,000	8,300	160
Lead	2,700	1,800	180
Nickel	6.1	15	31
Silver	4.0	<0.4	<0.4
Zinc	890	76	62

[a]ND = not detected.

are in the range reported in the ROD for most contaminants. However, the fluff characterization sample contained substantially more tetrachloroethene, 1,1,2-trichloroethane, DNOP, and antimony than did fluff samples reported in the ROD.

Characterization samples received were also analyzed for hazardous waste characteristics. Results are summarized in Table 21.

The two semivolatile POHCs in site materials, BEHP and DNOP, are poor candidates for testing the incineration process with regard to destroying other site waste organic contaminants because they are ranked as relatively easy to thermally destroy compounds in the

TABLE 21. M. W. MANUFACTURING SITE CHARACTERIZATION SAMPLE HAZARDOUS WASTE CHARACTERISTICS ANALYSIS RESULTS

Characteristic	Fluff waste	Surface soil	Subsurface soil	Regulatory level
Reactivity -S, mg/kg	<0.01	<0.01	<0.01	Contains
Reactivity -CN, mg/kg	<0.01	<0.01	<0.01	and reacts
Corrosivity, pH	6.85	8.15	6.37	<2, >12
Ignitability, °F	>200	>200	>200	<140
TCLP leachate, mg/L				
Arsenic	<0.10	<0.10	<0.10	5.0
Barium	0.10	0.37	0.21	100
Cadmium	0.11	0.07	0.07	1.0
Chromium	0.11	0.09	0.09	5.0
Copper	199	158	1.88	—[a]
Lead	3.1	3.2	0.20	5.0
Mercury	<0.002	<0.002	<0.002	0.2
Nickel	<0.01	<0.01	<0.01	—
Selenium	<0.10	<0.10	<0.10	1.0
Silver	<0.01	<0.01	<0.01	5.0
Zinc	5.1	0.49	0.12	—
Pesticides and other organics	ND[b]	ND	ND	

[a]— = no regulatory level.
[b]ND = not detected at detection limits ranging from 0.004 to 0.01 mg/L.

thermal stability based incinerability ranking.[4] This ranking groups the 333 compounds ranked into seven stability classes from most stable, or most difficult to destroy (Class 1), to least stable or easiest to destroy (Class 7). Both BEHP and DNOP are ranked in Class 6, or relatively easy to destroy. To present a challenge to the incineration process and develop data that suggest incineration is capable of achieving sufficient DREs for other site organic contaminants, it was decided to spike the test waste with naphthalene, a Class 1 (most difficult to destroy) POHC. The spiking level was defined to be 2 percent by weight. In addition, it was decided to spike the volatile POHC of greatest interest to Region III, tetrachloroethene, into test materials at a level of 4,000 mg/kg by weight. Tetrachloroethene is a Class 2 POHC. Spiking is needed because site material concentrations of tetrachloroethene, as confirmed by the characterization samples, are too low to allow establishing 99.99 percent DRE at achievable flue gas concentration quantitation limits.

5.2.2   Test Conditions

The test program defined will consist of six tests. All tests are to be conducted in the RKS at the IRF. The configuration of the RKS shown in Figure 18 will be used. This configuration includes the fabric filter APCS, installed as discussed in Section 9.
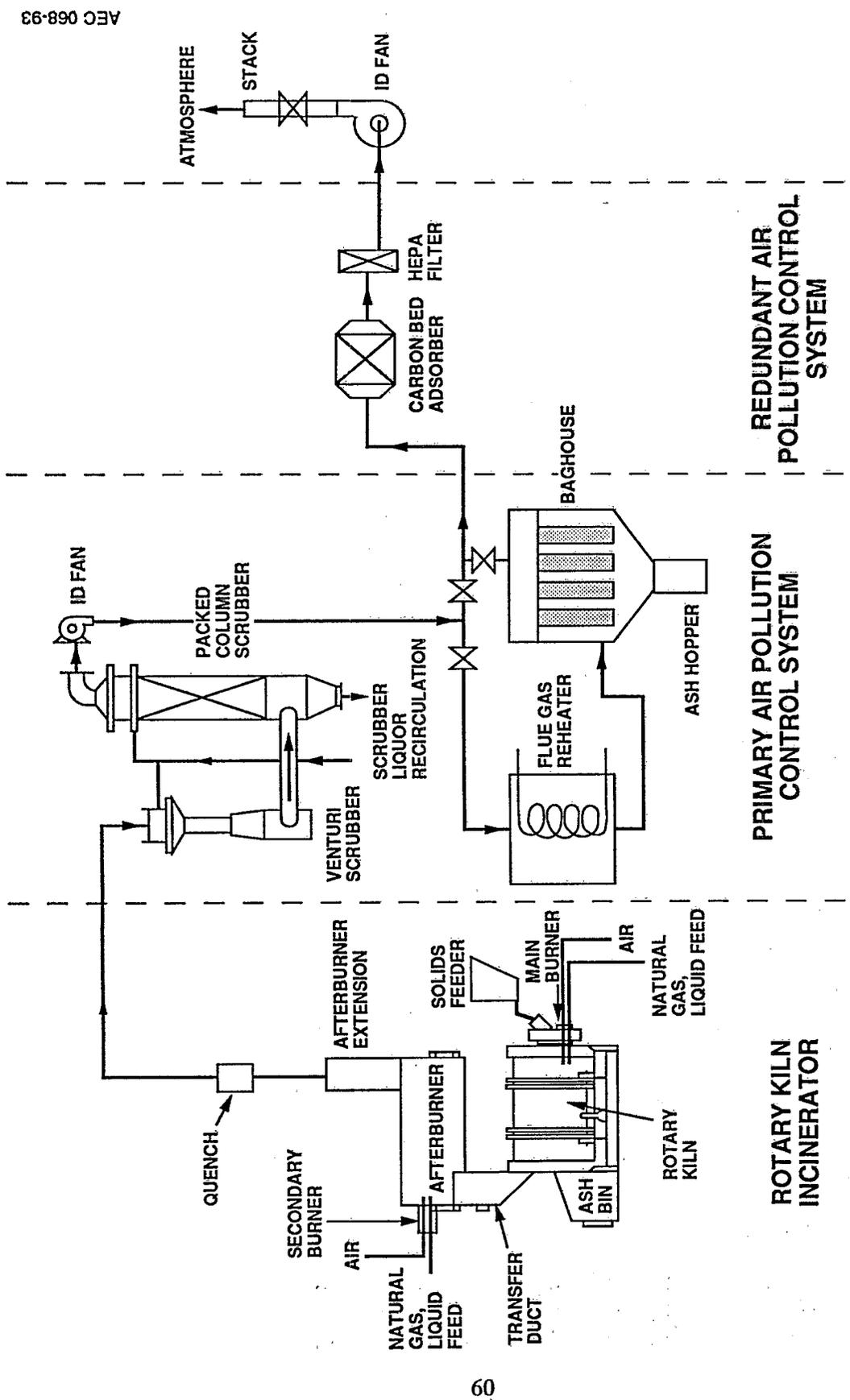
Figure 18. Schematic of the IRF rotary kiln incineration system.

In the planned test program, two sets of duplicate tests feeding fluff waste alone and one set of duplicate tests feeding contaminated soil alone will be performed. The two sets of fluff feed tests will be conducted at different kiln temperatures. Soil and fluff will be tested separately because the eventual site remediation may treat each material separately for logistical reasons. In addition, Region III would like data to determine whether the ash from incinerated soil alone meets the cleanup levels given in the ROD. The test matrix will be as shown in Table 22.

For all tests the kiln exit flue gas O_2 will be nominally 10 percent, afterburner exit gas temperature 1,090°C (2,000°F), and afterburner exit flue gas O_2 nominally 8 percent. The venturi/packed-column scrubber and baghouse APCS units will be operated at their normal design settings. Kiln rotation rate will be set to give a 30-minute kiln solids residence time.

Test material feedrate will be 54.5 kg/hr (120 lb/hr) for all tests. Test materials will be fed to the RKS via the fiberboard container ram feed system. This system sequentially batch feeds 1.5-gal (5.7-L) fiberboard containers (cubical cardboard boxes for these tests) to the kiln.

It is planned that, for all tests, the scrubber system will be operated at its design settings, listed in Table 10, and at as close to total recirculation (zero to minimum blowdown) as possible. For the fluff waste tests, kiln ash will be continuously deposited in initially clean 20-gal (76-L) drums placed in the RKS ash pit. For the soil tests, kiln ash will be continuously removed from the kiln ash hopper via the ash auger transfer system on the kiln and deposited into initially clean 55-gal (208-L) drums.

5.2.3 Sampling and Analysis Procedures

The RKS sampling locations and the scope of the planned sampling effort are shown in the process schematic given in Figure 19. For all tests, the planned sampling matrix will entail:

- Obtaining a composite sample of the test material feed

- Obtaining a composite sample of the kiln ash discharge

- Obtaining a composite sample of the pre-test and post-test scrubber system liquor

TABLE 22. TEST MATRIX

Test	Feed	Kiln exit gas temperature, °C (°F)
1	Fluff	870 (1,600)
2	Duplicate of Test 1	
3	Soil	870 (1,600)
4	Duplicate of Test 3	
5	Fluff	750 (1,400)
6	Duplicate of Test 5	

Sampling point	Test feed material	Kiln ash	Scrubber liquor	Baghouse ash	Continuous monitors					Flue gas				
					O_2	CO	CO_2	NO_x	Heated TUHC	EPA multiple metals train, test trace metals	Method 0010, test semivolatile POHCs	Method 0030, test volatile organic contaminants	Method 23, PCDD/PCDF	Method 5, particulate and HCl
1. Feed	X													
2. Kiln ash discharge		X												
3. Kiln exit flue gas					X									
4. Afterburner exit flue gas					X	X	X	X						
5. Scrubber liquor			X											
6. Baghouse hopper				X										
7. Baghouse exit flue gas					X	X	X	X	X	X	X	X	X	X
8. Stack gas					X	X	X						X	X

Figure 19. Test sampling locations.

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- Obtaining a composite sample of the baghouse ash

- Continuously measuring O_2 concentrations in the kiln exit flue gas; O_2, CO_2, and NO_x in the afterburner exit flue gas; CO, CO_2, NO_x, and TUHC concentrations in the baghouse exit flue gas; and O_2 and CO concentrations in the stack gas

- Sampling flue gas at the baghouse exit for trace metals using the EPA multiple metals train

- Sampling flue gas at the baghouse exit for the waste and spiked POHCs using a Method 0010 train

- Sampling flue gas at the baghouse exit for the waste and spiked volatile organic contaminants using Method 0030 (VOST)

- Sampling the flue gas at the baghouse exit for PCDDs/PCDFs using Method 23

- Sampling the baghouse exit and the stack for particulate and HCl using Method 5; the stack sample is needed to comply with the IRF's permit requirements

Test program samples will be analyzed for matrix-specific combinations of semivolatile POHCs, volatile organic contaminants, semivolatile target compound list (TCL) organic constituents, volatile TCL organic constituents, PCDDs/PCDFs, contaminant trace metals, and chloride. The analysis matrix is summarized in Table 23.

5.3 CURRENT STATUS

All planning and preparatory efforts toward initiating the planned test program were completed during FY93. Specifically:

- A preliminary test plan outline was prepared and distributed in November 1992. A revised test plan outline with revisions to address Region III comments was distributed in December 1992.

- A complete test plan was prepared and distributed in April 1993

- A stand-alone quality assurance project plan (QAPP) was prepared and distributed in September 1993

- Installation of the baghouse system required for the tests by Region III and discussed in Section 9 was completed in September 1993

At the close of FY93, all preparations needed to allow scoping tests to be initiated in mid-October, with planned tests following in November, were nearly complete.

TABLE 23. ANALYSIS PROTOCOL

Sample	Parameter	Analysis method	Frequency
Test feed material	Proximate analysis (moisture, volatile matter, fixed carbon, ash)	ASTM D-5142	1 composite for each test material
	Elemental analysis C, H, O, N, S Cl	ASTM D-3176 ASTM E-442	1 composite for each test material
	Heating value	ASTM D-3286	
	Test semivolatile POHCs	Soxhlet extraction by Method 3540A, GC/MS analysis by Method 8270A[a]	1/fluff test, 1 composite soil
	Test volatile organic contaminants	Purge and trap GC/FID of methanol extract by Method 8015A[a]	1/fluff test, 1 composite soil
	PCDDs/PCDFs	GC/MS by Method 8290[a]	1 composite for each test material
	Trace metals[b]	Digestion by the multiple metals filter method[c], ICAP analysis by Method 6010A[a]	1/fluff test, 1 composite soil
	TCLP extraction	Method 1311[a]	1/fluff test, 1 composite soil
Test feed TCLP leachate	Trace metals[b]	Digestion by Method 3010A, ICAP analysis by Method 6010A[a]	1/fluff test, 1 composite soil
Feed packaging material	Proximate analysis (moisture, volatile matter, fixed carbon, ash)	ASTM D-5142	1 composite
	Elemental analysis C, H, O, N, S Cl	ASTM D-3176 ASTM E-442	1 composite
	Heating value	ASTM D-3286	1 composite
	Test semivolatile POHCs	Soxhlet extraction by Method 3540A, GC/MS analysis by Method 8270A[a]	1 composite
	Test volatile organic contaminants	Purge and trap GC/FID of methanol extract by Method 8015A[a]	1/fluff test, 1 composite soil
	PCDDs/PCDFs	GC/MS by Method 8290[a]	1 composite for each test material
	Trace metals[b]	Digestion by the multiple metals filter method[c], ICAP analysis by Method 6010A[a]	1/fluff test, 1 composite soil
	Ash preparation	Per ASTM D-5142	1 composite
Feed packaging material ash	Test semivolatile POHCs	Soxhlet extraction by Method 3540A, GC/MS analysis by Method 8270A[a]	1 composite
	Test volatile organic contaminants	Purge and trap GC/FID of methanol extract by Method 8015A[a]	1 composite
	Trace metals[b]	Digestion by the multiple metals filter method[c], ICAP analysis by Method 6010A[a]	1 composite
	TCLP extraction	Method 1311[a]	1 composite

[a]SW-846.[5]
[b]As, Sb, Ba, Cd, Cr, Cu, Pb, Ni, Ag, and Zn.
[c]40 CFR 266, App. IX.[6]

(continued)

TABLE 23. (continued)

Sample	Parameter	Analysis method	Frequency
Feed packaging material ash TCLP leachate	Trace metals[b]	Digestion by Method 3010A, ICAP analysis by Method 6010A[a]	1
Kiln ash	Test semivolatile POHCs	Soxhlet extraction by Method 3540A, GC/MS analysis by Method 8270A[a]	1/test
	Test volatile organic contaminants	Purge and trap GC/FID of methanol extract by Method 8015A[a]	1/test
	PCDDs/PCDFs	GC/MS by Method 8290[a]	1/test
	Trace metals[b]	Digestion by the multiple metals filter method[c], ICAP analysis by Method 6010A[a]	1/test
	TCLP extraction	Method 1311[a]	1/test
Kiln ash TCLP leachate	Trace metals[b]	Digestion by Method 3010A, ICAP analysis by Method 6010A[a]	1/test
Pre-test scrubber liquor	Test semivolatile POHCs	Extraction by Method 3520A, GC/MS analysis by Method 8270A[a]	1/test
	Test volatile organic contaminants	Purge and trap by Method 5030A, GC/FID by Method 8015A[a]	1/test
	Trace metals[b]	Digestion by Method 3010A, ICAP analysis by Method 6010A[a]	1/test
	PCDDs/PCDFs	GC/MS by Method 8290[a]	1 sample before the first test
Post-test scrubber liquor	Test semivolatile POHCs	Extraction by Method 3520A, GC/MS analysis by Method 8270A[a]	1/test
	Test volatile organic contaminants	Purge and trap by Method 5030A, GC/FID analysis by Method 8015A[a]	1/test
	PCDDs/PCDFs	GC/MS by Method 8290[a]	1/test
	Trace metals[b]	Digestion by Method 3010A, ICAP analysis by Method 6010A[a]	1/test
	TCLP extraction	Method 1311[a]	1/test
Scrubber liquor TCLP leachate	Trace metals[b]	Digestion by Method 3010A, ICAP analysis by Method 6010A[a]	1/test
Baghouse ash	Test semivolatile POHCs	Extraction by Method 3520A, GC/MS analysis by Method 8270A[a]	1/test
	Test volatile organic contaminants	Purge and trap GC/FID of methanol extract by Method 8015A[a]	1/test
	PCDDs/PCDFs	GC/MS by Method 8290[a]	1/test
	Trace metals[b]	Digestion by the multiple metals filter method[c], ICAP analysis by Method 6010A[a]	1/test
	TCLP extraction	Method 1311[a]	1/test
Baghouse ash TCLP leachate	Trace metals[b]	Digestion by Method 3010A, ICAP analysis by Method 6010A[a]	1/test

[a]SW-846.[5]
[b]As, Sb, Ba, Cd, Cr, Cu, Pb, Ni, Ag, and Zn.
[c]40 CFR 266, App. IX.[6]

(continued)

TABLE 23. (continued)

Sample	Parameter	Analysis method	Frequency
Baghouse exit flue gas	Semivolatile TCL organics	Soxhlet extraction of Method 0010 samples by Method 3540A, GC/MS analysis by Method 8270A[a]	1/test
	Volatile TCL organics	Analysis of Method 0030 samples by Method 5040[a]	3 trap pairs/test
	PCDDs/PCDFs	GC/MS of Method 23 samples by Method 8290[a]	1/test
	Trace metals[b]	Digestion of multiple metals train samples by multiple metals procedure[c], ICAP analysis by Method 6010A[a]	1/test
	Particulate	Method 5[d]	1/test
	HCl	ICAP analysis of combined impinger solution by Method 9057[c]	1/test
Stack gas	Particulate	Method 5[d]	1/test
	HCl	IC analysis of combined impinger solution by Method 9057[c]	1/test

[a]SW-846.[5]
[b]As, Sb, Ba, Cd, Cr, Cu, Pb, Ni, Ag, and Zn.
[c]40 CFR 266, App. IX.[6]
[d]40 CFR 60, App. A.[7]

SECTION 6

EVALUATION OF THE SONOTECH FREQUENCY-TUNABLE PULSE COMBUSTION TECHNOLOGY

Sonotech, Inc., of Atlanta, Georgia, has developed a pulse combustion burner technology which claims to offer benefits when applied in a variety of combustion processes. The burner system incorporates a pulse combustor which can be tuned to excite large amplitude sonic pulsations inside a combustion process such as a boiler or incinerator. These pulsations serve to increase the rates of heat, momentum (mixing), and mass transfer in the combustion process. Sonotech claims that these heat, momentum, and mass transfer rate increases are sufficiently significant that faster and more complete combustion is accomplished.

Sonotech has targeted waste incineration as a potential application for the technology. As an initial demonstration that its pulse combustion system offered claimed benefits, Sonotech participated in an EPA Phase I Small Business Innovative Research (SBIR) program. In this recently completed program, Sonotech retrofitted a pulse combustion burner to the EPA bench-scale rotary kiln incinerator at the Air and Energy Engineering Research Laboratory (AEERL) in Research Triangle Park, North Carolina. Tests which measured the effect of pulsations on incinerator emissions of soot, CO, and TUHC were completed.

Based on the initial experience in the SBIR program, Sonotech proposed a followup demonstration under the SITE program. Specifically, Sonotech proposed that its pulse combustion technology be evaluated on a larger scale incineration system, the IRF RKS. Efforts completed during FY93 to support this test program are discussed in this section.

6.1 DESCRIPTION OF THE TECHNOLOGY

The phenomenon of pulse combustion has been studied since 1900. Active study of the phenomenon accompanied the advent and development of jet engines and rocket motors. The focus of most research has been on avoiding pulse combustion because of its deleterious effect on jet engine and rocket motor performance (e.g., structural failure). Perhaps the best known commercial application which takes advantage of the combustion efficiency improvement aspects of pulse combustion is the Lennox pulse furnace.

A pulse combustor typically consists of an air inlet, a combustor section, and a tailpipe. In pulse combustion, fuel oxidation and heat release rates vary periodically with time. These variations produce periodic variations (pulsations) in combustor section pressure, temperature, and gas velocities. The frequency of pulsations is generally close to the resonant frequency of the fundamental longitudinal acoustic mode of a duct consisting of the combustor section and tailpipe. Thus, by changing combustor and tailpipe geometry, for example by varying the length -

of the tailpipe, the frequency of pulsations can be changed, or tuned. Further, if properly applied, a pulse combustor can excite large amplitude (150 dB or higher) resonant pulsations within a cavity downstream of the pulse combustor tailpipe. This cavity could be the combustion chamber of a boiler or an incinerator, for example.

The periodic pulsations of pressure, gas velocities, and temperature give rise to increased rates of mass, heat, and momentum (mixing) transfer in pulse combustion compared to non-pulsating combustion. Thus, improved combustion efficiency and more complete organic compound oxidation (destruction) might be expected. Such are the claims of this SITE program's process developer. Sonotech claims that "large amplitude resonant pulsations excited by a tunable pulse combustor [will] significantly improve the incinerator's performance by increasing the rates of mass, momentum (i.e., mixing), and heat transfer within the incinerator. These, in turn, increase the incineration rate, reduce the amount of air required for incineration, reduce the severity of puffs, and reduce pollutant emissions. These improvements are expected to reduce capital investment and operating costs of a wide variety of incineration systems and improve their performance."

With the development of frequency-tunable pulse combustors to excite large amplitude pulsations in combustion chambers downstream of the pulse combustor, it became possible to apply pulse combustion to a variety of combustion processes such as boilers, dryers, calciners, and incinerators. In such applications, the pulse combustor could be used as the combustion process burner, supplying all of the heat input to the process. Alternatively, the pulse combustor could be used only as the driver to excite pulsations in the combustion process. In such applications, the pulse combustor needs deliver only a fraction, as little as 2 percent, of the combustion process heat input, while still exciting resonant pulsations in the process combustor. The remaining heat input would be supplied via the normal process means, e.g., the process conventional burner.

To excite large amplitude pulsations inside an incinerator, for example, the pulse combustor must operate at a frequency that equals one of the natural acoustic mode frequencies of the incinerator. When this condition is satisfied, the pulsations inside the pulse combustor and the incinerator are in resonance. Resonant driving of large amplitude pulsations is achieved by retrofitting a tunable pulse combustor to a wall of the incinerator, and varying its frequency until one of the natural acoustic modes of the incinerator is excited. The desired resonant operating condition is established in practice by using one or more pressure transducers to monitor the changes in the amplitude of pulsations inside the incinerator in response to changing the pulse combustor frequency. The desired operating condition is reached when these transducers indicate that the amplitude of pulsations inside the incinerator has been maximized.

The first trial of the Sonotech technology was in the SBIR program noted above. In this application, the pulse combustor was the sole heat input source to the bench-scale incinerator at AEERL. In the study, the effect of exciting large amplitude pulsations in the incinerator on the formation of transient "puffs" was studied. Transient puffs of incompletely burned organic constituents arise in the kiln exit flue gas of incinerators when a batch charge of organic waste demands more oxygen for complete destruction than available at the set kiln air feedrates. This puff consists of CO, TUHC, and soot.

Sonotech's interpretation of the findings of the SBIR program were that the excitation of pulsations within an incinerator with a frequency-tunable pulse combustor improved its performance as a result of increased mixing rates between the fuel and air and between reactive gas pockets and ignition sources, and due to increased rates of heat and mass transfer to and from the burning waste. These effects should reduce the amount of excess air required to completely burn a waste, increase the POHC DREs, minimize the formation of products of incomplete combustion (PICs), and eliminate or minimize the formation of detrimental puffs.

Sonotech expects to confirm the advantages of its frequency-tunable pulse combustion technology in the SITE demonstration at the IRF. This demonstration will entail retrofitting the kiln section of the RKS at the IRF with a pulse combustor "driver" which will deliver a heat input of 73 kW (250,000 Btu/hr), or roughly 15 to 20 percent of the typical heat input to the kiln of the RKS. The advantages Sonotech claims the application of the frequency-tunable pulse combustion technology to an incineration system has over conventional (nonpulsating) incineration are:

1. Lower CO, soot, and NO_x emissions. The high mixing, mass, and heat transfer rates within the incinerator produce complete combustion, which practically eliminates soot and CO production. Furthermore, the periodic mixing process and improved heat transfer minimize NO_x production.

2. Lower combustion air requirements. The improved mixing within the incinerator reduces the amount of air required for complete combustion.

3. Lower energy requirements. The improved heat transfer within the process increases the rate of drying and heating the waste, which may increase the burn rate and reduce the required fuel input into the system.

4. Higher incinerator capacity. The increase in mixing, mass, and heat transfer rates produced by the pulsations within the incinerator accelerate the transfer of heat and oxygen to the burning waste and CO away from the burning material, which shortens the waste burning time. Consequently, the waste can be moved faster through the incinerator, resulting in higher incinerator capacity.

5. Reduced severity of transient puffs. The improved mixing, mass, and heat transfer within the incinerator eliminate or reduce temperature and concentration nonuniformities within the process, resulting in better utilization of available oxygen and more uniform incineration through the incinerator volume. This lowers the likelihood of emissions of transient puffs due to the occurrence of "rich" combustion within the incinerator.

6. Reduced incineration system capital and operating costs due to 2, 3, and 4 above.

6.2 TEST PROGRAM

The objective of the demonstration test program is to develop the data needed to allow objective and quantitative evaluation of the above Sonotech claims for their frequency-tunable pulse combustion technology. The focus of the program will be on the evaluation of the claims

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that lower combustion pollutant emissions result from the application of the Sonotech technology, and that higher incinerator capacity results. However, test program data will also be taken to evaluate whether the Sonotech technology affects trace metal partitioning in the incinerator, the leachability of trace metals from incinerator discharges, or the severity of transient puffs.

To address the test program objectives, tests at four different incineration system operating conditions will be performed. The four planned conditions are:

- Conventional combustion:

  1. Baseline, typical operation

  2. Maximum waste feedrate

- Sonotech pulse combustion

  3. Same feedrate and conditions as 2

  4. Maximum waste feedrate

The waste to be fed for all tests will be a relatively high heat content contaminated material from a manufactured gas plant (MGP) Superfund site, specifically, the Peoples Natural Gas Company site in Dubuque, Iowa. The test material will be batch fed to the RKS via the fiberboard container ram feed system, which will feed 1.5-gal (5.7-L) cubical fiberboard containers to the kiln. When a relatively high heat content material is being fed, the maximum allowable waste feedrate is established based on the onset of puffs of incompletely combusted organic constituents (CO and TUHC) which survive the afterburner. Thus, a feed regimen that results in routine system exit flue gas CO spikes of over 300 ppm, lasting 30 to 60 seconds, which in turn cause 1-hour rolling average flue gas CO levels to be about 50 ppm, is the maximum feedrate that can be tolerated and still be characterized as barely acceptable operation.

Given this, Test 2 will be at a feedrate and other operating conditions which result in frequent (every charge to every third charge) CO spikes, however with 1-hour rolling average system exit CO levels of nominally 50 ppm or less. The 50 ppm rolling average maximum is selected to ensure that the usual permit limit for hazardous waste incinerators (the IRF RKS included) of 100 ppm, 1-hour rolling average, is not exceeded.

Test 1 will be at a decreased feedrate which results in only infrequent (less than one every tenth charge) system exit flue gas CO spikes. This feedrate will be no greater than 80 percent of the Test 2 feedrate. Test 1 represents baseline, typical, well-controlled incinerator operation.

Test 3 will be at the Test 2 feedrate and incineration temperatures; however, the Sonotech pulse combustion system will be in operation. Test 4 will be at whatever increased feedrate can be sustained with 1-hour rolling average system exit flue gas CO levels of 50 ppm or less.

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This test matrix will allow the development of data to evaluate the Sonotech claims as follows. Test 1 will provide emissions, POHC DRE, metals partitioning, and metals leachability data corresponding to baseline, typical, well-controlled incinerator operation while feeding the test contaminated material. Past IRF experience is that few CO spikes will occur, and those that do will peak at less than 100 ppm. The 1-hour rolling average CO emissions should be less than 10 ppm. NO_x emissions are expected to be in the 30 to 70 ppm range.

Test 2 will provide emissions, POHC DRE, metals partitioning, and metals leachability data corresponding to an operating condition at the maximum contaminated material feedrate possible under conventional incinerator operation. This operating condition will correspond to borderline incinerator failure and noncompliance with typical permit limits. Frequent system exit flue gas CO spikes of 300 to over 1,000 ppm are expected, and 1-hour rolling average CO emissions will likely be about 50 ppm.

Test 3 will provide emissions, POHC DRE, metals partitioning, and metals leachability data for the Test 2 operating condition with pulse combustion. Comparing the NO_x, CO, and TUHC emission data and POHC DREs for Test 3 to those for Test 2 will allow the evaluation of claims that lower emissions result from the application of pulse combustion.

In addition, Sonotech expects that, with the improved combustion efficiency resulting from the application of pulse combustion, acceptable incinerator operation (infrequent system exit flue gas CO spikes) will be possible at a decreased combustion air requirement. With a decreased combustion air supply, decreased auxiliary fuel will be needed to maintain incineration temperatures. If acceptable operation with decreased burner air and auxiliary fuel feedrates can be achieved for Test 3 at the Test 2 contaminated-material feedrate and incineration temperatures, evaluation of these claims will be possible.

Test 4 will provide emissions, POHC DRE, metals partitioning, and metals leachability data at the maximum incinerator feedrate possible under pulse combustion operation. Comparing Test 4 emissions and POHC DRE data to those from Tests 2 and 3 will allow evaluation of the claim that increased capacity at acceptable emissions is possible.

Each test will be performed three times (triplicate testing) to allow assessment of the precision of each emission and discharge stream composition measurement.

6.2.1 Test Facility

As noted above, the test program will be conducted in the RKS at the IRF. A process schematic of the RKS as it will be configured for these tests is shown in Figure 18. The RKS will be retrofitted with a Sonotech frequency-tunable pulse combustor system with firing rate capacity of 73 kW (250,000 Btu/hr) for the test program. The Sonotech burner will be mounted into the stationary end wall at the ash pit end of the kiln section of the RKS. The retrofit system will consist of a frequency-tunable pulse combustor, associated fuel and air flow controls, a process control system, and an appropriate structural support. Fuel (natural gas) and air supply will be taken from existing IRF supply lines. Appropriate safety interlocks between the Sonotech control system and the RKS system will be defined and installed.

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6.2.2 Test Feed Material

The test material for the test program will be a mixture of pulverized coal and contaminated sludge waste from the Peoples Natural Gas Company Superfund site in Dubuque, Iowa. This site is an abandoned MGP site, and the sludge waste at the site contains high concentrations of coal tar constituents.

The test feed mixture was prepared at the Peoples site by mixing and grinding a combination of 30 to 35 percent sludge with 65 to 70 percent coal. After being screened through a 2.5-in (6.4-cm) screen, the resulting mixture was a relatively free-flowing solid. After preparation, the material was transferred to 20 55-gal (208-L) drums and shipped to the IRF in late September 1993.

Samples of the test feed material taken from one of the drums received at the IRF were analyzed for ash content, moisture content, heating value, semivolatile and volatile organic constituents, and trace metals, and the TCLP leachate of the feed material was analyzed for volatile organic constituents and trace metals. Results of these analyses are summarized in Table 24. As shown, the test feed material contains several PAH compounds at concentrations ranging from 100 to over 1,400 mg/kg. In addition, it contains several volatile aromatic constituents at levels ranging from 3.7 to 55 mg/kg.

None of the feed material organic contaminants, however, is present in the feed material mixture at concentrations high enough to allow a clear determination of whether 99.99 percent DRE can be achieved. Thus, for the test program each feed-containing fiberboard container will be spiked with naphthalene and benzene. The spiking level will be at 10,000 mg/kg. Both compounds are feed-material contaminants and are ranked as very difficult to thermally destroy in the thermal-stability-based incinerability ranking.[4] Both compounds are ranked as class 1, the most difficult to thermally destroy of seven classes, with class 7 being easiest to destroy.

A solution of 50 percent (weight) naphthalene dissolved in benzene (equal weights of both) will be used to spike the feed material. Weighed quantities of the solution will be placed in appropriately sized high-density polyethylene (HDPE) bottles with polypropylene screw closures, and a bottle of the solution will be added to each feed container during feed repackaging.

The data in Table 24 show that the test feed material contains antimony, barium, beryllium, cadmium, chromium, lead, and mercury. Thus, metals partitioning will be measured for these metals.

6.2.3 Test Conditions

Current plans are to perform all tests at the same overall incinerator operating conditions, with a kiln exit gas temperature of 870°C (1,600°F) and an afterburner exit gas temperature of 1,090°C (2,000°F). In Test 1, the baseline test under conventional combustion conditions, and Test 4, the maximum feedrate test under pulse combustion operation, average flue gas O_2 levels are expected to be about 10 percent at the kiln exit and 8 percent at the afterburner exit. Lower average kiln exit O_2 levels will be experienced in Test 2, the maximum feedrate test under conventional operation. Sonotech claims that lower kiln exit O_2 levels

TABLE 24. ANALYSIS RESULTS FOR THE TEST MATERIAL FEED PREPARATION

Analyte	Sample concentration	TCLP leachate Concentration	TCLP leachate Regulatory level
Proximate analysis			
Moisture, %	13.8		
Ash, %	27.2		
Higher heating value, MJ/kg	17.7		
(Btu/lb)	(7,620)		
Trace metals, mg/kg		, mg/L	
Sb	17	—[a]	
As	<5	<0.05	5.0
Ba	110	0.34	100
Be	0.54	—	
Cd	3.8	<0.004	1.0
Cr	10	<0.007	5.0
Pb	130	<0.045	5.0
Hg	3.4	<0.001	0.2
Se	—	<0.075	1.0
Ag	<0.7	<0.007	5.0
Tl	<4	—	
Polynuclear aromatic hydrocarbons, mg/kg			
Acenaphthylene	440	—	
Anthracene	390	—	
Benz(a)anthracene	310	—	
Benzo(k)fluoranthene	190	—	
Benzo(ghi)perylene	110	—	
Benzo(a)pyrene	230	—	
Chrysene	290	—	
Dibenzofuran	330	—	
Fluoranthene	1,080	—	
Fluorene	490	—	
Indeno(1,2,3;-cd)pyrene	100	—	
2-Methylnaphthalene	450	—	
Naphthalene	1,430	—	
Phenanthrene	150	—	
Pyrene	730	—	
Volatile organic constituents, mg/kg		, mg/L	
Benzene	7.8	0.66	0.5
Ethylbenzene	3.7	—	
Styrene	10.1	—	
Toluene	21.7	—	
Total Xylenes	55.2	—	

[a]— = Not measured.

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associated with decreased combustion air requirements will also be the case for Test 3, pulse combustion operation at the Test 2 feedrate and temperature conditions. For all tests, kiln rotation rate will be that required to provide a feed material solids residence time of 1 hour, and the APCS components will be operated under their nominal design conditions.

The two test program variables will be test material feed regimen (feedrate and feed charge frequency) and whether conventional or pulse combustion is in operation. The specific feed regimens to be used for each test condition will be defined based on a series of scoping tests. The focus of the scoping tests will be to identify the feed regimen which gives the maximum waste feedrate for a given mode of operation (conventional or pulse combustion).

As noted above, test material will be batch-charged to the kiln in 1.5-gal (5.7-L) fiberboard containers via the RKS's ram feed system. Past IRF testing experience has shown that, depending the test material, puffs of uncombusted organic material which survive the afterburner can be achieved by feeding batch charges of between 11 and 53 MJ (10,000 and 50,000 Btu) at a rate of 12 to 20 per hour, with kiln and afterburner gas temperatures at the above-noted plan values.

Given the past experience, scoping tests will be initiated with containers charged with 2.27 kg (5.0 lb) of test material (40.2 MJ [38,100 Btu] per container based on the sludge/coal mixture heating value noted in Table 24). Charge feed frequency will start at 12 charges per hour. Variations in charge frequency, and test material weight per charge will be tried until the maximum test material feedrate, as defined in introductory paragraphs to Section 6.2, is discovered for both conventional combustion and pulse combustion. For conventional combustion operation, the Sonotech system will not be operated. For pulse combustion operation, the Sonotech system will fire natural gas at its design rate, and pulse frequency will be tuned to excite resonant pulses with amplitude greater than 160 dB in the RKS kiln.

It is possible that maximum test material feedrate for the Peoples Natural gas site material may be constrained by kiln temperature at minimum kiln burner fuel feedrate, instead of by high 1-hour rolling average CO emissions, as desired. The minimum total kiln burner auxiliary fuel feedrate consistent with safe operation is about 150 kW (500,000 Btu/hr). This minimum auxiliary fuel feed would be needed in the kiln main burner for the conventional combustion tests, or divided between the main burner and the Sonotech burner for the pulse combustion tests. The maximum total kiln heat input consistent with the target kiln operating temperature of 870°C (1,600°F) and exit gas O_2 of about 10 percent is approximately 530 kW (1.8 MMBtu/hr). Thus, the maximum test material feedrate will be at a heat input rate of 380 kW (1.3 MMBtu/hr). If the test material mix has a heating value of 23 MJ/kg (10,000 Btu/lb), then the maximum test material feedrate will be about 59 kg/hr (130 lb/hr). It is possible that a feed regimen that produces high 1-hour rolling average CO emissions with test material feedrate so constrained cannot be found. If this is the case, the option of replacing kiln main burner natural gas heat input by firing, or cofiring, a soot-producing solvent such as toluene (a sludge contaminant) to stimulate CO puffs will be recommended. Past experience has shown that puff production is enhanced when a soot-producing liquid waste or fuel that burns with a radiant flame is fired, with or without auxiliary natural gas, in the kiln burners.

After appropriate RKS operating conditions have been defined for the four planned tests, the evaluation testing will be initiated. As noted above, test material was prepared in one

batch at the Peoples site and packaged into 20 55-gal (208-L) drums for shipment to the IRF. Test material for the evaluation tests will be repackaged at the IRF into the 1.5-gal (5.7-L) fiberboard containers, with container contents as specified from scoping test findings.

For a given evaluation test, the RKS will be brought to steady operation at the desired conditions beginning on the prior day by firing natural gas only. Test material feed will then be initiated and steady RKS operation reestablished with waste feed. Kiln and afterburner auxiliary fuel-fired (natural gas) burner fuel and air flows, along with secondary combustion air flows, will be controlled to give the desired temperature and excess air conditions. Flue gas sampling will be started no sooner than 0.5 hour after the initiation of test material feed. Feed will continue until all flue gas sampling has been completed.

For all tests, the scrubber system will be operated at its design settings, listed in Table 10, and at as close to total recirculation (zero to minimum blowdown) as possible. Kiln ash will be continuously removed from the kiln ash hopper via the ash auger transfer system on the kiln and deposited into initially clean 55-gal (208-L) drums.

6.2.4   Sampling and Analysis Procedures

The RKS sampling locations and the scope of the sampling effort are shown in the process schematic, Figure 20. For all tests, the sampling matrix will entail:

- Obtaining a composite sample of the test feed material

- Obtaining a composite sample of the kiln ash discharge

- Obtaining a composite sample of the scrubber system liquor

- Obtaining a composite sample of the baghouse flyash

- Continuously measuring O_2 concentrations in the kiln exit flue gas; O_2, CO, CO_2, NO_x, and TUHC concentrations in the afterburner exit flue gas; O_2, CO_2, and NO_x in the baghouse exit flue gas; and O_2 and CO concentrations in the stack gas

- Collecting a gram-sized sample of the afterburner exit particulate using a high-volume Method 17 sampling train

- Sampling flue gas at the baghouse exit for trace metals using the EPA multiple metals sampling train, Method 29

- Sampling the flue gas at the baghouse exit for mercury using Method 101A

- Sampling the flue gas at the baghouse exit for the semivolatile POHCs and other PAH constituents using a Method 0010 train

- Sampling the flue gas at the baghouse exit for PCDDs/PCDFs using Method 23

KILN → AFTERBURNER → FLUE GAS QUENCH → VENTURI SCRUBBER → PACKED COLUMN SCRUBBER → FLUE GAS REHEAT → BAGHOUSE → CARBON BED → HEPA FILTER → ID FAN

Sampling points: 1, 2, 3, 4, 5, 6, 7, 8

Sampling point	Test feed material	Kiln ash	Scrubber liquor	Baghouse ash	O_2	CO	CO_2	NO_x	Heated TUHC	High-volume Method 17, particulate	EPA multiple metals train, test trace metals	Method 101A, mercury test	Method 0010, test semivolatile POHCs and PAHs	Method 0030, volatile organic constituents	Method 23, PCDD/PCDF	Method 5, particulate and HCl
	Continuous monitors									Flue gas						
1. Feed	X															
2. Kiln ash discharge		X														
3. Kiln exit flue gas					X											
4. Afterburner exit flue gas					X	X	X	X	X	X						
5. Scrubber liquor			X													
6. Baghouse hopper				X												
7. Baghouse exit flue gas					X				X		X	X	X	X	X	
8. Stack gas					X	X										X

Figure 20. Test sampling locations.

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- Sampling the flue gas at the baghouse exit for volatile organic constituents using the VOST, Method 0030

- Sampling the flue gas at the baghouse exit and the stack for particulate and HCl using Method 5; the stack sample is needed to comply with the IRF's permit requirements

Test program samples will be analyzed for matrix-specific combinations of semivolatile POHCs and PAH constituents, volatile organic constituents, PCDDs/PCDFs, contaminant trace metals, total carbon, and chloride. The matrix of planned analyses is summarized in Table 25.

6.3   CURRENT STATUS

Much of the planning for this test program was completed during FY93. Specifically:

- A test planning initiation meeting among RREL, PRC Environmental Management (the RREL SITE program contractor), Sonotech, Industrial Gas Technology Commercialization Center (the funding source for the development of the Sonotech system), and IRF representatives took place at the IRF in November 1992

- A data quality objectives development meeting among RREL, RREL QA, S-Cubed (an RREL QA support contractor), PRC, and IRF representatives took place at RREL in February 1993

- A test plan outline was prepared and distributed in June

- A meeting among RREL, PRC, EPA Region VII, Midwest Natural Gas (the company funding the remediation of the Peoples Natural Gas site), the Midwest Natural Gas remediation contractor, and IRF representatives was held in Dubuque, Iowa, in July to discuss test material preparation procedures and shipment schedules

- Test material was prepared, shipped, and received at the IRF in September

- A draft of the stand-alone QAPP was prepared and distributed for review in September

Further efforts culminating in installing the Sonotech combustion system and initiating the test program in March 1994 will proceed during FY94.

TABLE 25. ANALYSIS PROTOCOL

Sample	Parameter	Analysis method	Frequency
Test feed material	Proximate analysis (moisture, volatile matter, fixed carbon, ash)	ASTM D-5142	1 composite
	Elemental analysis C, H, O, N, S Cl	ASTM D-3176 ASTM E-442	1 composite
	Heating value	ASTM D-3286	1 composite
	Semivolatile organic constituents	Soxhlet extraction by Method 3540A, GC/MS analysis by Method 8270A[a]	2/test condition
	Volatile organic constituents	Purge and trap GC/MS by Method 8240A[a]	2/test condition
	Trace metals[b]	Digestion by the multiple metals filter method[c], GFAAS analysis by Method 7000A[a]	2/test condition
	Mercury	Digestion and CVAAS analysis by Method 7471[a]	2/test condition
	TCLP extraction	Method 1311[a]	2/test condition
Test feed TCLP leachate	Trace metals[b]	Digestion by Method 3015, GFAAS analysis by Method 7000A[a]	2/test condition
	Mercury	Digestion and CVAAS analysis by Method 7471[a]	2/test condition
Kiln ash	Semivolatile organic constituents	Soxhlet extraction by Method 3540A, GC/MS analysis by Method 8270A[a]	1/test run
	Volatile organic constituents	Purge and trap GC/MS by Method 8240A[a]	1/test run
	Trace metals[b]	Digestion by the multiple metals filter method[c], GFAAS analysis by Method 7000A[a]	1/test run
	Mercury	Digestion and CVAAS analysis by Method 7471[a]	1/test run
	TCLP extraction	Method 1311[a]	1/test run
Kiln ash TCLP leachate	Trace metals[b]	Digestion by Method 3015, GFAAS analysis by Method 7000A[a]	1/test run
	Mercury	Digestion and CVAAS analysis by Method 7470	1/test run
Pre-test scrubber liquor	Semivolatile organic constituents	Extraction by Method 3520A, GC/MS analysis by Method 8270A[a]	1/test run
	Volatile organic constituents	Purge and trap GC/MS by Method 8240A[a]	1/test run
	Trace metals[b]	Digestion by Method 3015, GFAAS analysis by Method 7000A[a]	1/test run
	Mercury	Digestion and CVAAS analysis by Method 7470	1/test run

[a]SW-846.[5]
[b]As, Ba, Be, Cd, Cr, Pb, and Tl.
[c]40 CFR 266, App. IX.[6]

(continued)

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TABLE 25. (continued)

Sample	Parameter	Analysis method	Frequency
Post-test scrubber liquor	Semivolatile organic constituents	Extraction by Method 3520A, GC/MS analysis by Method 8270A[a]	1/test run
	Volatile organic constituents	Purge and trap GC/MS by Method 8240A[a]	1/test run
	Trace metals[b]	Digestion by Method 3015, GFAAS analysis by Method 7000A[a]	1/test run
	Mercury	Digestion and CVAAS analysis by Method 7470	1/test run
	TCLP extraction	Method 1311[a]	1/test run
Scrubber liquor TCLP leachate	Trace metals[b]	Digestion by Method 3015, GFAAS analysis by Method 7000A[a]	1/test run
	Mercury	Digestion and CVAAS analysis by Method 7470	1/test run
Baghouse ash	Semivolatile organic constituents	Soxhlet extraction by Method 3540A, GC/MS analysis by Method 8270A[a]	1/test run
	Volatile organic constituents	Purge and trap GC/MS by Method 8240A[a]	1/test run
	Trace metals[b]	Digestion by the multiple metals filter method[c], GFAAS analysis by Method 7000A[a]	1/test run
	Mercury	Digestion and CVAAS analysis by Method 7471[a]	1/test run
	TCLP extraction	Method 1311[a]	1/test run
Baghouse ash TCLP leachate	Trace metals[b]	Digestion by Method 3015, GFAAS analysis by Method 7000A[a]	1/test run
	Mercury	Digestion and CVAAS analysis by Method 7470	1/test run
Afterburner exit particulate	Semivolatile organic constituents	Soxhlet extraction by Method 3540A, GC/MS analysis by Method 8270A	1/test run
	Total carbon	ASTM D-3178	1/test run
Baghouse exit flue gas	Semivolatile organic constituents	Soxhlet extraction of Method 0010 samples by Method 3540A, GC/MS analysis by Method 8270A[a]	1/test run
	Volatile organic constituents	Purge and trap GC/MS analysis of Method 0030 samples by Method 5040	3 trap pairs/test run
	PCDDs/PCDFs	GC/MS analysis of Method 23 samples by Method 8290[a]	1/test run
	Trace metals[b]	Digestion of multiple metals train samples by multiple metals procedure[c], GFAAS analysis by Method 7000A[a]	1/test run
	Mercury	Sample preparation by Method 101A[d], CVAAS analysis by Method 7470[a]	1/test run
	Particulate	Method 5[e]	1/test run
	HCl	IC analysis of combined impinger solution by Method 9057[a]	1/test run
Stack gas	Particulate	Method 5[e]	1/test run
	HCl	IC analysis of combined impinger solution by Method 9057[a]	1/test run

[a]SW-846.[5]
[b]As, Ba, Be, Cd, Cr, Pb, and Tl.
[c]40 CFR 266, App. IX.[6]
[d]40 CFR 61, App. B.[8]
[e]40 CFR 60, App. A.[7]

SECTION 7

TEST INCINERATION OF BALLISTIC MISSILE PROPELLANT COMPONENTS

Presidents Clinton and Yeltsin agreed in principle to a draft agreement on April 4, 1993, between the U.S. Department of Defense (DOD) and the Committee for Defense Industry of the Russian Federation concerning cooperation in the elimination of Russian Strategic Offensive Arms. This agreement was signed and became effective on August 26, 1993. The agreement obligates the DOD to provide the Russian Federation with a list of equipment for the Federation's possible use in eliminating strategic offensive arms in accordance with schedules negotiated in the Strategic Arms Reduction Treaty (START). Included in this equipment list are eight mobile incinerators each capable of destroying at least 750 metric tons per year of ballistic missile liquid propellant comprised of unsymmetrical dimethyl hydrazine (UDMH) liquid fuel and nitrogen tetroxide (N_2O_4) oxidizer.

The Defense Nuclear Agency (DNA) is responsible for providing the incinerators. One requirement for the incinerators to be provided is that they meet both U.S. and Russian Federation environmental regulatory requirements. Thus, to minimize the possibility of Russian rejection of the incinerators, and the associated adverse effects on the schedule for the destruction of the ballistic missile propellant, the DNA has sponsored a series of tests at the IRF to demonstrate that Russian ballistic missile propellant can be incinerated in compliance with U.S. and Russian environmental laws and regulations. These tests will also supply the design information required to commercially procure the eight incinerators.

The general objectives of the initial tests are to:

- Demonstrate the U.S. and Russian environmental certifiability of the incineration of former Soviet Union ballistic missile fuel UDMH

- Demonstrate the U.S. and Russian environmental certifiability of the incineration of former Soviet Union ballistic missile oxidizer N_2O_4

Environmental certifiability will be established by showing that both UDMH and N_2O_4 can be separately destroyed in an incinerator to levels which meet both U.S. and Russian environmental regulations, while resulting in emissions of incineration by products considered acceptable under those regulations. Efforts completed in FY93 to support this test program are discussed in this section.

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7.1   TEST PROGRAM

The planned test program will be conducted in the IRF RKS. A process schematic of the RKS as it will be configured for these tests is shown in Figure 18. However, because very little flue gas particulate is expected from the incineration of either component of the ballistic missile liquid propellant, the baghouse system shown in Figure 18 will be bypassed.

7.1.1   Environmental Regulations

As noted above, the objective of the initial tests are to establish that UDMH and N_2O_4 can be destroyed in an incineration system in a manner that meets U.S. and Russian environmental regulations. The applicable U.S. environmental regulations are the hazardous waste incinerator performance standards established under RCRA. These standards require that the incinerator achieve:

- At least 99.99 percent DRE of the POHCs in the waste feed to the incinerator

- HCl emissions of less than 1 percent of the HCl entering the incinerator's APCS or 1.8 kg/hr, whichever is greater

The promulgated regulations require that particulate emissions be no greater than 180 mg/dscm (0.08 gr/dscf) corrected to 7 percent O_2. However, recent EPA guidance, planned for incorporation into hazardous waste incinerator operating permits as they are issued or renewed, states that particulate emissions be limited to 34 mg/dscm (0.015 gr/dscf) corrected to 7 percent O_2.

In addition, hazardous waste incinerator permits currently being enforced in the U.S. require that CO emissions be no greater than a 1-hour rolling average of 100 ppm, corrected to 7 percent O_2, and limit hazardous constituent trace metal feedrates to levels designed to prevent exceeding risk-based ambient levels. The hazardous constituent trace metals are antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, silver, and thallium. Finally, current guidance states that total tetra- through octa-chlorinated PCDDs/PCDFs be limited to 30 ng/dscm corrected to 7 percent O_2.

Discarded or off-specification UDMH to be destroyed or disposed of would be the listed hazardous waste U098. The POHC for this waste for which an incinerator would need to achieve 99.99 percent DRE would obviously be UDMH. Discarded or off-specification N_2O_4 would be listed waste P078. P078 is listed as nitrogen dioxide (NO_2). However, N_2O_4 is the term used to refer to the equilibrium mixture of N_2O_4 and NO_2 expressed as

$$N_2O_4 \rightleftharpoons 2NO_2 \qquad \text{(7-1)}$$

Because neither N_2O_4 nor NO_2 is an organic constituent, no DRE requirement would apply.

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The Russian environmental regulations limit the emissions of UDMH and several potential UDMH PICs from the incineration of UDMH. These limits are summarized in Table 26. The limits noted in the table are occupational exposure limits in terms of maximum permissible concentrations in workplace air. Corresponding ambient air standards for general population exposure are a factor of 100 lower. Region-specific regulations may further constrain a sources' duration of operation to ensure maintenance of the ambient standards For example, in a highly industrialized region with many CO or NO_x sources, a UDMH incinerator may be constrained to operate only a set number of hours per day or days per week to ensure that ambient CO or NO_2 levels from resulting from the collection of sources in the region are not exceeded. The candidate locations for operating the transportable incinerators to be supplied to the Russian Federation are sufficiently remote from highly industrialized urban areas that no additional region-specific constraints will apply.

European hazardous waste incinerator regulations might also be considered in addressing the environmental certifiability of missile propellant incineration. A summary of select European incinerator regulations is given in Table 27. Of the European regulations noted in Table 27, the German regulations are currently the most stringent. Other European countries either do not specifically regulate incinerator emissions or have less stringent emission limits, such as the French limits noted in Table 27. Recognizing this, and coupled with the desire to have a common set of regulations within Europe, the European Community (EC) proposed a new directive in 1992, which is also given in Table 27. The EC directive is expected to be adopted by EC members in 1994.

Comparing Russian and the EC directive limits in Table 27 to the U.S. incinerator standards noted above shows that the EC particulate emission standard, which equates to 6.5 mg/dscm at 7 percent O_2, is significantly more stringent than even the U.S. guidance level of 34 mg/dscm at 7 percent O_2. The EC CO standard equates to 56 ppm daily average at 7 percent O_2. This is comparable to the U.S. standard of 100 ppm, 1-hour rolling average at 7 percent O_2. The Russian regulations cannot be directly compared to either the EC or U.S. standards because the Russian regulations are in terms of ambient concentrations. The EC metal emission limits also cannot be directly compared to the U.S. limits because the U.S. limits are feedrate based. However, the EC limits for antimony, lead, mercury, and thallium are likely to be significantly more stringent than the U.S. requirements. In addition, the EC directive extends to cobalt, manganese, nickel, tin, and vanadium, but does not address barium or silver.

With respect to UDMH and N_2O_4 incineration, the primary requirements that need to be demonstrated are that 99.99 percent UDMH DRE can be achieved with acceptable CO and NO_x emissions are possible for both UDMH and N_2O_4 incineration. The U.S. incinerator standard of 100 ppm CO, 1-hour rolling average at 7 percent O_2, might represent an appropriate target. This equates to 183 mg/dscm at 7 percent O_2. Thus, only a 10-fold dilution of stack emissions into ambient air would be needed to meet the Russian workplace standard of 20 mg/m^3. Typical stack to maximum ambient concentration dilution factors are much larger, generally 100 to several thousand.

The German standard of 200 mg/Nm^3 as NO_2 at 11 percent O_2 might be considered an appropriate target. This level equates to an emission limit of 136 ppm NO_x at 7 percent O_2. The U.S. hazardous waste incinerator standards do not address NO_x emissions. However, new source performance standards (NSPS) for similar combustion processes established under the

TABLE 26. RUSSIAN FEDERATION ENVIRONMENTAL REGULATIONS FOR UDMH INCINERATION

Compound	Maximum permissible concentration in workplace air, mg/m^3
UDMH	0.1
Dimethylamine	1.0
N-Nitrosodimethylamine	0.01
Hydrogen cyanide (HCN)	0.3
1,1,4,4-Tetramethyl-2-tetrazene	3.0
Formaldehyde	0.5
CO	20
NO_2	2.0

TABLE 27. EUROPEAN HAZARDOUS WASTE INCINERATOR EMISSION LIMITS

Pollutant	Germany, 17th BImSch V, mg/Nm^3, 11% O_2, dry, daily average	France Regulation mg/Nm^3, 7% CO_2, wet	France Recent permit requirements, mg/Nm^3, 7% CO_2, wet	EC directive, mg/Nm^3, 11% O_2, dry, daily average
Particulate	10	150	30	5
HCl	10	100	50	5
HF	1	—[a]	—	1
SO_2	50	—	—	25
NO_x	200[b]	—	—	—
CO	50	—	—	50
Total organic carbon	10	—	—	5
Heavy metals				
Cd + Tl	0.05			0.05
Hg	0.05	5 total	5 total	0.05
Others[c]	0.5			0.5
Dioxins and furans, TEQ[d]	0.1 ng/Nm^3	—	—	0.1 ng/Nm^3

[a]— = No standard.
[b]As NO_2.
[c]Sb, As, Cr, Co, Pb, Mn, Ni, Sn, and V.
[d]TEQ = 2,3,7,8 tetrachloro dibenzo-p-dioxin (TCDD) toxicity equivalents.

Federal Clean Air Act are comparable to the German incinerator standard. For example, the NSPS for large municipal waste incinerators (greater than 250 tons/day [227 Mg/day] capacity) is 180 ppm NO_x at 7 percent O_2; and the NSPS for residual oil fired utility, industrial, commercial, and institutional boilers with heat input rates greater than 100 MMBtu per hour (29 MW) is 0.3 lb NO_x (as NO_2) per MMBtu heat input (129 ng/J), which equates to about 180 ppm NO_x at 7 percent O_2. A 100-fold dilution of stack emissions of 200 mg/Nm^3 would satisfy the Russian workplace standard for NO_2. This is at the lower bound of typical dilution factors, as noted above.

Test data will be compared to the NO_x and CO emission standards noted above. Dispersion modeling will also be performed to allow comparing test emission level data to the Russian ambient workplace standards.

Emissions of particulate, HCl, HF, SO_2, heavy metals, and dioxins and furans, regulated in Germany and proposed for the EC, are expected to be negligible. Total organic carbon emissions should also be negligible if the CO emission limit is met. Emission rates of several of these pollutants will be measured in the planned initial tests, however. In addition, emission rates of UDMH and the UDMH PICs having Russian occupational exposure requirements, noted in Table 26, will also be measured.

In summary, the specific test program objectives are:

- To develop the data to evaluate whether UDMH and N_2O_4 can be incinerated in compliance with the U.S. hazardous waste incinerator performance standards and recent permitting guidance of:

  — 99.99 percent POHC DRE

  — HCl emissions less than the greater of 1 percent of the APCS inlet flowrate of 1.8 kg/hr

  — CO emissions of less than 100 ppm hourly rolling average at 7 percent O_2

  — Particulate emissions of less than 34 mg/dscm (0.015 gr/dscf) corrected to 7 percent O_2

  — Total tetra- through octa-PCDD/PCDF emissions of less than 30 mg/dscm corrected to 7 percent O_2

- To develop trace metal emission rate from the incineration of UDMH and N_2O_4 data for comparison to both the EC directive limits and the U.S. incinerator performance Tier II limits

- To develop particulate, HCl, total organic carbon, and PCDD/PCDF emission rate data from the incineration of UDMH and N_2O_4 for comparison to the EC directive limits

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- To develop CO and NO_x (NO plus NO_2) emission rate data from the incineration of UDMH and N_2O_4 for comparison to German incinerator standards and the emission rate limits corresponding to the Russian occupational exposure limits

- To develop UDMH PIC emission rate data from the incineration of UDMH for comparison to the emission rate limits corresponding to the Russian occupational exposure limits

7.1.2   Test Conditions

The planned initial test program will consist of nine incineration tests. Three tests will be performed under the same incineration system operating conditions feeding each component of the missile propellant. Triplicate testing is a requirement for U.S. hazardous waste incinerator trial burns. In addition, triplicate testing establishes a measure of confidence in test results by allowing the precision of the test program sampling and analysis procedures to be evaluated. Two sets of triplicate tests feeding UDMH (six total) will be required to complete all the flue gas sampling procedures planned for the UDMH feed tests, as noted in Section 7.1.3. Thus, nine tests in total, six feeding UDMH and three feeding N_2O_4, will be performed.

As noted in Section 7.1.1, the initial tests will focus on demonstrating that 99.99 percent UDMH DRE can be achieved under at least one set of incineration conditions, with acceptable CO, NO_x, particulate, HCl, total organic carbon, trace metal, PCDD/PCDF, and UDMH PIC emissions. Thus, the incineration conditions selected for the tests are those expected to achieve the most effective propellant component destruction. The initial tests will, therefore, serve as a baseline to show that environmentally acceptable incineration can be achieved under at least one set of incineration conditions, although perhaps not the optimum set of conditions.

The six UDMH destruction tests will be performed at kiln exit gas temperature of 980°C (1,800°F). Only UDMH will be fed to the kiln along with the required combustion air. The RKS auxiliary fuel, natural gas, will not be fed during actual testing, although natural gas will be used for incinerator heat up, and to maintain incinerator temperatures overnight between tests. UDMH will be fed to the kiln via the liquid waste/fuel nozzle of the kiln's dual fuel burner. The UDMH will be directly pumped and metered from its nitrogen-blanketed storage container to the burner nozzle.

The three N_2O_4 destruction tests will also be performed at kiln exit gas temperature of 980°C (1,800°F). Diesel fuel will serve as the material to be oxidized by N_2O_4 for its destruction. The diesel fuel will be fed to the kiln via the liquid nozzle of the kiln's dual fuel burner. The N_2O_4 oxidant will be added to the burner primary air supply.

This mode of operation will require an N_2O_4 evaporator between the N_2O_4 storage container and the kiln burner, which will deliver N_2O_4 vapor to the burner at the correct pressure. The evaporator will be fed from the N_2O_4 storage container by pressurization of the storage container nitrogen blanket. The N_2O_4 supply line to the kiln burner will be heat-traced to ensure that no N_2O_4 recondensation occurs. The feed line will tee into the burner primary air supply line at the kiln burner.

For both test feeds (all initial tests) the RKS afterburner will be fired with natural gas to maintain an afterburner exit gas temperature of 1,090°C (2,000°F). The IRF hazardous waste management permit specifies a minimum afterburner temperature of 1,017°C (1,863°F) whenever a hazardous waste is being fed to the system. The 1,090°C (2,000°F) set temperature is a typical afterburner operating temperature and also allows a margin of flexibility above the permit-mandated temperature.

The feedrates of both UDMH and N_2O_4/diesel fuel will result in kiln chamber heat input rates of between 290 and 440 kW (1 and 1.5 MMBtu/hr), typical RKS operation. Actual test weight feedrates will be established based on preliminary scoping tests to be performed before the evaluation tests are initiated. These scoping tests will confirm the ability to incinerate both propellant components, while maintaining planned incineration conditions, with acceptable CO, total organic carbon, and NO_x emissions as discussed above. In particular, it is expected that several N_2O_4/diesel fuel ratios will need to be tried during scoping tests to identify ratios that give acceptable NO_x emission rates.

Current expectations are that the propellant component feedrates summarized in Table 28 will yield the target test conditions. For the N_2O_4 tests, the Table 28 entries assume that a 100 percent excess of diesel fuel will give acceptable NO_x emissions.

For all tests, the RKS scrubber system will operate at its nominal design conditions, listed in Table 10, and at as close to total recirculation (zero to minimum blowdown) as possible.

The feed materials will be supplied by the San Antonio Air Logistics Center's Directorate of Aerospace Fuels (SA-ALC/SF) at Kelly Air Force Base, Texas. Thirteen 55-gal (208-L) drums of UDMH containing a total of 1,930 kg (4,240 lb) will be shipped to the IRF. Two cylinders of MON-1 grade N_2O_4, each containing 910 kg (2,000 lb) (total of 1,820 kg [4,000 lb]) will be shipped.

7.1.3 Sampling and Analysis Procedures

The RKS sampling locations and the scope of the sampling effort are shown in the process schematic given in Figure 21. For all tests, the sampling matrix defined to meet the test program objectives listed in Section 7.1.1 will entail:

- Continuously measuring O_2, CO, NO_x, and TUHC concentrations in the kiln exit flue gas; O_2, CO_2, and NO_x concentrations in the afterburner exit flue gas; O_2, CO_2, and NO_x concentrations in the scrubber exit flue gas; and O_2 and CO concentrations in the stack gas

- Sampling flue gas at the scrubber exit and the stack for particulate and HCl using Method 5; the stack gas sample is needed to comply with the IRF's permit requirements

Additional sampling procedures will be performed for the UDMH incineration tests. These are:

- Sampling flue gas at the kiln exit, afterburner exit, and scrubber exit for:

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TABLE 28. EXPECTED APPROXIMATE TEST CONDITIONS

Parameter	UDMH tests	N_2O_4 tests
Kiln		
Propellant component feedrate, kg/hr (lb/hr)	45 (100)	91 (200)
Diesel fuel feedrate, kg/hr (lb/hr)	—	36 (80)
Combustion air feedrate[a], scm/hr (scfh)	740 (26,000)	800 (28,400)
Exit gas:		
Temperature, °C (°F)	980 (1,800)	980 (1,800)
Moisture, %	9.2	6.9
O_2, % dry	11.4	13.8
Flowrate, dscm/hr (dscfh)	710 (25,000)	830 (29,400)
Afterburner		
Natural gas feedrate, scm/hr (scfh)	31 (1,090)	36 (1,280)
Combustion air feedrate[a], scm/hr (scfh)	350 (12,500)	380 (13,400)
Exit gas:		
Temperature, °C (°F)	1,090 (2,000)	1,090 (2,000)
Moisture, %	11.5	10.3
O_2, % dry	8.6	9.7
Flowrate, dscm/hr (dscfh)	1,030 (36,300)	1,220 (43,200)

[a]Includes routinely experienced inleakage.

- — UDMH and dimethylamine using a variation of the National Institute for Occupational Safety and Health (NIOSH) Method S143

- — N-nitrosodimethylamine and 1,1,4,4-tetramethyl-2-tetrazene (tetramethyltetrazene) using Method 0010

- — HCN using the California Air Resources Board (CARB) Method 426

- — Formaldehyde using Method 0011

- Sampling flue gas at the scrubber exit for PCDDs/PCDFs for one test using Method 23

Figure 21. Test sampling locations.
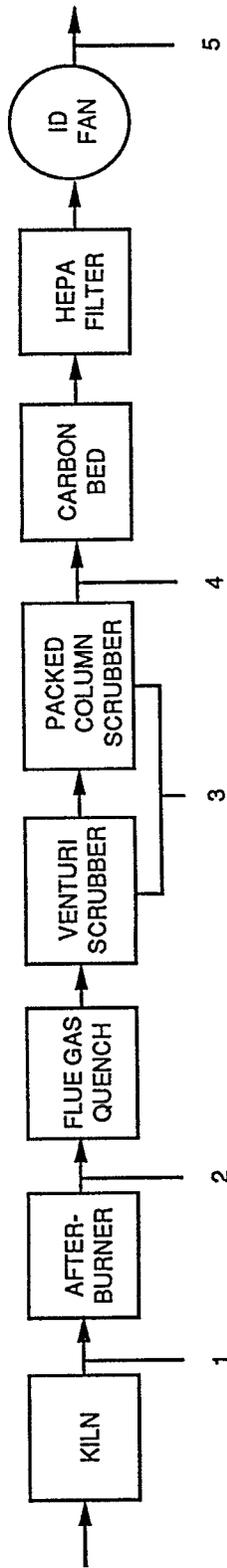
Sampling point	Continuous monitors					Scrubber liquor	Flue gas						
	O₂	CO	CO₂	NOₓ	Heated TUHC		EPA multiple metals train, trace metals	Method 23, PCDD/PCDF	Method 5, particulate and HCl	NIOSH Method S143, UDMH and DMA	Method 0010, nitrosodimethylamine and TMT	Method 0011, formaldehyde	CARB Method 426, HCN
1. Kiln exit flue gas	X	X		X	X					U1	U2	U1	U2
2. Afterburner exit flue gas	X	X	X	X	X					U1	U2	U1	U2
3. Scrubber liquor						X							
4. Scrubber exit flue gas	X		X	X	X		N	N, U1ᵃ	N, U1	U1	U2	U1	U2
5. Stack gas	X	X							X				

X: All tests.
N: N₂O₄ tests.
U1: UDMH tests, test set 1 of 2.
U2: UDMH tests, test set 2 of 2.
ᵃOne U1 test only.

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Additional sampling procedures will also be performed for the N_2O_4 tests. These are:

- Sampling flue gas at the scrubber exit for trace metals using the EPA multiple metals train

- Sampling flue gas at the scrubber exit for PCDDs/PCDFs using Method 23

Measurements of NO_x, UDMH, and UDMH PICs are specified at the three locations noted, specifically to supply data to allow evaluating the need for a secondary combustion chamber (afterburner) and/or a wet scrubber APCS. Additional sampling and analysis is also planned for all tests to allow a wider scope of environmental acceptability to be evaluated. This additional sampling will measure particulate, HCl, trace metal, and PCDD/PCDF emission rates. This additional sampling will be performed in the scrubber exit gas. Pre- and post-test scrubber liquor samples will also be taken and analyzed for UDMH (for UDMH incineration tests), chloride, nitrate, nitrite, and trace metals.

The number of sampling procedures specified for the UDMH tests cannot be performed simultaneously at the IRF due to the unavailability of sampling ports in all the locations specified. Thus, the UDMH sampling matrix will be completed over two sets of tests. The procedures denoted U1 in Figure 21 will be simultaneously completed over one set of three test days; the procedures denoted U2 in the figure will be completed during a second set of three test days.

The analysis procedures to be applied to test program samples are summarized in Table 29.

7.2   CURRENT STATUS

The planning for this test program was initiated in June 1993 during a visit to the IRF by two DNA representatives. Following the discussions at this meeting, a test plan outline was prepared and distributed in July. With DNA approval of the test plan outline in September, a complete test plan was prepared for distribution in October.

Current plans are to complete all test planning documentation in early FY94 and initiate the testing in December 1993. Sampling tests will follow in January and February, 1994. All FY94 efforts will be supported by DNA under interagency cost reimbursement order (IACRO) No. 93-691, which will become EPA interagency agreement (IAG) No. RW97936997.

TABLE 29. ANALYSIS PROTOCOL

Sample	Analyte	Analysis method	Frequency
NIOSH Method S143 combined impinger solutions	UDMH	Phosphomolybdic acid addition, colorimetric analysis by NIOSH Method S143[a]	3 per test (kiln, afterburner, and scrubber exit), UDMH tests only
	Dimethylamine	Neutralization then GC/FID by NIOSH Method 2010[a]	3 per test (kiln, afterburner, and scrubber exit), UDMH tests only
Method 0010 train	N-nitrosodimethylamine, tetramethyltetrazene	Extraction by Method 3540A, GC/MS analysis by Method 8270A[b]	3 per test (kiln, afterburner, and scrubber exit), UDMH tests only
CARB Method 426 train	Cyanide	Distillation and colorimetric analysis by CARB Method 426[c]	3 per test (kiln, afterburner, and scrubber exit), UDMH tests only
Method 0011 train	Formaldehyde	Extraction with methylene chloride analysis, by HPLC with UV/vis detection by Method 8315[b]	3 per test (kiln, afterburner, and scrubber exit), UDMH tests only
Method 23 train	PCDD/PCDF	Extraction and analysis by Method 8290[b]	1 per test for N_2O_4 and set 2 of UDMH tests
Multiple metals train	Trace metals[d]	Digestion by multiple metals procedure[e], ICAP analysis by Method 6010A[b]	1 per test for N_2O_4 and set 2 of UDMH tests
Method 5 train	Particulate	Gravimetry by Method 5[f]	1 per test at stack, 1 per test at scrubber exit for N_2O_4 and set 2 of UDMH tests
	Cl⁻	IC by Method 9057[b]	1 per test at stack, 1 per test at scrubber exit for N_2O_4 and set 2 of UDMH tests
Pretest scrubber liquor	Trace metals[d]	Digestion by Method 3010A, ICAP analysis by Method 6010A[b]	1 per test
	Cl⁻, NO_3^-, NO_2^-	IC by Method 300.0[g]	1 per test
Post-test scrubber liquor	Trace metals[d]	Digestion by Method 3010A, ICAP analysis by Method 6010A[b]	1 per test
	Cl⁻, NO_3^-, NO_2^-	IC by Method 300.0[g]	1 per test
	UDMH	Phosphomolybdic acid addition, colorimetric analysis by NIOSH Method S143[a]	1 per test for UDMH tests

[a]Reference 9, NIOSH Methods.
[b]Reference 5, SW-846.
[c]Reference 10, CARB Methods.
[d]See Table 30.
[e]Reference 6, 40 CFR 266, App. IX.
[f]Reference 7, 40 CFR 60, App. A.
[g]Reference 11, Water and Wastes.

TABLE 30. TRACE METALS TO BE DETERMINED IN SELECTED TEST PROGRAM SAMPLES

Antimony
Arsenic
Barium
Beryllium
Cadmium
Chromium
Cobalt
Lead
Manganese
Nickel
Silver
Thallium
Tin
Vanadium

SECTION 8

EVALUATING THE EFFECTIVENESS OF ADDITIVES
AS SORBENTS FOR METAL CAPTURE

There is currently considerable interest in the potential use of mineral-based sorbents for capturing and retaining hazardous constituent trace metals in incineration processes. A number of fundamental, bench-scale research programs are currently underway at several universities and research laboratories. These studies are investigating the application of sorbents both in the combustion flue gas and in the solids bed.

Most of the research completed to date has focused on quantifying the effectiveness of various proposed sorbents for capturing vaporized metals from the flue gas. In such applications, it is theorized that vaporized metals will react with the sorbent particles at the elevated incinerator temperatures or heterogeneously condense onto the sorbents as the flue gas cools. In the absence of available condensation sites, vaporized metals will primarily undergo homogeneous condensation, forming a fine fume. Thus, the goal of this approach is to make particles available in the flue gas with which the metals can react or upon which they can condense. Metals bound to larger sorbent particles will be more effectively collected by APCSs than metals presented as a fine fume. In addition, studies completed to date suggest that chemical reaction between the metal and the sorbent dominates over physical adsorption, offering the additional advantage of reduced potential for metal leaching from collected particulate.

Other researchers have studied the incorporation of sorbents into the solid feed. This approach seeks to capture and bind the metals in the incinerator ash, thereby preventing them from exiting with the combustion gases. For this approach to be effective, research completed to date suggests that the metal should become volatile in the incinerator environment and chemically react with the sorbent material.

The test program described in this section is designed to further investigate this second approach by screening several minerals for their suitability as sorbent materials for capturing metals in the solid bed and preventing their release to the flue gas. In addition to capturing the metals, an ideal sorbent would retain them in the ash when disposed, so that a TCLP leachate of the ash would contain metals concentrations below respective regulatory levels. Thus, the objective of this screening test program planned for completion at the IRF is to evaluate several candidate sorbents with respect to:

- The degree to which they facilitate retention of trace metals in the solid bed that would be the bottom ash discharge from a rotary kiln incinerator

- The degree to which they retain trace metals in the solid bed when subjected to TCLP extraction

If screening test results show that one or more of the candidate sorbents test significantly alters test metal behavior in terms of fraction of metal feed retained in the solids bed, or decreased fraction of solids bed metal leachable in the TCLP test, then a confirmation test program in the IRF RKS may be planned.

The screening tests in this program will be conducted in the IRF TTU. A brief description of this unit, and the outline of the planned test program, are discussed in the following subsections.

8.1   TEST FACILITY DESCRIPTION

The TTU at the IRF consists of a small commercial pathological incinerator that has been modified to allow for continuous test material feed and treated-material (e.g., ash) removal, for variable and controlled thermal treatment temperatures, and for expanded process operation monitoring. The TTU is illustrated in Figure 22.

The combustor portion of the TTU consists of three chambers: the charge chamber, the retention chamber and the breeching chamber. The charge chamber is designed to accept the TTU's solid material feed stream. It corresponds to the primary combustion chamber, or kiln portion, of a waste incinerator. Its inner cross section is 0.66 m (2 ft 2 in) square, its height 1.9 m (6 ft 2 in), and its chamber volume 0.82 m^3 (29 ft^3). The retention chamber, which directly follows the charge chamber, is designed to effect complete organic constituent destruction. It corresponds to the secondary combustion chamber, or afterburner portion, of a waste incinerator. Its inner cross section is also 0.66 m (2 ft 2 in) square, its height 1.5 m (5 ft), and its chamber volume 0.67 m^3 (23.5 ft^3). The breeching chamber serves as a second-stage afterburner. Its inner diameter is 0.41 m (1 ft 4 in), its total height 0.76 m (2 ft 6 in), and its chamber volume 0.10 m^3 (3.5 ft^3). All chambers are lined with a 13-cm (5-in) thickness of refractory.

As received from the incinerator vendor, all three chambers were designed to be fired with natural-gas-fueled burners. The burners installed in the charge and retention chambers are natural-gas-fired, with 350 kW (1.2 million Btu/hr) capacities and 5-to-1 turndowns. Modulating burner controls allow variable firing rates to control temperatures in each chamber at preset levels between 260° and 1090°C (500° and 2,000°F) with variable air-to-fuel ratio. The breeching chamber has a manually adjustable 220 kW (750,000 Btu/hr) burner.

Test material is fed to the charge chamber via a feed system that transports quartz trays containing the test material through the chamber via a variable-speed chain-drive mechanism. Each quartz tray is 23 cm (9 in) long by 13 cm (5 in) wide by 5 cm (2 in) deep, and holds up to 2.3 kg (5 lb) of test material. The variable-speed chain drive allows trays containing test material to have charge chamber residence times of between 20 minutes and 1 hour. Multiple trays can be fed in sequence to simulate continuous feed to a thermal treatment system.

Combustion gas temperatures are recorded using type K or R thermocouples at the following locations in the system:

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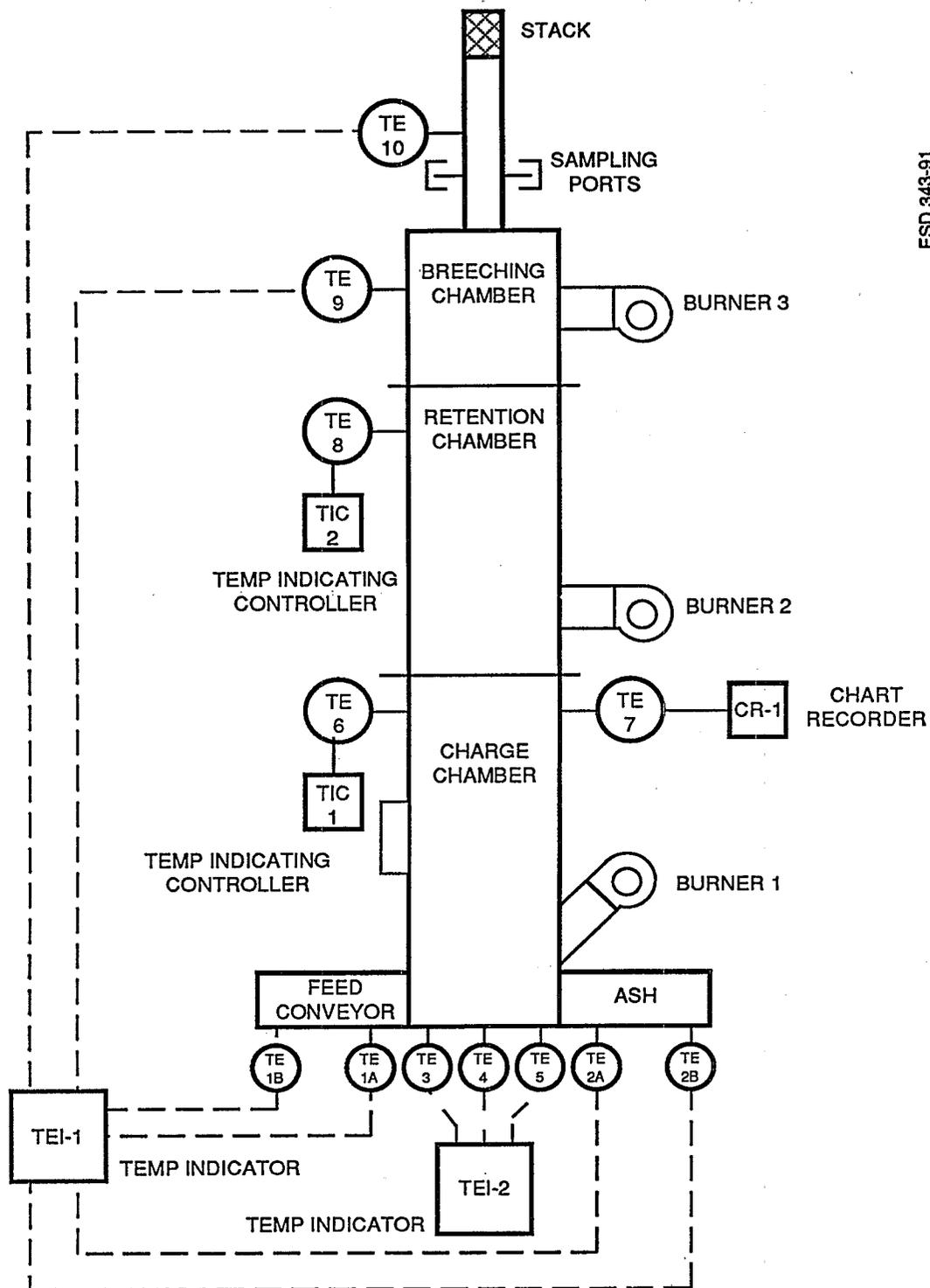
Figure 22. The IRF TTU.

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- Inside feed door
- Inside discharge door
- Bottom of charge chamber center
- Charge chamber exit gas
- Retention chamber exit gas
- Breeching chamber exit gas
- Stack gas

8.2 TEST PROGRAM

The test program to be performed will consist of 50 tests. The test variables will be sorbent material, solid bed temperature, feed chlorine content, and metal form in the feed. Six sorbents will be evaluated in this study. Four of the six, diatomaceous earth, kaolinite, bauxite, and alumina, were selected based on the most promising results from other researchers. The attapulgite clay used in past IRF trace metal studies will be tested as the fifth sorbent to serve as a link to the past IRF studies. The sixth material, quartz, was selected to be the neutral material to serve as a system blank or background material. The trays used to feed the test materials to the TTU are quartz.

The approximate mineral content of diatomaceous earth, kaolinite, and bauxite is given in Table 31. Quartz is presumed to be pure silica (SiO_2); alumina is presumed to be pure Al_2O_3. This attapulgite clay is a hydrated magnesium aluminum silicate [$(Mg,Al)_5Si_8O_{22}(OH)_4 \cdot 4H_2O$] containing some dolomite [$Ca,Mg (CO_3)_2$], calcite [$CaCO_3$], and silica.

Three solids bed temperatures will be tested: 540°, 700°, and 870°C (1,000°, 1,300°, and 1,600°F). Two feed chlorine contents will be tested, 0 and 4 percent by weight. Polyvinyl chloride (PVC) powder will be added to chlorine-containing feed mixtures to provide the desired chlorine content.

Sorbent behavior in retaining five trace metals will be evaluated in the test program. The five metals are arsenic, cadmium, chromium, lead, and nickel. Two forms of incorporating

TABLE 31. APPROXIMATE SORBENT MINERAL COMPOSITION

	Diatomaceous earth	Kaolinite	Bauxite
SiO_2	90.4	52	11
Al_2O_3	6.5	45	84
Fe_2O_3	2.3	1	5
TiO_2		2	
CaO	0.2		
MgO	0.3	—	
Other oxides	0.3		

the metals into metals/sorbent mixtures for testing will be investigated. Past trace metal tests at the IRF[1,2] have used aqueous metal spike solutions containing soluble nitrate salts of the metals, with the exception of As which has been added as As_2O_3. This form will be one of the two used in these tests. The second form of metal spiking will use metal compound dispersions or suspensions. Such dispersions consist of metal compound powders suspended in a liquid carrier analogous to pigments dispersed in paint or ink.

Table 32 summarizes the matrix of test variable combinations planned for testing. The table notes 48 combinations to be tested. Test condition 36 in Table 32 will be repeated twice (performed in triplicate) over the course of the test program, giving a total of 50 tests. For each test, weighed amounts of appropriate mixtures of sorbent, PVC (for tests with chlorine-containing feed), and metal spiking preparation will be charged to one of the quartz trays used to introduce feed to the TTU. Charge depth will be nominally 2 cm.

The composition of the metal spiking solution will be as given in Table 33. The appropriate quantity of the spiking solution will be combined with the solid sorbent and PVC (if added) to result in solid charge metal concentrations approximating those noted in the rightmost column of Table 33 for sorbents that do not contain the spiked metals.

The metal dispersion to be used as the second form of metal spiking will consist of finely ground (particle size typically between 0.1 and 5 μm) metal compounds in a matrix of fuel oil and vegetable oil. The metal compounds to be used for these tests will be metal oxides. Stable dispersions can be made with the compounds chosen.[12] Table 34 gives the metal and metal oxide concentrations in the dispersion to be prepared for these tests. The appropriate quantity of metal dispersion will be combined with the solid charge to result in a mixture with total metal concentrations approximating those noted in the rightmost column of Table 34, again for sorbents with negligible test metal concentrations.

For each of the planned tests, the TTU will be allowed to reach steady state at the desired temperature condition before feeding the test tray for each test. The feed tray will be fitted with thermocouples so that the bed temperatures can be monitored. The feed tray will be fed to the TTU to start the test, then removed when the feed material has reached the target temperature.

Four sample matrices will be collected or prepared for the analytical measurements: unspiked sorbent, TTU feed, TTU residual discharge, and TCLP leachates of TTU residual discharges. These samples will be analyzed for the test trace metals.

8.3   CURRENT STATUS

All planning efforts for this test program were completed during FY93. After a substantial literature review and extended telephone discussions with several researchers in the field, a test plan outline describing the recommended test program was prepared and distributed in May. The complete test program QAPP, incorporating test program modifications in response to technical review of the test plan outline, was prepared and distributed in September. Current plans are to initiate testing in November, in parallel with the M. W. Manufacturing Superfund site treatability tests discussed in Section 5.

TABLE 32. TEST MATRIX

Test	Sorbent	Metal form	Feed chlorine, %	Solids bed temperature, °C
1	Quartz beads (silica)	Aqueous nitrates	0	540
2			0	700
3			0	870
4			4	540
5			4	700
6			4	870
7		Metal dispersions	0	540
8			0	700
9			0	870
10			4	540
11			4	700
12			4	870
13	Attapugite clay	Aqueous nitrates	0	540
14			0	700
15			0	870
16			4	540
17			4	700
18			4	870
19		Metal dispersions	0	540
20			0	700
21			0	870
22			4	540
23			4	700
24			4	870

(continued)

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TABLE 32. (continued)

Test	Sorbent	Metal form	Feed chlorine, %	Solids bed temperature, °C
25	Diatomaceous earth	Aqueous nitrates	0	540
26			0	700
27			0	870
28			4	540
29			4	700
30			4	870
31	Kaolinite	Aqueous nitrates	0	540
32			0	700
33			0	870
34			4	540
35			4	700
36			4	870
37	Alumina	Aqueous nitrates	0	540
38			0	700
39			0	870
40			4	540
41			4	700
42			4	870
43	Bauxite	Aqueous nitrates	0	540
44			0	700
45			0	870
46			4	540
47			4	700
48			4	870

TABLE 33. METAL SPIKE SOLUTION CONCENTRATIONS

| Metal | Spike solution | | | Approximate resulting feed metal concentration, mg/kg |
	Metal concentration, g/L	Compound	Compound concentration[a], g/L	
Arsenic	7.75	As_2O_3	10.2	250
Cadmium	1.55	$Cd(NO_3)_2 \cdot 4H_2O$	4.25	50
Chromium	4.65	$Cr(NO_3)_3 \cdot 9H_2O$	35.8	150
Lead	7.75	$Pb(NO_3)_2$	12.4	250
Nickel	4.65	$Ni(NO_3)_2 \cdot 6H_2O$	23.0	150

[a]Sufficient HNO_3 will be added to maintain lead arsenate compounds in solution.

TABLE 34. TEST PROGRAM METAL DISPERSION CONCENTRATIONS

| Metal | Dispersion | | | Approximate resulting feed metal concentration, mg/kg |
	Metal concentration, g/kg	Compound	Compound concentration, g/kg	
Arsenic	7.73	As_2S_3	12.7	250
Cadmium	1.49	CdO	1.7	50
Chromium	9.31	Cr_2O_3	13.6	300
Lead	7.80	PbO	8.4	250
Nickel	4.45	$NiCO_3$	9.0	150
Total			45.4	

SECTION 9

INSTALLATION OF A FABRIC FILTER AIR POLLUTION
CONTROL SYSTEM WITHIN THE IRF RKS

The RKS primary APCS, used in most testing efforts completed over the past 6 years, represents an APCS typical of that employed in industrial hazardous waste incineration systems built in the 1970s and 1980s. However, more recent installations have incorporated more state-of-the-art APCSs employing a fabric filter for particulate removal. Thus, to upgrade the IRF-RKS capabilities to allow testing with a state-of-the-art APCS, it was decided to install a fabric filter system during FY93.

Conceptual design efforts leading to a system specification were initiated in April. As acid gas (e.g., HCl) control would continue to be a critical requirement of the RKS APCS, it was decided that the baghouse system be located downstream of the existing wet scrubber. Thus, because flue gas exiting the existing wet scrubber is water-saturated, flue gas must be reheated to comfortably above the dew point before entering the baghouse. Although several approaches can be employed to effect flue gas reheat, the availability of a 100-kW airheater resulted in this approach being selected.

Figure 23 is a schematic of the system designed. The location of the baghouse system within the RKS process flow schematic is illustrated in Figure 18. As shown in Figure 23, baghouse system inlet flue gas can be taken from the induced draft (ID) fan at the discharge from the packed column. Flue gas at this location is saturated with water vapor at typically 65° to 75°C (150° to 170°F). Typical flue gas flowrates are 20 to 35 dscm/min (800 to 1,200 dscfm). The water-cooled heat exchanger shown in Figure 23 cools the flue gas by about 5°C (10°F) to lower its dew point slightly. The 100-kW reheater then heats the flue gas to nominally 120°C (250°F), well above its dew point, so that no water condensation can occur in the baghouse. After the baghouse, flue gas is routed through the carbon bed/HEPA filter secondary APCS as required by the IRF's hazardous waste management permit when hazardous waste is being burned. Either the baghouse system or the secondary APCS, or both, can be bypassed, as shown in Figure 23. Table 35 summarizes the design specifications of the baghouse collector.

The system design specified placing the baghouse system physically between the incinerator and the horizontal length of ductwork between the scrubber system and the secondary APCS. The location formerly housed the single stage ionizing wet scrubber system occasionally used in RKS tests. The ionizing wet scrubber system was removed and stored to make room for the baghouse.

Most of the facility modification work required to install the baghouse system was performed in July and August. The baghouse was delivered to the IRF by the vendor in early

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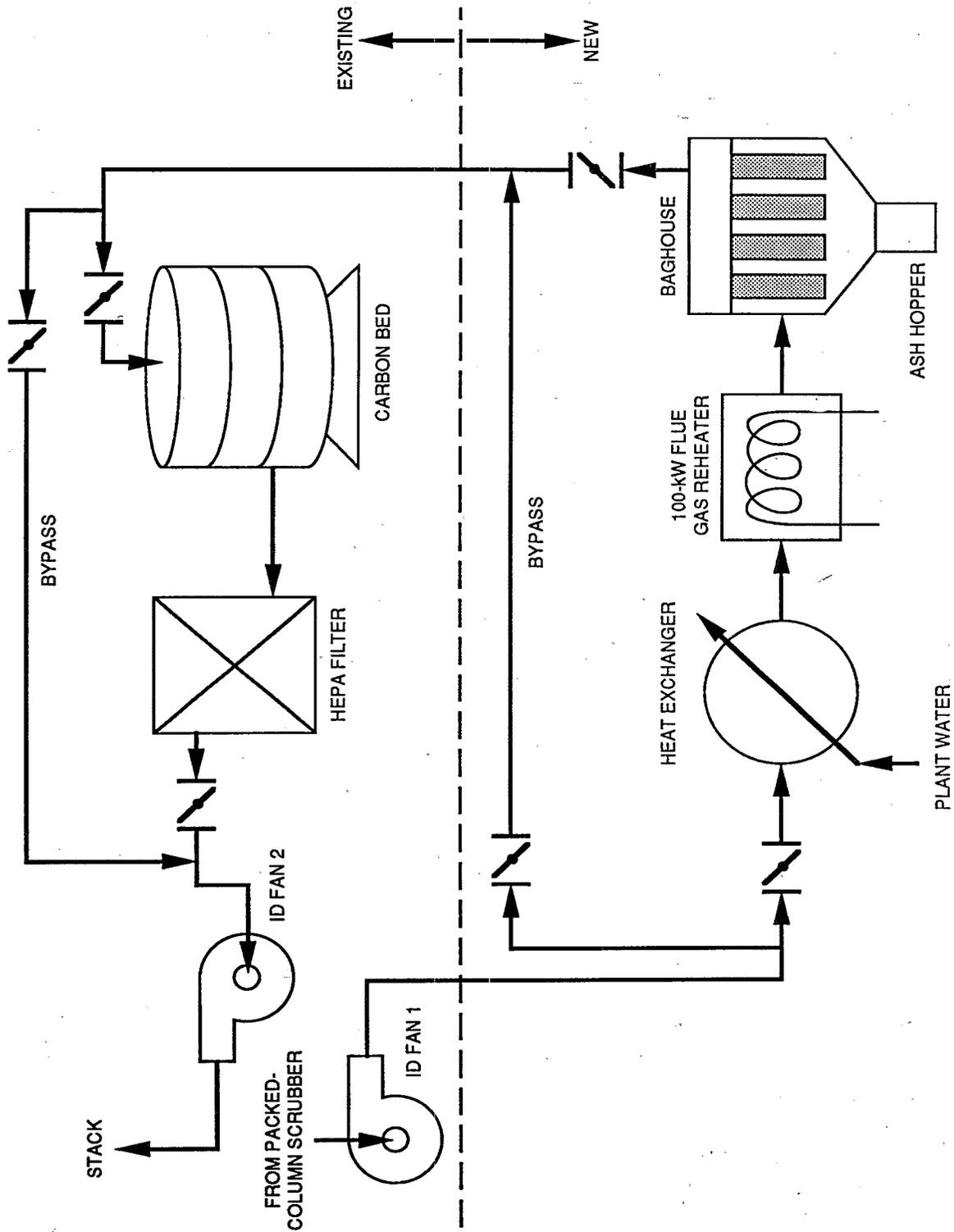
Figure 23. Baghouse APCS schematic.

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TABLE 35. DESIGN CHARACTERISTICS OF THE RKS BAGHOUSE COLLECTOR

System capacity, inlet gas flow	70 m^3/min (2,500 acfm) at 120°C (250°F)
Operating temperature, max	200°C (400°F)
Operating pressure	±12.4 kPa (±50 in WC)
Diameter	1.8 m (6 ft)
Overall height	4.2 m (13 ft, 8.375 in)
Filter elements (bags)	
Material	16 oz. Nomex
Length	1.8 m (6 ft)
Number	69
Total filter area	45 m^2 (488 ft^2)
Materials of construction	
Collector internals	304 SS
Airlock	316 SS
Venturi nozzles	Aluminum
Insulation	Heat loss less than 8.8 kW (30,000 Btu/hr) at 200°C (400°F)

September. Because much of the preparatory work had been completed during the previous 2 months, actual baghouse installation and final connection proceeded rapidly such that system startup and shakedown was possible at the close of FY93.

SECTION 10

EXTERNAL COMMUNICATIONS

During FY93, 7 research reports were prepared or finalized and 6 technical papers were presented or published. These are listed in Table 36. This level of external communication and technology transfer testifies to the high level of research being supported at the IRF.

Table 37 lists some of the visitors to the IRF during FY93. The list attests to the visibility of the work being performed at the IRF to the incineration research community.

TABLE 36. IRF PROGRAM REPORTS AND PRESENTATIONS IN FY93

Reports

- Waterland, L. R., "Operations and Research at the U.S. EPA Incineration Research Facility, Annual Report for FY92," draft October 1992, revised December 1992, published as EPA/600/R-93/087, June 1993

- Whitworth, W. E., Jr., and L. R. Waterland, "Evaluation of the Impact of Incinerator Waste Feed Cutoffs," draft November 1992

- King, C., and L. R. Waterland, "Pilot-Scale Incineration of Contaminated Sludges from the Bofors-Nobel Superfund Site," revised October 1992, published as EPA/600/R-92/240, March 1993

- Siag, A., D. J. Fournier, Jr., and L. R Waterland, "Pilot-Scale Incineration of Contaminated Soil from the Chemical Insecticide Corporation Superfund Site," revised September 1992, published as EPA/600/R-93/036, April 1993

- King, C., J. W. Lee, and L. R. Waterland, "Pilot-Scale Incineration of Contaminated Soils from the Drake Chemical Superfund Site," published as EPA/600/R-93/047, May 1993

- Fournier, D. J., Jr., and L. R. Waterland, "The Fate of Trace Metals in a Rotary Kiln Incinerator with a Calvert Flux-Force/Condensation Scrubber System," draft January 1993

- Siag, A., and L. R. Waterland, "Pilot-Scale Incineration of Contaminated Soils from the Scientific Chemical Processing Superfund Site," revised May 1993

Papers and Presentations

- Waterland, L. R., and W. E. Whitworth, Jr., "Evaluation of the Impacts of Incinerator Waste Feed Cutoffs," presented at the Air & Waste Management Association International Conference on Waste Combustion in Boilers and Industrial Furnaces, Clearwater, Florida, March 1993; published in Waste Combustion in Boilers and Industrial Furnaces, Proceedings of an International Conference, A&WMA SP-86, Air & Waste Management Association, Pittsburgh, Pennsylvania, 1993

- Richards, M. K., W. E. Whitworth, Jr., and L. R. Waterland, "Hazardous Waste Incinerator Emissions Resulting from Waste Feed Cutoffs," presented at the Nineteenth Annual RREL Hazardous Waste Research Symposium, Cincinnati, Ohio, April 1993

- Waterland, L. R., M. K. Richards, and H. O. Wall, "Comparison of Thermal Treatment PCB Data from Two Superfund Sites," presented at the Nineteenth Annual RREL Hazardous Waste Research Symposium, Cincinnati, Ohio, April 1993

- Lee, J. W., S. Venkatesh, and R. C. Thurnau, "The U.S. EPA Incineration Research Facility," presented at the Nineteenth Annual RREL Hazardous Waste Research Symposium, Cincinnati, Ohio, April 1993

- Waterland, L. R., and D. J Fournier, Jr., "Potential Surrogate Metals for Incinerator Trial Burns," presented at the 1993 Incineration Conference, Knoxville, Tennessee, May 1993; published in Proceedings of the 1993 Incineration Conference, University of California, Irvine, California, 1993

- Lee, J. W., L. R. Waterland, W. E. Whitworth, Jr., and M. K. Richards, "Evaluation of the Emissions Impact of Repeated Incinerator Waste Feed Cutoffs," presented at the Third International Congress on Toxic Combustion Byproducts, Cambridge, Massachusetts, June 1993

TABLE 37. VISITORS TO THE IRF

Person	Affiliation	Date	Purpose of visit
R. Wade	USACE, Waterways Experiment Station	10/1/92	To witness New York Harbor TTU testing
S. Makhijani A. Senthil	CPCB, New Dehli, India	11/2/92	Facility tour
K. Partymiller R. Argus Z. Plavnik D. Brooks M. Richards	PRC PRC Sonotech Industrial Gas Technology EPA/RREL	11/17,18/92	Preliminary Sonotech SITE test program planning
W. Schofield G. Patterson A. George	DRE Southwest Marsten Bentley Marsten Bentley	11/19/92	To discuss possible metal dispersion testing
B. Blackburn S. Schulberg M. Richards	S-Cubed S-Cubed EPA/RREL	12/7-10/92	QA technical systems review
J. Chaney	USACE, PBA	1/8/93	Facility tour
J. Truholt A. Doribati	ADPCE ADPCE	2/18/93	Hazardous waste inspection
E. Rothschild	Geraghty & Miller	3/2/93	Facility tour
G. Stryker	Four Nines	3/15/93	Facility tour
M. Subbaruman K. Knudsen T. Holt	Rockwell, ETEC Rockwell, ETEC Rockwell, ETEC	3/17/93	Preliminary molten salt oxidation process test planning
D. Burns H. Burns	WSRC WSRC	3/18/93	To witness initial simulated mixed-waste testing
D. Burns	WSRC	3/24/93	To witness simulated mixed-waste testing
H. Pope M. McDerment D. Burns M. Looper C. McVay R. Thurnau	DOE/SRP DOE/SRP WSRC WSRC WSRC EPA/RREL	3/30/93	To discuss additional WSRC test needs and initiate DOE/EPA interagency agreement planning

TABLE 37. (continued)

Person	Affiliation	Date	Purpose of visit
C. Cooley G. Knight W. Quapp L. Apel A. Wollerman J. Petersen R. Thurnau	DOE/EM-50 WPI INEL INEL SAIC Callidus EPA/RREL	4/1/93	To discuss DOE mixed-waste thermal destruction research/technology development needs
D. Burns P. Lowe	WSRC WSRC	4/19,20/93	DOE QA surveillance for WSRC tests
A. Baker	EPA	4/19-21/93	EPA property audit
W. Fortner G. Thomasson L. Seaton M. Garvey K. Shuster D. Bell D. Wallace	USACE/PBA USACE/PBA EPA/Region VI EPA/OE EPA/OSW DOD DOD	5/27/93	Facility tour
D. Burns	WSRC	6/8/93	To witness WSRC tests
R. Schultz H. Thompson J. Anthony R. Thurnau	DNA DNA SAIC EPA/RREL	6/10/93	Preliminary ballistic missile propellant test planning
O. Vincent R. Damer G. Carroll	EPA/OSORD EPA/RREL EPA/RREL	6/27,28/93	Health and safety technical assistance visit
G. Lewis D. Donton	Sparkman HS	9/7/93	Facility tour
E. A. Burns	SRA	9/14/93	Facility tour, discussion of SBIR test program
M. Richards G. Carroll P. Lin J. Fuhrmann	EPA/RREL EPA/RREL EPA/RREL EPA/RREL	9/27-29/93	Project review and planning
A. Doribati M. Adams G. Carroll	ADPCE ADPCE EPA/RREL	9/30/93	Permit renewal, RFI discussions

SECTION 11

PLANNED EFFORTS FOR FY94

In addition to the test programs planned for completion in FY94, as discussed in Sections 5 through 8, several other candidate programs are being considered for inclusion in the IRF FY94 schedule beginning in May 1994. The current most likely candidate is a program to evaluate the treatability, via low-temperature thermal desorption, of three contaminated materials from the Rocky Mountain Arsenal Superfund site. Initial test planning discussions have begun with Argonne National Laboratory staff. Argonne is supporting the Department of the Army in its efforts to remediate the site.

Other candidate test programs for FY94 include:

- Testing to support the DOE's mixed-waste thermal destruction technology development program

- Evaluation of other innovative incineration systems

- Extended liquid ballistic missile propellant testing

- Additional trace metal fate testing to support the installation and permitting of the CIF at DOE's Savannah River Plant

- Testing to evaluate whether the major constituents comprising the TUHC emissions from an incinerator can be identified

Detailed plans for testing during the second half of FY94 will be firmed up as the year progresses.

REFERENCES

1. Fournier, Jr., D. J., W. E. Whitworth, Jr., J. W. Lee, and L. R. Waterland, "The Fate of Trace Metals in a Rotary Kiln Incinerator with a Venturi/Packed Column Scrubber," EPA/600/2-90/043, February 1991.

2. Fournier, Jr., D. J., and L. R. Waterland, "The Fate of Trace Metals in a Rotary Kiln Incinerator with a Single-Stage Ionizing Wet Scrubber," EPA/600/2-91/032, September 1991.

3. Barton, R. G., W. D. Clark, and W. R. Seeker, "Fate of Metals in Combustion Systems," Combustion Science and Technology, Vol. 74, pp. 327-342, 1990.

4. "Guidance on Setting Permit Conditions and Reporting Trial Burn Results, Volume II of the Hazardous Waste Incineration Guidance Series," EPA/625/6-89/019, January 1989.

5. "Test Methods for Evaluating Solid Waste: Physical/Chemical Methods," EPA SW-846, Third edition, Revision 1, July 1992.

6. 40 CFR Part 266, Appendix IX.

7. 40 CFR Part 60, Appendix A.

8. 40 CFR Part 61, Appendix B.

9. Eller, P. M., ed., "NIOSH Manual of Analytical Methods," Third edition, February 1984, with supplements 1, 2, 3, and 4 (1985, 1987, 1989, 1990).

10. "Stationary Source Test Methods, Volume III, Methods for Determining Emissions of Toxic Air Contaminants from Stationary Sources," State of California, Air Resources Board, Sacramento, California, March 1988.

11. "Methods for Chemical Analysis of Water and Wastes," EPA-600/4-84-017, March 1984.

12. W. Schofield, L., Weitzman, and A. George, "Metal Dispersion Spiking Systems for RCRA Trial Burns," in Waste Combustion in Boilers and Industrial Furnaces, Proceedings of an International Specialty Conference, Air & Waste Management Association, Pittsburgh, Pennsylvania, March 1993.