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SF-00006-05 (4/86)

DEPARTMENT : POLLUTION CONTROL AGENCY

STATE OF MINNESOTA

Office Memorandum

DATE :

910019

TO : John Velin
Director
Legislative Commission on Minnesota Resources

FROM : John N. Holck, Section Chief
Program Development Section
Ground Water and Solid Waste Division

John N. Holck

PHONE : 296-8612

SUBJECT : MUNICIPAL SOLID WASTE MATERIALS RECOVERY STUDY - - FINAL REPORT TO THE LEGISLATIVE COMMISSION ON MINNESOTA RESOURCES 1989 - Subd. 4 - E

INTRODUCTION:

This memorandum summarizes the efforts of the Minnesota Pollution Control Agency (MPCA) on behalf of the Municipal Solid Waste recovery project. We determined that a mass balance model would not achieve the desired results based on our literature review.

The alternative work plan proposed by the MPCA was to compare emissions of two solid waste incinerators. Characterization of the separate waste streams would have been used to explain differences in lead and cadmium emissions and the concentration of these metals in the incinerator ash. Based on the laboratory analysis of components of the waste stream we were to recommend methods of reducing the toxicity of both emissions and incinerator ash.

Also included is a summary of two major studies done by the California Waste management board and the Department of Energy. Attached is a bibliography of the most pertinate literature as well as a more extensive list of related articles.

NARRATIVE:

The municipal solid waste materials recovery project, as initially envisioned had three goals:

1. To develop a mass balance model to predict changes in emissions and ash when non-combustibles and toxic materials were removed from the waste stream prior to incineration. Permitters would then be able to predict the impact of reduction of certain items in the waste stream on the volume and toxicity of the ash. Realistic goals and timetables for reduction and perhaps increased management options for the ash could then be developed.

2. To develop a testing protocol to be used in sampling and analysis since no unified protocol exists. This would ensure standardized procedures used by all facilities and help measure the success of efforts to reduce the non-combustible portion of the waste stream prior to incineration. Any data collected by this project that might have value for natural resource planning would be transferred to the Minnesota Land Management data base.

Pursuant to 1989 Laws, Ch 335, Art 1, sec 29, subd 4(e)

3. To conduct a literature search including ongoing review of new information. This phase would provide information on other attempts to reduce the quantity and toxicity of ash and emissions and help avoid previous errors.

After a search was done and the literature reviewed, the enormity of the project became apparent. California did a similar 1.2 million dollar study and came up with more questions than answers so the Legislative Commission on Minnesota Resources project was redefined.

The original goal of developing a mass balance model was deemed impractical by our staff. Because of the variability of testing, operating conditions and heterogeneity of the waste that comes into an incinerator, it is difficult to develop a model for one facility. Furthermore, a model for one facility might not be useful for others since there are many different types of incinerators and attendant air pollution control equipment in Minnesota.

On June 12, 1990, a special subcommittee of the Legislative Commission on Minnesota Resources (LCMR) met to consider the amended work plan for the project on Municipal Solid Waste Materials Recovery. The subcommittee agreed that additional studies on Minnesota incinerators would be redundant. They recommended that the literature search be finished and that no additional field research be done.

A very brief summary of two major studies to determent the effect of removing the non-combustible portion of municipal solid waste before incineration follows.

The California waste management board tested two different waste streams, a mixed waste composed of approximately 60 percent residential and 40 percent commercial and a regular commercial stream made up of 95 percent commercial and five percent residential. Tests were run on samples of the waste coming in and the fly ash and bottom ash. Two testing teams performed simultaneous emissions tests at the boiler outlet and the stack. Testing was done over a three week period in July of 1988.

The California study found that there was a good correlation between the amount of volatile metals in the fuel, ash and air emissions. There seemed to be no clear difference in the emissions from the mixed waste and the commercial waste. Variations in emmissions testing results seemed to be more a result of differences in sample collection teams and the laboratories performing the tests on the samples. Analyses of the waste showed that ferrous, plastic, textiles and rubber products contribute the majority of the heavy metals to refuse. By encouraging source reduction, recycling, and reformulation of these products, the amount of metals going into the municipal waste could be reduced.

The second major study was actual field research conducted by National Recovery Technologies at three sites in Tennessee and Virginia to measure the effect of separation of materials on metals in air emissions. Funded by the United States Department of Energy, data on air emissions, ash, boiler efficiencies and disposal capacities were compared for incineration of raw municipal waste and waste with most of the non-combustibles removed.

An estimated 90 percent of the steel, glass and grit, and 75 percent of the aluminum was removed along with some polyvinyl chloride and other rigid plastics, ferrous metals and batteries. When presorted trash was incinerated, the study found there was a decrease in the quantity, by weight, of ash by about 50 percent, a decrease in heavy metals in uncontrolled emissions, fuel values (BTU's per pound) were increased by 25 percent, a reduction of leachable lead in bottom ash, and an increase in leachable cadmium in bottom ash. National Recovery Technologies did not test fly ash however, and leachable heavy metals are concentrated in the fly ash. The study shows the effect of removal of all these items as a group and the individual contributions of each item cannot be assessed.

CONCLUSIONS:

The literature search proved very helpful in defining the problems and scope of any study to be done on the waste stream going into incinerators. The cost and difficulty of such a study, which might not add definitive answers to the body of literature out there, forced us to re-evaluate the entire project. The studies done in California and by National Recovery Technologies make some significant points but also have some serious limitations. No doubt more and better research will be done in this complex area in the future.

JNH:tkt

Attachments

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COORDINATED WASTE, ASH, AND EMISSIONS SAMPLING AT THE COMMERCE REFUSE-TO-ENERGY FACILITY

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ABSTRACT

The Commerce waste-to-energy facility is a 360 ton/day commercial refuse incinerator which generates 11.5 megawatts of electricity and is equipped with ammonia injection, a dry scrubber and a baghouse for emission control. The California Waste Management Board, in cooperation with other state and local agencies, performed extensive testing of two different waste streams (predominantly residential and commercial), ash, and emissions from the facility in July, 1988.

The program objectives were to: 1) characterize the two different waste streams and analyze samples for trace organics and metals; 2) develop a sampling method and to obtain representative ash samples for analysis by the California Waste Extraction Test (WET) and the federal Extraction Procedure Toxicity Test (EP Tox); 3) perform simultaneous emissions testing by two testing teams for criteria pollutants, trace organics and metals at the inlet and outlet of control equipment; and 4) determine if correlations can be made between emissions, ash, and waste.

INTRODUCTION

California is facing decreasing landfill capacity and a growing awareness of the adverse environmental effects associated with continued landfilling. In response to these concerns, communities across the state have considered alternate disposal methods including waste incineration. Numerous facilities were proposed and there are now three operating municipal waste-to-energy (WTE) plants in the state; however, many other proposed projects were rejected by the public due to environmental and health concerns.

In response to requests by the California Waste Management Board (CWMB) for funding to study the impacts of the technology, the state legislature allocated one million dollars for a demonstration program. In June of 1987, the CWMB convened a technical advisory committee (TAC) comprised of state and local agencies involved in the permitting of WTE facilities. The agencies are: the California Air Resources Board, the California Department of Health Services, the State Water Resources Control Board, the Central Valley Regional Water Quality Control Board, the California Energy Commission, the County Sanitation Districts of Los Angeles County, and the South Coast Air Quality Management District. The TAC recommended focussing on the ability of the technology to comply with the environmental and public health regulations of the state, specifying the need to characterize the waste, ash, and air emissions of the facility.

The TAC developed the sampling and analytical protocols and selected the Commerce WTE facility as the test site. The Commerce plant was chosen since it was the only WTE plant in commercial operation and it was felt that its relatively small size (360 TPD) would allow greater flexibility. The testing began in July of 1988 and continued for three weeks.

The WTE Demonstration Program was designed to examine plant operation at opposite ends of the waste composition spectrum. First, the committee specified use of a mixed waste composed of approximately 60% residential and 40% commercial refuse, and then the regular commercial waste stream composed of 95% commercial and 5% residential refuse. Sampling these two wastes and the resulting ash and emissions should give insight into how fuel characteristics and plant operation affect the plant's ability to perform within environmental regulatory guidelines.

FACILITY DESCRIPTION

The Commerce WTE facility consists of a single mass fired waterwall boiler designed to combust from 300 to 420 tons per day of refuse with a heating value of 5000 to 6000 Btu/lb. A schematic of the plant design is shown on Figure 1. The plant operations are divided into three areas: refuse receiving and storage, combustor/boiler section, and air pollution control train. The storage pit will contain up to 1200 tons of refuse. The combustor is a three section Detroit Stoker reciprocating grate of 490 sq ft with a gross heat release rate of 336000 Btu/sq ft/hr. The grate sections are sloped at 12.5 degrees with an 18 inch drop off between sections to induce breakup and mixing of the refuse bed. Combustion air is drawn from the refuse storage building and supplied by under-grate and overfire fans. The single outdoor boiler is of the membrane waterwall type designed to produce 115000 lbs/hr of superheated steam at 750 degrees F and 650 psig.

The power generating system includes a steam turbine-generator set with capacity of 11.5 MW, 10 MW of which is sold to Southern California Edison Co.

Air emissions are managed by furnace operation at combustion conditions which reduce the formation of pollutants followed by control equipment. The design of the combustor/boiler section included the time, temperature, and turbulence conditions necessary to complete the combustion process. The air pollution control system includes Exxon Thermal DeNOx, a spraydryer and a fabric filter baghouse. The DeNOx system injects ammonia into the combustor at the temperature zone of 1700 to 1800 degrees F for reduction of nitrogen oxides to nitrogen. The spray dryer introduces an atomized lime slurry concurrent with the flue gas flow for acid gas removal. Evaporation of the slurry reduces the temperature of the flue gas from about 500 to 300 degrees F which causes trace organics and heavy metals to condense on particulate matter. A conditioning agent is injected (via a dry venturi section) prior to the baghouse which contains eight modules of 156 8-inch diameter teflon coated fiberglass bags. Operation provides an air to cloth ratio of 1.5:1 and a filter cake containing some unreacted lime which leads to further removal of acid gases. The baghouse was designed for a grain loading of .007 grain/dscf at 12% CO_2. The control efficiencies by design were 20-50% for NOx, 90% for SOx, and 95% for HCl. The permit limits are shown below.

pollutant	limit lb/hr	ppm at 3% O_2
NOx	41	150
SOx	9	25
CO	18	115
HC	3	30
PM	5.5	--

The ash handling system includes an ash quench tank for combined combustor bottom ash and fly ashes collected from the boiler, economizer, spray drier, and baghouse hoppers.

TEST PROGRAM

The test schedule for the demonstration program was designed to concurrently sample the waste, ash, and air emissions. Testing on the mixed wastes began on Monday, July 18. A total of seven ash samples (collected over five days) and four waste samples (collected over four days) were taken for the mixed wastes. The air emissions testing on the commercial wastes was done over a two week period and a total of seven ash samples (over five days) and six waste samples (over three days) were collected. A larger number of waste samples were taken for the commercial waste since there would be more variability between incoming loads through the day. The emissions testing consisted of parallel sampling done by two teams at the boiler outlet and the stack.

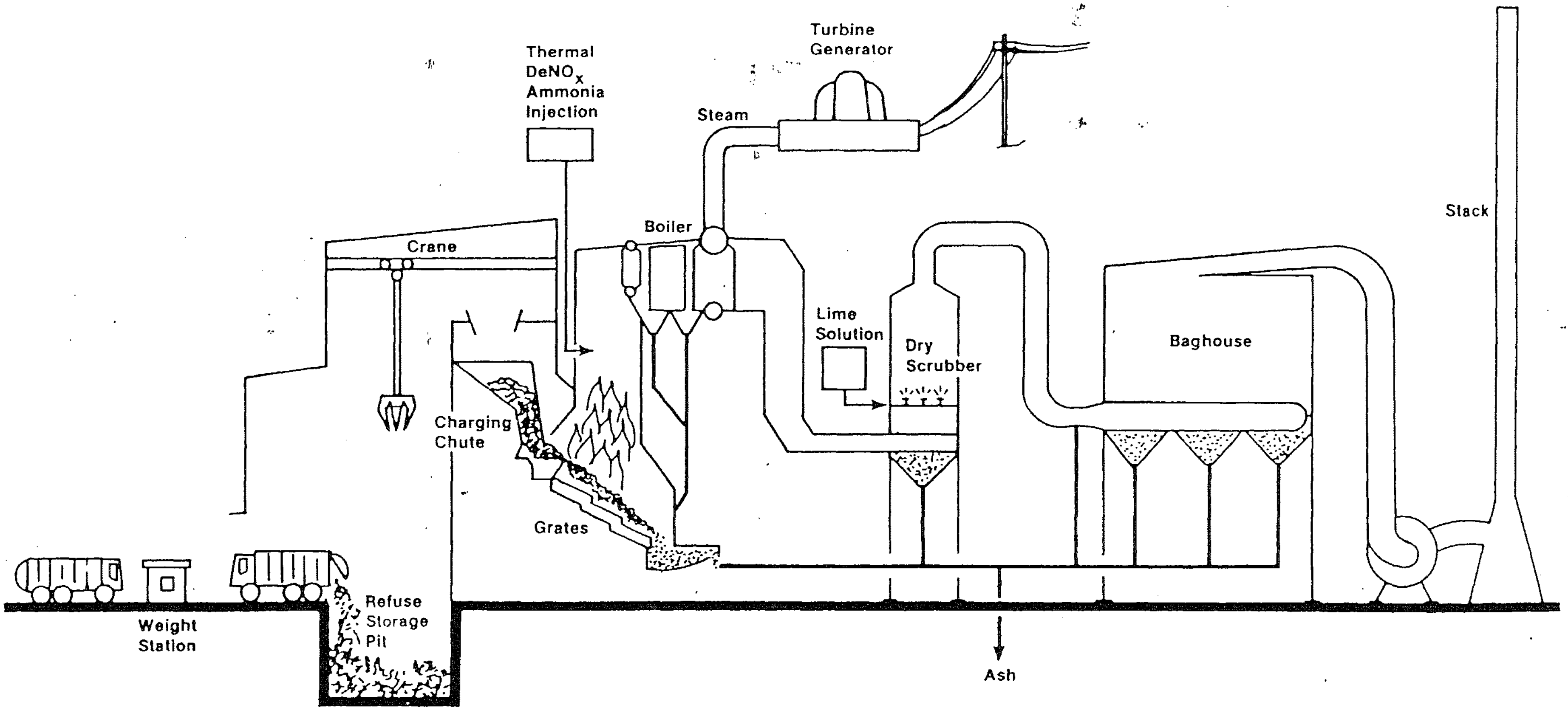


FIGURE 1 Project Schematic Design

WASTE SAMPLING

The waste sampling schedule for the mixed waste consisted of grapple loads taken from the pit at one hour intervals throughout the day, for four days. For the commercial waste, sampling was split between the morning and afternoon on three days for a total of six samples. This was done to give a finer resolution to the waste variation with time. The waste samples were transported to the Puente Hills Landfill for sorting into 19 components. The sample sizes for sorting ranged from 865 to 1118 pounds. Each sorted component was size reduced to produce representative portions for proximate, ultimate, and elemental analyses. Organic analyses were performed on reconstituted composite samples. Cal Recovery Systems, Inc conducted the sample composition study and contracted the laboratory analyses to Enseco California Analytical Laboratories and Spotts, Stevens, and McCoy Inc.

ASH SAMPLING

Ash sampling was performed on four successive days for each waste stream. Grab samples were obtained with a front-end loader (from the end of the conveyor belt at the ash shed) at thirty minute intervals for a collection period of thirty seconds. Over the course of a 4 hour sampling period, nine grab samples were taken and mixed. Large, extraneous objects were removed from the pile and the ash was passed through a 2-inch screen. Over-sized objects were subjected to an EPA recommended integrity test and the recombined ash was riffled into grid forms, halved, redistributed into the grids and composite samples selected randomly. The ash analyses were performed by Montgomery and Enseco Laboratories.

AIR EMISSION TESTING

The emissions testing was performed from July 18 to August 5, 1988. Source testing teams from the ARB and Energy Systems Associates (ESA) performed parallel and simultaneous testing at the boiler outlet (inlet to the air pollution control equipment) and the stack (see Figure 1). Sampling for criteria and non-criteria pollutants was performed. Criteria pollutants measured were found to be in compliance with permit limits. This paper will focus on the results of dioxin, furan, metal, and PAH emission tests. Triplicate runs were performed for both types of fuel except for the PAH testing for the mixed waste where only duplicates were performed. The dioxin, furan, and PAH emissions were collected using a modified method 5 train. The spent trains were dismantled and samples recovered in the field. ARB's samples were analyzed by Enseco Laboratories and ESA's samples were analyzed by Triangle Laboratories.

Both ARB and ESA have established procedures to document the accuracy of the reported sampling and analytical results. These procedures included the use of sampling blanks, field spikes, leak checks, and field and laboratory chain of custody techniques.

RESULTS OF WASTE ANALYSIS

The results of the waste composition analysis are summarized in Table 1. The commercial waste samples were, in general, more variable in composition than the mixed waste samples and were also dissimilar on a daily basis. This variability or heterogeneity was due in part to the composition of the incoming wastes, the degree of mixing achieved within the pit, and the selection of representative grapple loads for the sampling study. Comparison of the two wastes using the component weight averages shows that the mixed waste samples contained a large fraction of yard waste while the commercial waste samples were higher in paper, wood, and textiles. The glass and aluminum content of each waste was lower than in other studies conducted nationwide for both wastes.

The laboratory analysis conducted on each component of each sample plus duplicates of two samples included proximate, ultimate, and elemental. The results are reported as weight percent or mg/Kg of component. These raw data were weighted by the component composition data of Table 1 and summed to give the sample total values. Organic analyses (PCB, PAH, furans, and dioxins) were performed on composite combined samples.

PROXIMATE AND ULTIMATE ANALYSES

The results of the proximate and ultimate analyses are summarized in Table 2. Both wastes had a lower moisture content than reported in other waste studies. This is due in part to the season of the sampling, to significant drying which occurred during the mixing, sampling, transfer, sorting, and size reduction procedures, and to the specific nature of the refuse. The mixed waste samples contained more moisture and ash than the commercial samples; however, the range of the commercial values was greater. The carbon and hydrogen content of the commercial waste was higher than the mixed waste due to larger plastics and textiles fractions. The nitrogen and sulfur content of the mixed waste was greater due to the yard waste and the other inorganic contributions. The textile and other organic wastes provided the majority of the chlorine in the commercial waste samples.

TABLE 1 COMMERCE WASTE COMPOSITION SUMMARY
(weight percent as received)

Component	Mixed	Commercial	Component	Mixed	Commercial
Paper	31	40	Glass	3.8	2.9
Plastic	9.1	10.8	Aluminum	0.6	0.4
Yard	27	3.1	Ferrous	5.9	6.7
Wood	5.3	13	Other Org	3.0	5.4
Textile	4.2	9.4	Other Inorg	4.6	4.2
Food	5.5	4.2			

TABLE 2 ULTIMATE ANALYSIS SUMMARY
(average weight percent)

Constituent	Mixed Waste	Commercial Waste
Ash	22	19
Moisture	18	13
Carbon	30	37
Hydrogen	4	5
Oxygen	25	25
Nitrogen	.75	.5
Sulfur	.5	.1
Chlorine	.25	.5

ELEMENTAL ANALYSES

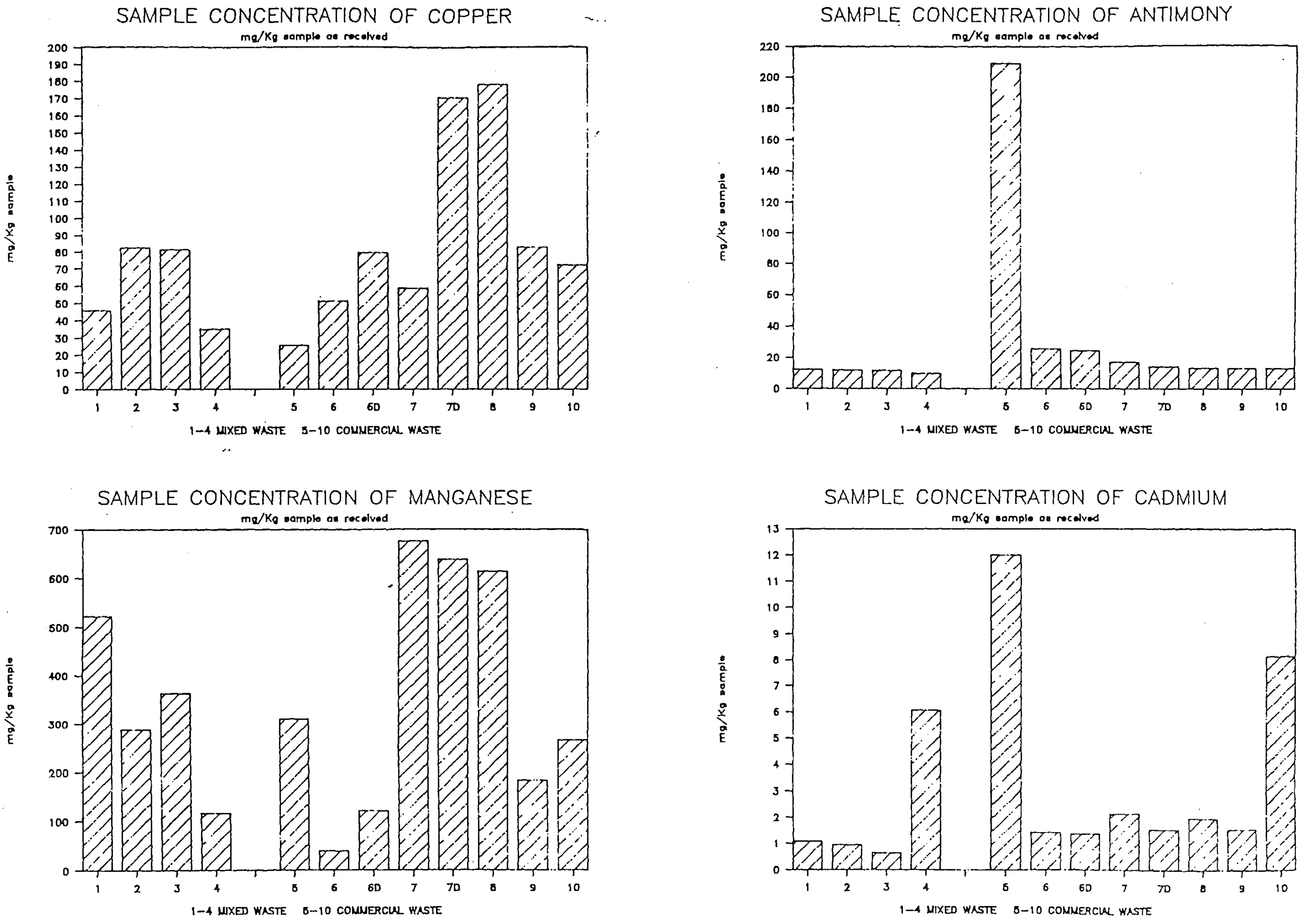
The elemental analyses consisted of testing of each component of each sample for twenty seven elements, a majority of which were metals. Many of the elements were undetected in one or more of the components and the limits of detection were variable. The sample total concentrations for each element are presented in Table 3 where samples 1-4 are from the mixed waste and 5-10 are from the commercial waste. The concentrations were compiled using the detection limits as concentration data and thus should be considered as high values for metals such as antimony, barium, cadmium, mercury, selenium, and silver. The values for the duplicated samples are comparable despite the heterogeneity of the refuse and of the individual components and the difficulty of producing representative subsamples for analysis.

The sample concentrations for several metals are shown graphically on Figures 2 and 3. A wide range of values was common and frequently a single component contributed a majority of the total concentration. This was especially the case for nickel in sample 8 (form ferrous), antimony in sample 5 (from textiles), and lead in sample 4 (from ferrous). Overlooking the single high values for metals such as antimony and nickel shows that the range of concentrations was narrow. The total concentration values were more distributed for lead, cadmium, and chromium and several components were significant contributors. These metals were also detected in virtually every component of every sample analyzed. The ferrous components contain the highest concentrations of lead as well as the greatest degree of variability, nine of the ferrous component analyses gave results at or below detection limits, while two were above 2800 mg/Kg ferrous. Sample 1 contained the highest zinc concentration, 68% of which was contributed by the yard waste component. While zinc containing paints or other materials may be disposed with yard wastes, concentrations above 100 mg/Kg are probably rare.

TABLE 3
TOTAL ELEMENTAL CONCENTRATIONS IN EACH SAMPLE
(mg/Kg sample as received)

	Mixed Waste Samples				Commercial Waste Samples							
Element	1	2	3	4	5	6	6D	7	7D	8	9	10
Moisture %	16.1	24.2	14.4	19.0	11.1	6.7	7.1	7.9	8.6	15.7	18.7	16.7
Aluminum	8032	12552	13486	9416	7422	9733	7012	10288	10150	16665	12033	12842
Antimony	12.2	11.8	11.5	9.6	209	25.7	24.6	17.0	14.1	13.2	13.0	13.0
Arsenic	13.4	13.4	21.2	13.0	11.7	12.7	10.0	13.0	16.0	28.3	20.6	19.6
Barium	7.1	8.0	7.4	5.5	5.9	5.9	5.8	6.8	7.1	5.9	5.5	5.8
Beryllium	0.61	0.50	0.59	0.54	0.60	0.66	0.69	0.68	0.67	0.62	0.62	0.56
Bismuth	17.3	12.6	11.9	16.7	17.6	22.3	11.9	32.5	19.2	21.1	13.7	14.4
Boron	16.3	12.3	11.7	15.9	13.8	17.0	19.9	20.1	24.8	15.6	16.8	14.9
Cadmium	1.1	1.0	0.6	6.1	12.0	1.4	1.4	2.1	1.5	2.0	1.6	8.2
Calcium	3349	2536	3040	3293	2095	2497	2228	1957	1852	3040	2631	1849
Chromium	37.9	30.1	92.9	207	36.3	819	776	36.5	41.8	454	128	37.8
Cobalt	9.9	5.9	6.1	8.4	7.2	198	204	14.1	12.3	14.0	7.3	7.3
Copper	45.9	82.6	81.3	35.1	25.8	51.4	79.5	58.8	170	178	83.1	72.4
Iron	102646	43559	134211	52896	53689	20042	18515	133118	132026	89613	36766	55695
Lead	36.0	19.3	88.1	349	180	123	137	25.1	22.3	72.1	79.0	28.4
Magnesium	3647	1268	1572	1750	1224	677	959	1060	1208	3070	1761	1178
Manganese	523	288	364	117	312	38.9	122	677	639	615	185	267
Mercury	0.024	0.036	0.024	0.048	0.025	0.029	0.022	0.049	0.012	0.028	0.010	0.018
Molybdenum	10.0	8.6	10.4	9.3	10.7	10.5	10.1	11.3	11.2	20.9	24.3	10.4
Nickel	38.1	14.5	46.4	11.9	15.3	25.0	25.5	24.4	58.3	361	28.1	18.9
Phosphorous	445	436	527	1143	207	171	170	207	217	293	439	195
Potassium	3926	2690	5644	7928	1156	1384	1338	1083	1292	1773	3082	1332
Selenium	0.26	0.33	0.26	0.22	0.13	0.23	0.36	0.23	0.22	0.27	0.22	0.40
Silicon	23284	32088	36030	29777	20661	42611	42611	22557	22027	26125	32687	15391
Silver	1.5	1.4	1.2	1.2	1.3	1.2	1.2	1.5	1.5	1.5	1.2	1.2
Thallium	12.5	9.3	10.0	10.6	10.8	10.5	10.5	14.6	12.6	13.3	10.8	10.6
Vanadium	22.7	17.8	20.9	20.2	20.8	19.5	19.4	23.8	23.4	23.7	21.8	19.2
Zinc	621	95.4	91.9	96.8	164	199	58.3	347	395	450	292	419

FIGURE 2



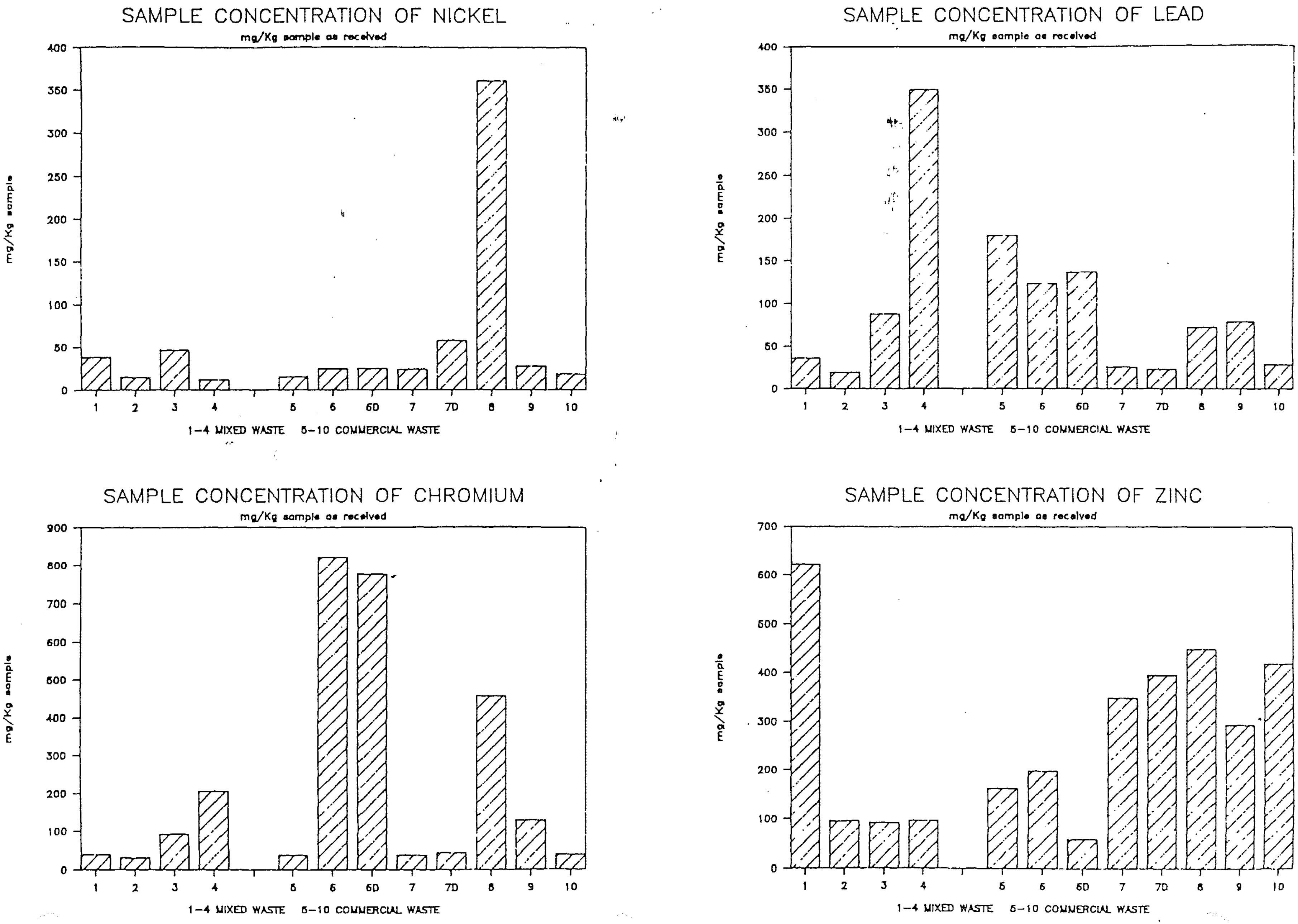
SAMPLE CONCENTRATION OF COPPER

SAMPLE CONCENTRATION OF ANTIMONY

SAMPLE CONCENTRATION OF MANGANESE

SAMPLE CONCENTRATION OF CADMIUM

FIGURE 3



SAMPLE CONCENTRATION OF NICKEL

SAMPLE CONCENTRATION OF LEAD

SAMPLE CONCENTRATION OF CHROMIUM

SAMPLE CONCENTRATION OF ZINC

Statistically the high values could be excluded from the raw data, however these results give insight into the heterogeneity of municipal solid wastes and are indicative of the spikes which are measured in ash and air emissions from incineration facilities.

The average metal concentrations by waste type are shown in Table 4 for comparison. The average lead concentration for the mixed waste was 123 mg/Kg (range: 19.3 to 349 mg/kg). Of that, nearly 45% was contributed by the ferrous component. The average zinc concentration in the mixed waste was 226 mg/Kg (range: 100 to 621 mg/Kg). On average, 50% of the zinc in the mixed waste came from a single sample with the exceptionally high concentration of 1960 mg/Kg in yard waste. For the commercial waste, the greatest contributor of lead was again the ferrous component providing 30% of the average lead concentration (85 mg/kg, range: 22.3 to 180). The average zinc concentration (312 mg/Kg, range: 58 to 450) was dominated by the contribution of the other-organic component at 40%. The barium and mercury concentrations were lower than other reported values.

ORGANIC ANALYSES

The results of the organic analyses indicated concentrations below detection limits for a majority of the polynuclear aromatic hydrocarbons (PAH). The compounds that were detected are benzo(a)anthracene, fluorine, pyrene, phenanthrene, and fluoranthene at 50 to 300 ug/Kg sample. None of the organochlorine pesticides were detected and only one PCB was found in one sample at 7.1 mg/Kg sample. A majority of the samples had detectable concentrations of the hepta dioxin and furan congeners at 50 to 500 ug/Kg sample and the octa congeners at 100-4000 ug/Kg sample.

TABLE 4
AVERAGE ELEMENTAL CONCENTRATION BY WASTE TYPE
(mg/Kg waste as received)

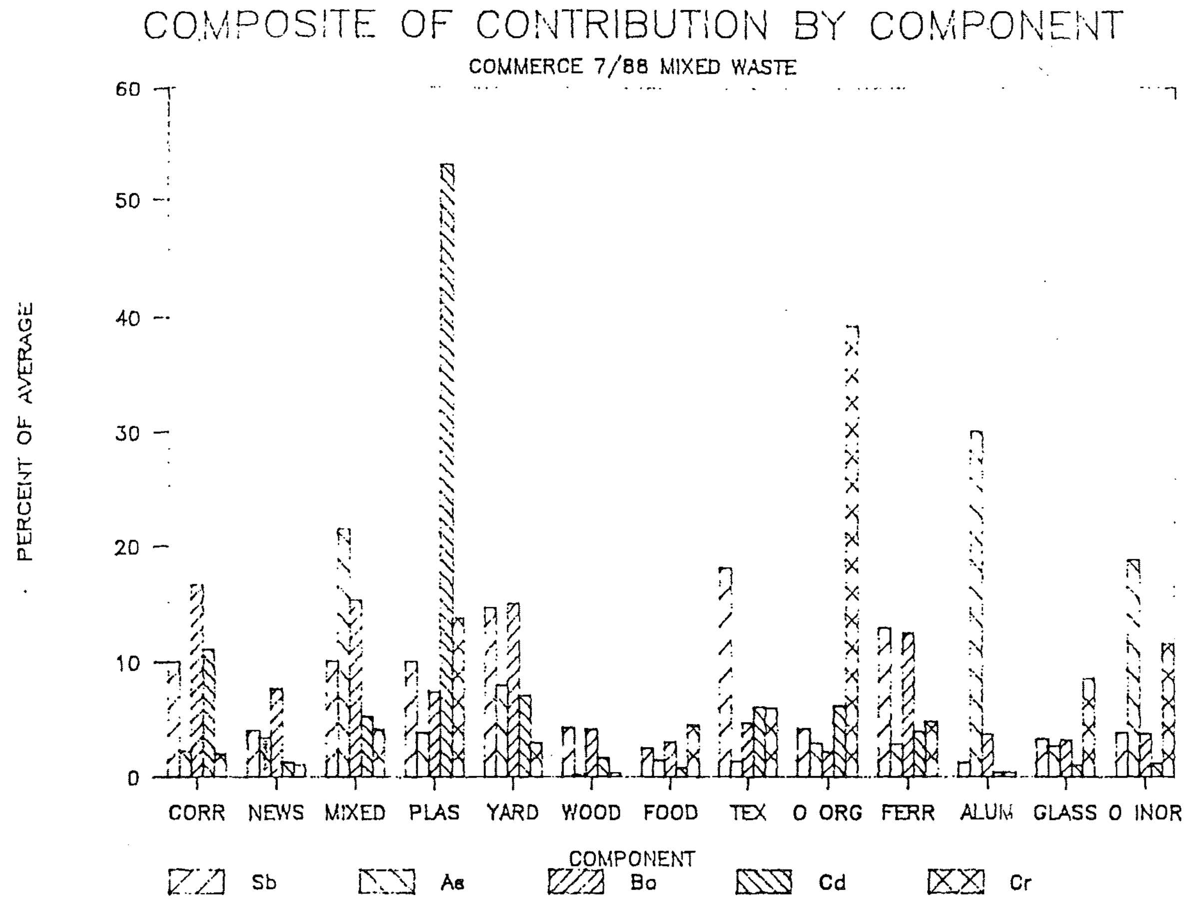
Element	Mixed Waste	Commercial Waste
Arsenic	15.2	17.7
Barium	7.0	6.0
Cadmium	2.2	4.5
Chromium	91.8	252
Copper	61.2	78.3
Lead	123	84.7
Mercury	0.033	0.027
Nickel	27.7	78.8
Zinc	226	312

A comparison of the wastes in terms of component contributions is shown on Figure 13 and 14 as a percent of total concentration for several metals. This is a composite profile of each waste compiled from the averages from Table 7 as computed for each element. For the six metals presented, the plastics, ferrous, and other organic components are the major contributors to the mixed waste (overlooking the zinc in yard waste from sample 1). The profile changes for the commercial waste showing that the other organic, ferrous, and textile components predominate. Referring back to Tables 2 and 3 shows that these components constituted 18% of the mixed waste and 21.5% of the commercial waste by weight while contributing about 60% of these metals to the wastes. This disproportionate loading is indicative of the use of these metals in a small fraction of consumer products which are subsequently disposed. Source reduction, recycling, and reformulation of this small fraction of the waste would have a substantial impact on the total metals loading, and could reduce the metals content of the residual ash from incineration facilities by half.

Organic analyses

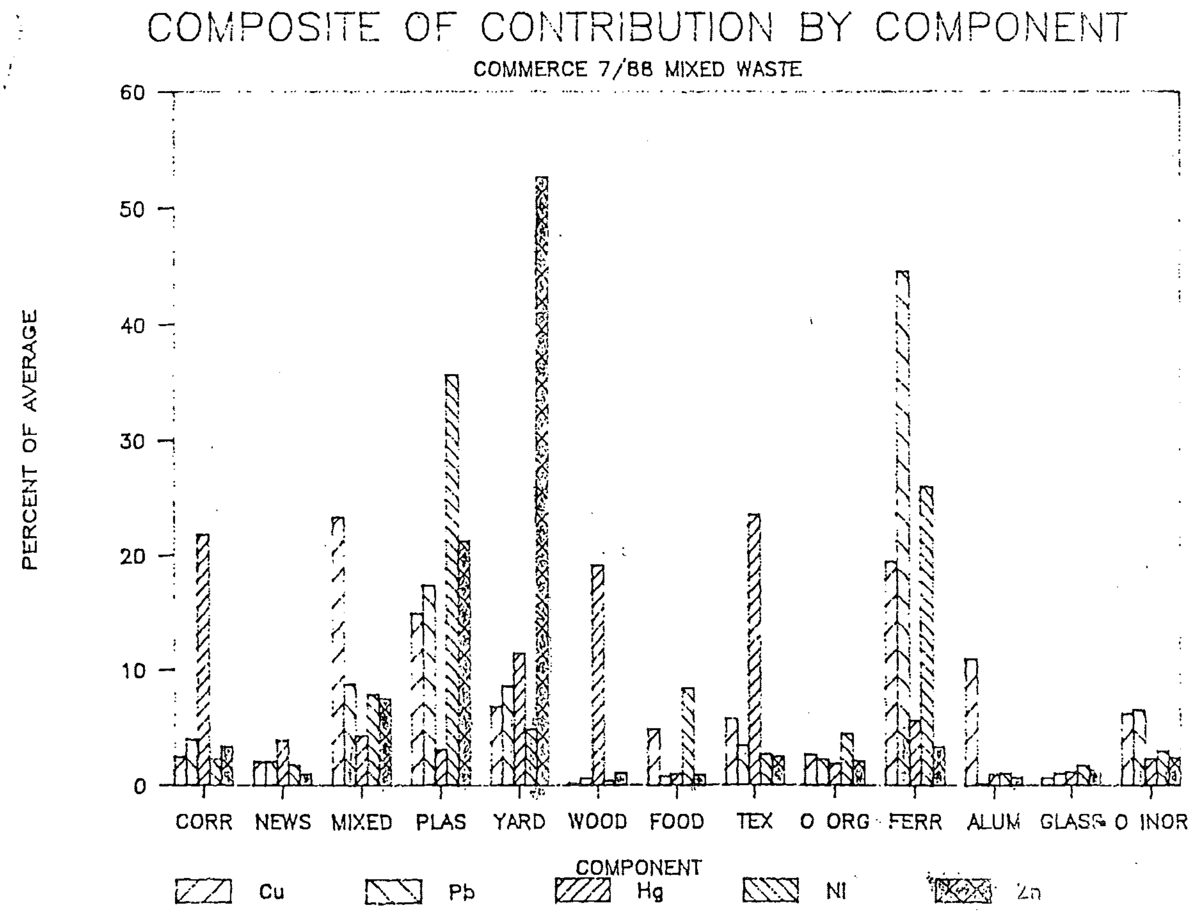
The organic analyses were performed on composite samples recombined from the size reduced components in the proportions encountered in the field sampling study. The compounds tested for are shown in Table 11. The results of the polynuclear aromatic hydrocarbon, organochlorine pesticide, and pcb analyses indicated concentrations below detection limits. Benzo(a)anthracene was found in samples 3, 4, and 10 at 190, 260, and 440 ug/Kg sample respectively, and acenaphthene was found at 760 ug/Kg in sample 9. Several other compounds were detected up to several hundred ug/Kg in varous samples. The only pcb compound detected (aroclor 1248) was found at 7.1 mg/Kg in the duplicate sample 6.

The polychlorinated dioxins and furans analyses were performed on combined composite samples (samples 1 and 2, 3 and 4, 5 and 6, 7 and 8, 9 and 10). The analysis included many of the tetra through octa chlorinated compounds and totals. The majority of the results were below or at the detection limits. The total hepta and octa furans were found at 350 and 3500 ug/Kg of combined sample 1 and 2. The total hepta dioxins were found at 220 to 500 ug/Kg and the total octa dioxins at 550 to 4000 ug/Kg combined sample.



COMPOSITE OF CONTRIBUTION BY COMPONENT

COMMERCE 7/88 MIXED WASTE

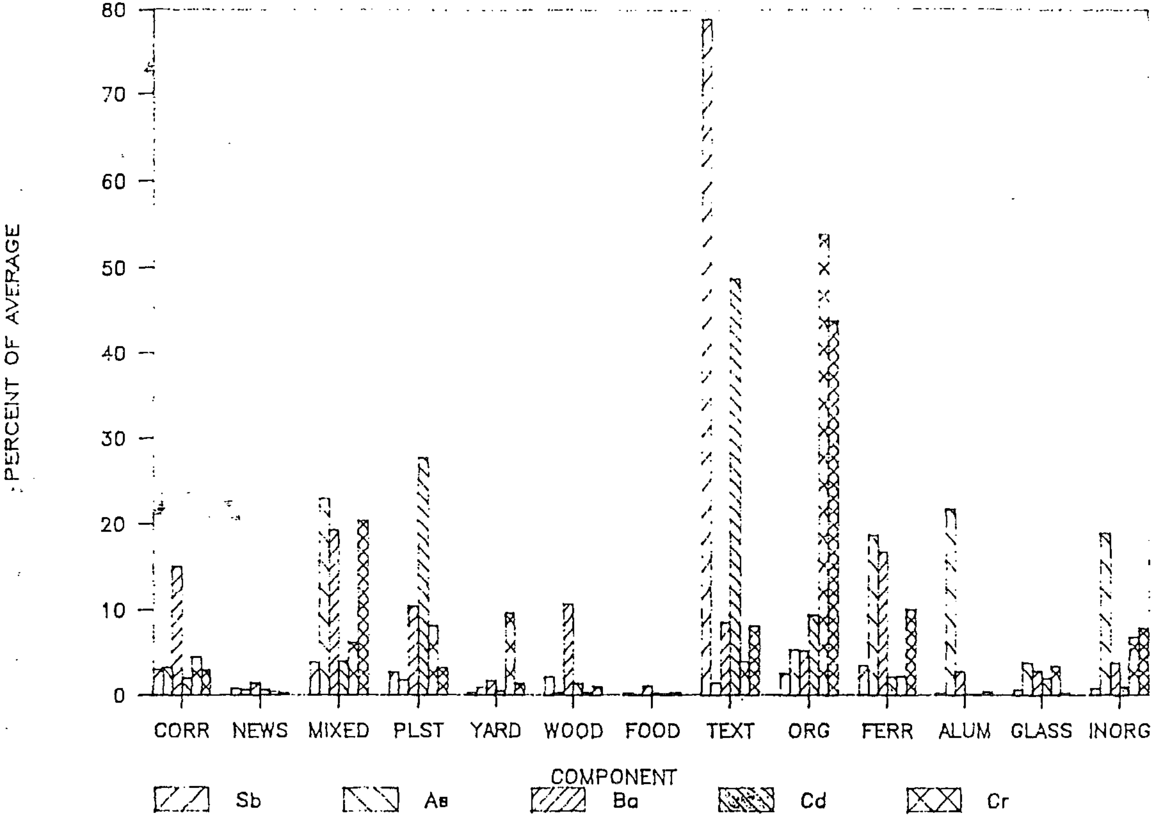


COMPOSITE OF CONTRIBUTION BY COMPONENT

COMMERCE 7/88 MIXED WASTE

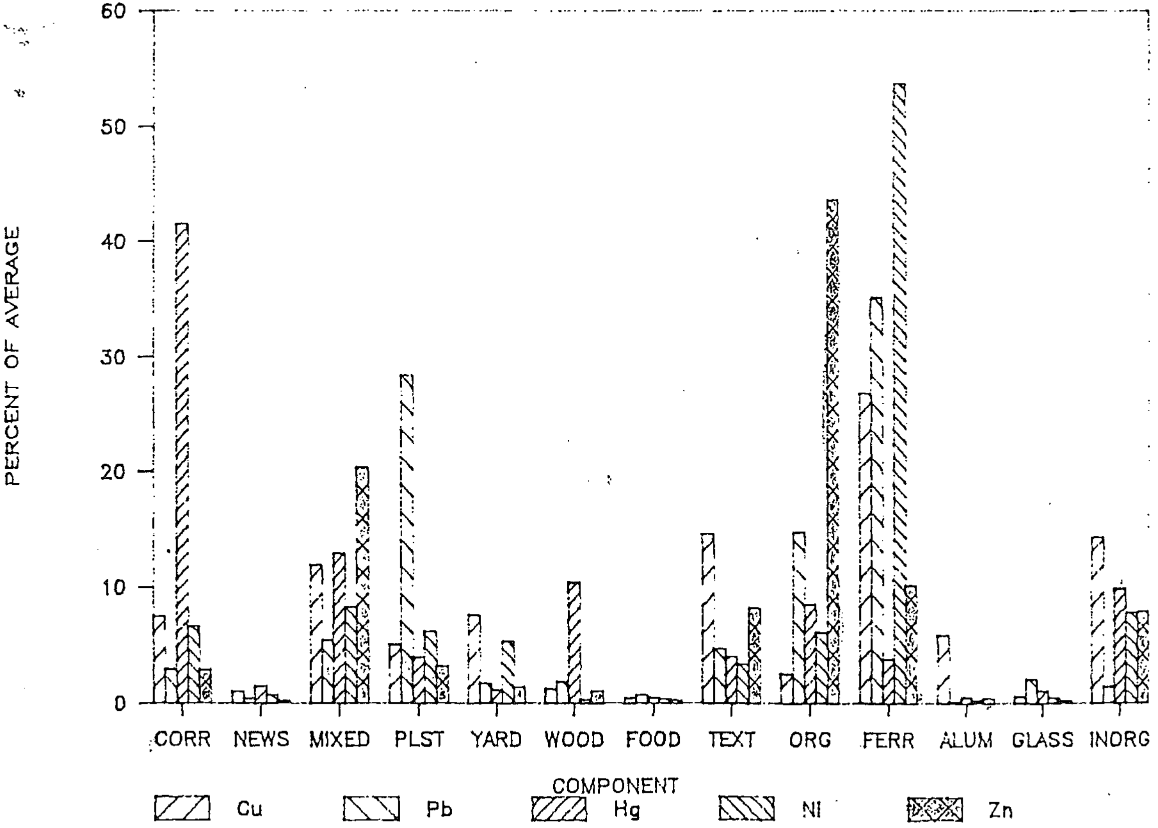
COMPOSITE CONTRIBUTION BY COMPONENT

COMMERCE 7/88 COMMERCIAL WASTE



COMPOSITE CONTRIBUTION BY COMPONENT

COMMERCE 7/88 COMMERCIAL WASTE



RESULTS OF ASH ANALYSIS

The ash samples were analyzed using the California criteria for identification of hazardous waste. Initial analyses (including the waste extraction test (WET) for 20 metals, chlorinated and polynuclear organics, and inorganic constituents) were done on 20 samples of ash from each waste. Based on the results of those analyses, further WET, loss on ignition, and total organic carbon tests were conducted on 40 samples, and the federal extraction procedure toxicity tests (EP Tox) were performed on 32 samples.

WASTE EXTRACTION TEST RESULTS

Results of the ash tests show that in general the range of values was narrow compared to that reported in other studies. This is due to the ash collection and mixing procedures as prescribed in the protocol. These data represent composite samples over a time frame of 4 hours and will not be analogous to grab sample results. The averages of the data however, are comparable to data reported from similar facilities. The range and average of the ash analyses are shown in Tables 5 to 8 for several metals along with the regulatory limits for each test protocol. The averages were compiled using the detection limits as concentration values.

Nearly all of the samples exceed the regulatory limits for lead for each of the tests performed regardless of the waste composition. The soluble threshold limit concentration (STLC) and EP Tox limits are 1 mg/L for cadmium which was exceeded by greater than three-fourths of the samples. A few of the samples contained concentrations greater than the limits for zinc in TTLC and STLC, and mercury and nickel in STLC. A comparison of the data from the STLC and EP Tox analyses shows that the STLC test is more rigorous for arsenic, barium, cadmium, chromium, and mercury, however the results for lead are comparable.

TABLE 5 TOTAL THRESHOLD LIMIT CONCENTRATION
(TTLC, mg/Kg)

		Mixed Waste Ash		Commercial Waste Ash	
Element	Limit	Range	Average	Range	Average
Arsenic	500	3-9	5.7	3-12	5.9
Barium	10000	54-640	334	110-710	300
Cadmium	100	28-89	44	10-92	44
Chromium	2500	<14-170	81	38-380	116
Copper	2500	100-4300	1006	670-9700	4000
Lead	1000	890-5300	1770	480-7900	2480
Mercury	20	4-14	7.5	3-18	10.2
Nickel	2000	<15-250	127	<15-1800	200
Zinc	5000	1900-8500	3475	1000-18000	5290

TABLE 6 SOLUBLE THRESHOLD LIMIT CONCENTRATION
(STLC, mg/L)

Element	WET Limit	Mixed Waste Ash Range	Mixed Waste Ash Average	Commercial Waste Ash Range	Commercial Waste Ash Average
Arsenic	5	.07-.52	.25	<.01-.55	.27
Barium	100	.51-3.9	1.8	.56-4.4	1.5
Cadmium	1	.34-3.6	1.9	.99-3.5	2.2
Chromium	560	.5-4.4	1.8	.87-5.0	2.1
Copper	25	.36-10	5.5	.16-42	13.5
Lead	5	1.2-34	11.2	1.4-33	16.5
Mercury	.2	.03-.19	.07	<.002-.32	<.09
Nickel	20	.19-180	38.5	<.15-31	2.0
Zinc	250	97-210	158	84-320	175

The deionized water extraction results show that significant amounts of barium, lead, mercury, and zinc are water soluble (the pH of the resultant DI extract is 11-12). In fact the water soluble results for lead were above the STLC limits for thirty percent of the samples.

Comparison of the TTLC ash results by waste type shows that the commercial waste ash contains on average about fifty percent more total chromium, lead, mercury, nickel, and zinc than the ash from the mixed waste. The STLC results show a similar trend (between 10 and 50 percent more in the commercial ash extractables) except that the nickel was much greater in eight of the mixed waste ash samples. The results of the EP Tox and DI analyses display little difference by ash type.

TABLE 7
EXTRACTION PROCEDURE TOXICITY CONCENTRATION
(EP Tox, mg/L)

Element	Limit	Mixed Waste Ash Range	Mixed Waste Ash Average	Commercial Waste Ash Range	Commercial Waste Ash Average
Arsenic	5	<.01-.04	<.01	nd(.01)	<.01
Barium	100	.29-.79	.48	.19-.72	.38
Cadmium	1	.80-1.9	1.3	.3-1.7	1.2
Chromium	560	<.14-.59	<.2	<.14-.42	<.21
Lead	5	.92-32	12.2	4.4-33	14.7
Mercury	.2	.004-.06	.025	<.002-.04	.014
Selenium	1	nd(.01)	<.01	nd(.01)	<.01
Silver	5	nd(.05)	<.05	nd(.05)	<.05

TABLE 8
DEIONIZED WATER EXTRACT
(DI, mg/L)

	Mixed Waste Ash		Commercial Waste Ash	
Element	Range	Average	Range	Average
Arsenic	nd(.01)	<.01	nd(.01)	<.01
Barium	.24-1.1	.7	.41-1.0	.65
Cadmium	nd(.03)	<.03	nd(.03)	<.03
Chromium	<.14-.22	<.15	nd(.14)	<.14
Copper	.17-2.4	.63	0.1-1.2	.37
Lead	1.4-9.6	3.3	<.41-12	5.3
Mercury	<.02-.12	.06	nd(.02)	<.02
Nickel	<.15-.33	<.18	<.15-1.1	<.34
Zinc	.8-2.4	1.6	.28-6.4	2.7

ORGANIC AND INORGANIC ANALYSES

The dioxin analysis indicated that the hepta and octa congeners are predominant in both the combined and fly ashes (see Table 9). The distribution of furans shows the penta and hexa forms being favored. Very few ash samples contained detectable concentrations of PAH compounds. Ash extracts were not found to be hazardous due to aquatic toxicity.

TABLE 9
Ash Concentrations of Dioxins and Furans
(mg/Kg ash)

	Mixed Waste Ash			Commercial Waste Ash		
Compound	Combined	Baghouse	Scrubber	Combined	Baghouse	Scrubber
TCDF	1.5	19.0	2.2	2.61	11.0	3.5
PCDF	1.1	24.0	2.0	1.92	12.0	2.0
HxCDF	1.2	18.0	2.4	2.03	16.0	4.8
HpCDF	0.55	6.0	-	2.14	8.2	2.6
OCDF	-	1.6	-	3.1	4.5	2.0
TCDD	0.12	1.1	-	0.24	0.81	-
PCDD	0.51	2.4	-	0.49	0.6	-
HxCDD	0.76	6.6	-	1.74	3.2	-
HpCDD	0.93	7.3	0.79	2.67	6.0	1.5
OCDD	1.43	5.8	-	4.38	7.0	3.5

The ash samples were tested for inorganic constituents and other parameters such as pH and TOC as water extractables. The data are averaged for ash from each waste type and shown below.

DI EXTRACT CONCENTRATION (mg/L)

ash type	chloride	sodium	potassium	sulfate	pH	TOC%
mixed	1200	180	150	710	12.2	2.9
comm.	1600	190	140	600	12.0	2.3

EMISSIONS TESTING RESULTS

FACILITY OPERATIONS DATA

The facility ran at or near normal conditions for all test days except for two days - 7/18 and 7/28. On 7/18, the plant had switched from burning commercial waste to the mixed waste. The facility operator required most of the day to achieve stable combustion due to the higher moisture content and composition of the mixed waste. The poor combustion conditions were verified by higher CO emissions and lower steam flowrate of 60% of design. Significantly higher metal emissions were found on 7/28, and subsequently one bag in the baghouse was discovered to have fallen off its support.

Average stack emissions data during the mixed and commercial tests are listed below. Other process data collected show that during the testing the ammonia flowrate was between 17 to 30 lbs/hr with peaks to 49 lbs/hr. The lime feed rate to the slaker was 360 lbs/hr and the agglomerate feed rate to the dry venturi was 75 lbs/hr. The pressure drop in the baghouse averaged 5.2 inches of water, and ranged between 3.6 and 7.9 inches over the testing period.

AVERAGE STACK EMISSIONS DATA

%CO_2		NOx at 12% CO_2		CO at 12% CO_2	
mixed	comm.	mixed	comm.	mixed	comm.
9.3	9.9	113	106	33	27
6.8-10.1	9.3-10.6	80-177	91-127	23-79	17-57

EMISSIONS RESULTS

Tables 10-13 summarize the ARB and ESA testing results for dioxin, furan, PAH, and metal emissions. The results were calculated assuming that compounds not detected were present at one half the detection limit. Both ARB and ESA detected concentrations of these constituents similar to that measured at other waste to energy facilities.

The ESA results are generally lower in concentrations than the ARB results. Additionally, it appears that the difference in results between ARB and ESA is generally larger than the difference in emissions between the two fuel mixtures.

DIOXIN AND FURAN EMISSIONS

All of the dioxin and furan homologs were detected in each of the tests. The furan concentrations were generally greater than the dioxins but no consistent relationship between the tests prevails. The range of the dioxin congener concentrations was narrow while the tetra, penta, and hexa furan compounds were predominate.

The dioxin and furan emission results were normalized by several different toxic equivalent methods. The results show that the differences between fuels and testing groups are less than an order of magnitude, and the air pollution control equipment efficiencies were greater than 99%. Results from testing at the stack with the facility burning the mixed waste were very similar between the two testing groups with ARB results about twice that of ESA. A greater variability between the two groups is evident for the commercial waste tests with ARB's results about 6 times greater than ESA's. The results of a dioxin train exchange performed as an additional QA/QC measure show that ESA's train analyzed by Enseco Labs has a California DHS toxic equivalent value nearly equal to ARB's sample which was analyzed by Triangle Labs.

TABLE 10 SUMMARY OF EMISSIONS TESTING
(ng/Nm^3 at 12% CO$_2$)

	Mixed Waste*				Commercial Waste			
	Inlet		Stack		Inlet		Stack	
Total	ARB	ESA	ARB	ESA	ARB	ESA	ARB	ESA
PCDD/F	412	577**	2.57	1.39	4255	810	30.8	3.32
CAL DHS#	37.9	42.1	0.25	0.14	112	53.9	0.94	0.16
EADONS#	16.3	17.8	0.11	0.05	46.7	20.7	0.34	0.07
EPA#	7.54	9.61	0.06	0.02	24.6	10.5	0.2[illegible]	0.04
PAH	18.6	31.4	7.49	0.46	19.6	7.46	3.08	1.30
PAH less naphthalene	17.5	25.4	0.71	0.14	9.54	3.80	0.58	0.09

* average of two mixed waste tests since 7/18 test was not at normal operation.

** results of one test only due to interferences in other test analysis.

\# computed toxic equivalents

Of particular interest are the results of the dioxin testing performed on the first day where the facility was running at less than optimal combustion. The toxic equivalent emissions for this test compared to the average of the other mixed waste tests are 50 and 5 times greater for ARB and ESA results respectively (see Table 11). The hexa dioxin and furan homologs predominated the emissions results.. Also the air pollution control equipment efficiency dropped to 75% and 96% using ARB and ESA results.

PAH EMISSIONS

Both ESA and ARB had high naphthalene concentrations in their blank trains and Triangle Labs informed ESA that naphthalene is a decomposition product of the adsorbent used in the PAH sampling trains. Therefore, it appears more appropriate to compare the PAH results as the total less the naphthalene concentration.

The total PAH less naphthalene emissions for the mixed waste are higher for both testing teams. The efficiency of the pollution control equipment was better than 90% for both fuels. The differences in the results between the two testing teams are greater than the differences each testing team found between fuels. Total hydrocarbon emissions at the boiler were below 1 ppm during most of the test periods, however high levels did occur and were found to correspond to simultaneously high CO emissions (up to 700 ppm at 12% CO_2) indicative of incomplete combustion.

METAL EMISSIONS

The metal emission results (Table 12) show that most metals are controlled at a better than 99% efficiency. Barium, cadmium, chromium, and nickel were found to have higher boiler emission rates from the mixed waste tests by ESA, however the stack emissions appear mixed since there are large differences in emissions between the testing teams. Mercury emissions data are not presented since the analytical tests were not complete and the results were underestimated.

TABLE 11
PCDD/PCDF TEST ON 7/18 MIXED WASTE
(ng/Nm^3 at 12% CO_2)

	Inlet		Stack	
TOTAL	ARB	ESA	ARB	ESA
PCDD/F	1192	254	182	27.8
Toxic Equivalent				
CA DHS	55.0	16.6	13.5	0.68
EADONS	23.3	6.06	6.01	0.25
EPA	12.3	2.92	3.50	0.17

TABLE 12
SUMMARY OF METALS EMISSION TESTING
(ug/Nm^3 at 12% CO_2)

	Mixed Waste				Commercial Waste*			
	Inlet		Stack		Inlet		Stack	
Metal	ARB	ESA	ARB	ESA	ARB	ESA	ARB	ESA
As	159	78.0	0.22	0.16	133	68.9	0.28	0.10
Ba	94.2	4659	7.9	117	155	1579	11.4	88.7
Cd	1560	1677	0.29	1.97	921	930	1.25	0.40
Cr	383	3616	1.14	2.33	469	730	2.93	0.45
Cu	5710	8820	4.98	27.0	14050	41800	9.09	56.4
Pb	16270	18132	2.87	1.97	15775	17950	0.13	4.00
Ni	754	4231	10.6	6.32	854	2307	53.2	0.24
Zn	76430	90930	12.3	38.5	54990	87300	75.7	34.6

* Results of two tests

It is interesting to note the change in emissions of metals when one bag in the baghouse fell from its supports which occurred during the 7/28 metals test (see Table 13). Several of the metals showed a 10 to 100 fold increase in emission rate.

TABLE 13
METALS EMISSIONS TEST ON 7/28 COMMERCIAL WASTE
(ug/Nm^3 at 12% CO_2)

	Inlet		Stack	
Metal	ARB	ESA	ARB	ESA
Arsenic	59.8	92.0	0.29	1.38
Barium	228	2490	20.0	110
Cadmium	765	1330	22.4	18.0
Chromium	154	1027	16.8	3.63
Copper	3900	7600	125	26.1
lead	17280	20400	318	360
Nickel	284	540	56.9	2.60
Zinc	45200	122600	1840	1330

MASS FLUX COMPARISON

The development of a mass balance requires a complete characterization of the waste, ash, and air emissions as well as operations data. This is difficult to achieve for an incineration facility considering the heterogeneity of the waste and ash as well as the variability of operating conditions. The ash collection and analysis protocol was designed to study the ash leaching characteristics and not the total elemental content. A small amount of the field ash was oversize material and was discarded. Also the laboratory protocol calls for removal of extraneous material prior to analysis. The significance of the discarded material is critical to determining the total elemental concentration of the ash; however, for the volatile metals (or elements which are present in the combustible fraction of the refuse) the fines and fly ash will contain the majority of the metals present in the refuse. This portion of the ash was analyzed and with several assumptions these data can be compared to the more complete waste analysis and air emissions data.

Comparison of the waste and ash elemental mass fluxes can be made after converting the data to a pounds per hour basis using the plant operation data given below:

average MSW feed rate		ash production rate	
mixed waste	commercial waste	mixed waste	commercial waste
500 tpd	375 tpd	160 tpd	120 tpd

The ash production rates were estimated from the historical Commerce facility average of 32% ash from MSW. The ash data must be adjusted to compensate for the large amount of discarded material prior to analysis. The average amount of oversize material which was removed from the field ash constituted 20% by weight. The laboratory protocol resulted in removal of extraneous material yielding about 25% of the sample ash as fines. Thus, only about 20% of the field ash was analyzed. Once this correction factor is applied to the ash data a direct comparison can be made.

The stack emissions represent a very small amount of the mass flux from the facility because most of the metals emissions were controlled at better than 99% efficiency. The data collected at the inlet to the control equipment (flue gas) consist of the metal vapor and particulate matter which, once collected, constitute the fly ash. These data should be comparable to the combined ash concentration data for the volatile metals. The inlet data from Table 12 were converted to a pounds per day basis using the average flue gas volumetric flow rates of 44200 and 42000 Nm^3/min for the mixed waste and commercial waste respectively. This computation was done for the data from each of the test teams because the results from each are considered valid.

The results of these conversions are presented in Table 14 and can be compared using the following assumptions: 1) The values in Tables 4 and 5 represent averages, some of which are skewed by one high value or a significant number of non-detected samples, 2) The ash values can be considered low because the concentration in the extraneous matter was not quantified and not included in the ash flux values, and 3) While an effort was made to perform the waste sampling, ash sampling, and air emissions testing concurrently, due to the heterogenous nature of the waste and ash, the data are not comparable on a daily average basis.

Considering the limitations of this study and the assumptions made above, the mass flux comparison yielded positive results. For each of the volatile metals (cadmium, copper, lead, and zinc) the mass flux from msw to flue gas to ash was within an order of magnitude. Thus a majority of the mass of the volatile metals present in the msw was conveyed by the flue gas and recovered in the ash fines. The values for arsenic, chromium, and nickel are 3 to 50 times higher for the waste than for the ash which, in turn, are comparable to the flue gas values. These metals are not readily volatilized and have uses which depress volatilization (such as ferrous alloy) and should be found in the extraneous material which was discarded from the ash. The ash values for barium exceed the flue gas values which could indicate that a majority of the barium in ash comes from the grate fines, however the ash values are three times higher than the msw values. This leads to the conclusion that the barium concentration in the msw was low at 7 mg/Kg (other reported concentrations range from 15 to 110 mg/Kg).

TABLE 14
METALS MASS FLUX COMPARISON
(pounds/day basis)

	Mixed Waste			Commercial Waste		
Element	MSW	Ash	Flue Gas	MSW	Ash	Flue Gas
Arsenic	15	.37	.34-.70	13	.28	.30-.59
Barium	7.0	21	.41-20	4.5	15	.68-6.9
Cadmium	2.2	2.8	6.8-7.4	3.4	1.9	4.0-4.1
Chromium	92	5.5	1.7-16	190	5.3	2.1-3.2
Copper	61	64	25-39	59	191	62-184
Lead	123	113	71-79	63	120	69-79
Nickel	28	8.6	3.4-19	59	11	3.7-10
Zinc	226	216	336-400	234	270	240-383

CONCLUSION

The completion of the testing program at the Commerce facility has provided current data on a state-of-the-art facility, which can be used not only in evaluating the Commerce facility, but also in evaluating proposed facilities. It has also provided some comparisons between fuels, ash, testing teams, and laboratories. Correlations between the three aspects of the testing program (fuel, ash and emissions) follow volatile/nonvolatile partitioning of the metals as expected.

The results indicate that, 1) emissions of volatile metals correlate well between the fuel, ash, and emissions, 2) significant amounts of soluble metals exist in the ash, and 3) the differences between the two fuel mixtures were not great. The air emissions results indicate that, 1) the differences in emissions measured were less due to fuel mix, and more due to testing team and laboratory, and 2) careful facility maintenance and operation is required to avoid high concentrations of criteria and non-criteria pollutant emissions.

The waste analyses have given a detailed profile of the components of MSW and the ferrous, plastic, textile, and rubber products were found to contribute the majority of the heavy metals to refuse. A recommendation from this study is to encourage source reduction, recycling, and reformulation of these products in order to reduce the amounts of metals present in municipal refuse. Currently, however, there is a great need to stabilize and segregate the disposed ash due to its significant leaching potential.