September 1999 • NREL/SR-570-26068

Subcontractor Report

Utilization of Ash from Municipal Solid Waste Combustion

Final Report
Phase II

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City and County of Honolulu
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City and County of Honolulu
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NREL Technical Monitor: L.S. Wentworth

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TABLE OF CONTENTS

INTRODUCTION

The H-POWER waste-to-energy facility is a large refuse derived fuel (RDF) facility on the island of Oahu in Hawaii. The H-POWER facility takes in annually about 572,500 tonnes (630,000 tons) of municipal solid waste (MSW) generated on that island. Workers first inspect this MSW to remove about 8,100 tonnes/yr (9,000 tons/yr) of bulky items that exceed the capacity of the shredders, as well as explosive materials such as barbecue propane tanks. The MSW then goes through waste processing equipment which shreds and removes a large portion of ferrous and other noncombustible material to produce about 478,000 tonnes (527,000 tons) a year of a fluffy material called RDF. This RDF is fired in two boilers producing about 336,000 megawatt hours of electric power.

About 97,000 tonnes (107,000 tons) of wet combined ash is produced by the H-POWER facility each year. About 60%, 58,200 tonnes/yr (64,200 tons/yr), of the ash is heavy material that falls off the grates into a water bath at the bottom of the boilers. This fraction is called bottom ash. The remaining ash fraction, fly ash, is carried from the combustion chamber in the flue gas and collected in the hoppers of the superheaters, economizers, air preheaters, spray dry absorbers, and electrostatic precipitators.

For each ton of MSW disposed of at H-POWER, sufficient electricity is produced to preclude burning of approximately 227 liters (60 gallons) of fuel oil that would otherwise need to be imported. The volume of the ash produced is approximately 10% of the volume of the MSW. This saving in landfill space is critical on a small island like Oahu.

Nevertheless, the disposal of 97,000 tonnes (107,000 tons/yr) of combined ash from this facility is expensive and requires valuable landfill space. The purpose of this study was to carefully investigate alternative disposal of this ash material to help ensure that any proposed beneficial uses are safe, economical, and in the public interest. Three principal questions to be investigated were:

1. Can the beneficial uses proposed save money over the current disposal cost (about $1.8 million/yr) and extend the life of the ash monofill?

2. Can the proposed beneficial uses be carried out in full compliance with current environmental, health, and safety standards, and in a manner that is in the best interest of the public?

3. Will the proposed ash uses be able to meet or exceed civil engineering criteria that apply to each use application?

Three beneficial uses of H-POWER combined ash were investigated in this study. They are an intermediate cover for final closure of the Waipahu Landfill, a daily cover at the Waimanalo Gulch Landfill, and a partial replacement for aggregate in road asphalt. These proposed beneficial uses all result in decreased landfill requirements and lower city operating costs. All three are enhanced by using combined ash that has been screened to remove pieces of metal, glass, and stone larger than about 3/8-in. in diameter.
In August 1998, a bottom ash metal removal system was constructed at the H-POWER facility. This system results in a bottom ash that has better size, consistency, and quality characteristics, and, when combined with fly ash, will yield improved physical and chemical characteristics of the combined ash. The removed metals are separated into ferrous and nonferrous fractions and sold as scrap.

An important differentiating aspect of this study is that all proposed uses examine combined fly and bottom ash from a modern waste-to-energy facility that meets the 1990 requirements of the Clean Air Act Amendments for Maximum Achievable Control Technology. This is important because most studies of beneficial uses of ash from waste-to-energy facilities have focused only on use of the bottom ash. Because of the smaller industrial component of the MSW on Oahu and the removal of metals before and after combustion, the resulting combined ash from this facility may be unique.

EXECUTIVE SUMMARY

This ash study investigated the beneficial use of municipal waste combustion combined ash from the H-POWER facility. The beneficial uses studied were grouped into the following three tasks that are described and discussed in this report:

Task 1: Intermediate Cover for Final Closure of the Waipahu Landfill

Task 2: Daily Cover at the Waimanalo Gulch Landfill

Task 3: Partial Replacement for Aggregate in Asphalt for Road Paving

This study is a follow on to a Phase I study(1) which investigated chemical and physical properties of H-POWER bottom ash, fly ash, and combined ash alone and with certain admixtures. This report also updates the Phase I study by including additional U.S. Environmental Protection Agency (EPA) Toxicity Characteristic Leachate Procedures (TCLP) and total chemistry data with a corresponding refinement in the statistical analysis, particularly on the chemistry of the combined ash. The results of the additional chemical and physical data show that TCLP results remain well below EPA TCLP standards and continue to trend downward for all metals except barium, which appears to have stabilized slightly below EPA's barium drinking water standard (Appendix A).

The additional total chemistry data found in Phase II provides strong evidence that the Phase I total chemistry data for lead in combined ash was anomalous. The Phase I total metal data consisted of duplicate analyses of aliquots taken from a single ash sample. One duplicate aliquot was recorded at 15,809 ppm, the other at 3,172 ppm. The average lead concentration was thus recorded as 9,490 ppm. The sampling in Phase II tested 68 separate samples for lead and found that the data varied from a low of 890 ppm to a high of 5,100 ppm with an average of 2,221 ppm (Appendix B). A likely explanation for the anomalous high value is that a drop of solder from an electronic circuit board was in this particular sample. See discussion in Section II (b) of this report.

Additional geotechnical engineering tests in Phase II showed that both 100% H-POWER combined ash and a 90%-10% mixture of H-POWER combined ash and Ameron quarry fines have low coefficients of permeability, superior to the best native soils currently used to inhibit infiltration of rainwater and erosion in landfills. Mililani soil, a lateritic silt soil excavated throughout Oahu, is often used as landfill construction material. These new engineering tests also showed that both the 100% and the 90%-10% mixtures have good compressive and shear strengths and were superior in shrinkage cracking tests following air drying. These later tests are critical because cracking would allow a direct flow path for rainwater or water applied to support vegetation into the wastes disposed in any landfill using combined ash in the cover material (Appendix C).

In this Phase II study, health risk assessments were performed for the first two uses of combined ash outlined in the tasks. The assessments focused on lead exposure, assuming lead concentrations at 2,449 ppm, which is the upper value of the 95% confidence interval around the mean for the H-POWER combined ash. Risk assessment for lead using the California Department of Toxic Substances Control (DTSC) lead model projected upper 99^{th} percentile blood lead concentrations of 3.41 μg Pb/dL or lower for children. This is well below the acceptable benchmark levels of 10 μg Pb/dL for children. Background exposures accounted for blood lead levels of 1.9 μg /dL for children, and site exposures accounted for blood lead levels of 1.5 μg /dL or less. The 99^{th} percentile of blood lead levels for workers during construction activities was projected to be at 7.3 μg Pb/dL or less, well below the adult lead acceptable benchmark level of 25 μg Pb/dL for men and 10 μg Pb/dL for women of childbearing age. Background exposures accounted for blood lead levels of 1.0 μg /dL for adults, and site exposures accounted for blood lead levels of 6.3 μg /dL or less. Most of the site exposures resulted from the assumption that workers and members of the public routinely ingested pure ash.

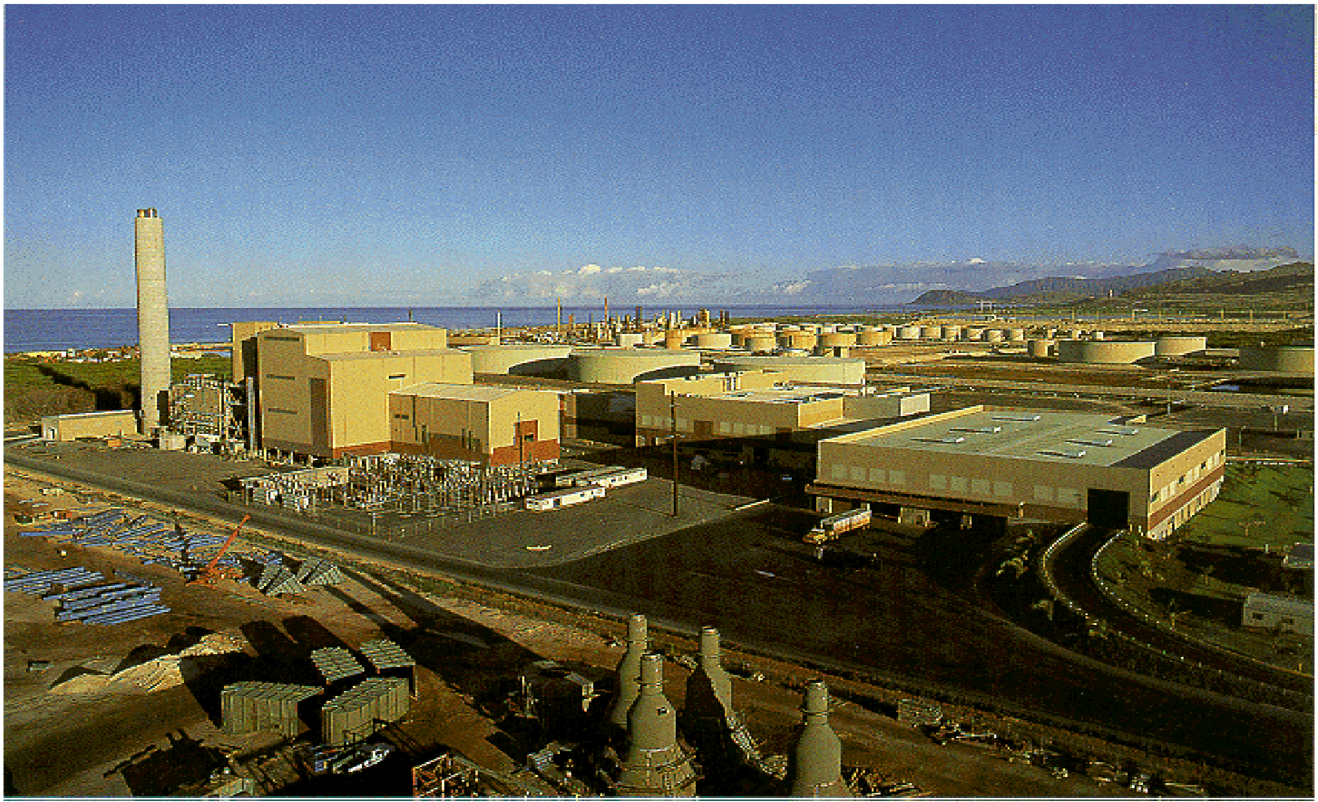
Noncarcinogenic risk assessment for other metals of concern and dioxins/furans resulted in estimated hazard indices of 0.6 and lower, which are below the EPA regulatory hazard index ratio of 1.0. In addition, the estimated daily intakes of dioxins and furans were 0.30 pg/kg/day or less of 2,3,7,8-TCDD equivalents for all worker receptors and 0.14 pg/kg/day or less for all members of the public for all beneficial use scenarios. These values are significantly less than EPA's estimate of the public's average daily intake from background exposures, which is 1-3 pg/kg/day (EPA, 1994).

The estimated excess lifetime cancer risks from all proposed uses involving H-POWER combined ash were 5×10^{-5} or below for workers and $4x10^{-6}$ or below for members of the public. Most of this risk (55-70%) was due to arsenic, which has been decreasing in TCLP leachates. All lifetime cancer risks for members of the public are well within EPA's acceptable risk range of $1x10^{-4}$ to $1x10^{-6}$ for members of the public. Although EPA's risk range used in the Superfund program may not be administratively applicable to the use of H-POWER combined ash in beneficial uses, this risk range is being provided to provide context for the risk assessment results. As a comparison point for worker risks, Travis et al. (1987) found that the individual excess lifetime risk at which federal agencies always acted to reduce worker risk was approximately $4x10^{-3}$, and the individual excess lifetime risk level considered to be *de minimis* was approximately $1x10^{-4}$. Additionally, many OSHA standards are set at exposure levels associated with individual excess lifetime risks in excess of $1x10^{-3}$. These risk comparisons demonstrate that no adverse health effects are anticipated from any of the proposed beneficial uses.

The Phase II activities also included a 6-day daily cover demonstration study to quantify airborne dust and metal exposure levels when using ash as daily cover at the Waimanalo Gulch Landfill. Extensive air sampling was conducted during specific ash-related activities. It showed that the combined ash was not a significant source of respiratory dust or metal exposure to workers or the public. Mining in an ash monofill was also investigated to see if this combined ash could be recovered and used as daily cover in addition to the freshly produced combined ash. This also showed that a potential respiratory dust exposure risk was not significant.

A trial demonstration for the use of combined ash as a partial substitute for natural aggregate in asphalt has been executed by resurfacing a segment of road at the H-POWER facility. The prepared asphalt was an approximately 5.5% ash mix. Higher ash substitution was not possible at this time, because of the high moisture content of the combined ash. A comprehensive environmental testing program is currently under way to determine whether metals contained in the combined ash will leach from the ash-amended pavement under natural as well as simulated environmental conditions. When the test data are available, a comprehensive risk assessment will be prepared to determine the environmental and human health risks posed by the use of H-POWER combined ash as a partial aggregate replacement in road asphalt.

LIST OF APPENDICES



H-POWER Facility at Campbell Industrial Park

I. BACKGROUND

Municipal waste combustion (MWC) combined ash produced at H-POWER, a refuse derived fuel (RDF) type waste-to-energy facility, is currently being landfilled in a lined monofill at the Waimanalo Gulch Landfill. Approximately 97,000 tonnes (107,000 tons) of wet combined ash is produced annually, and estimates indicate that the monofill will reach current capacity in about 10 years. It will be difficult and expensive to find new areas to site, permit, and construct a new ash monofill on Oahu when this one is full.

This study was initiated to find uses for the ash that would lower the present and future cost of landfilling and extend the life of the present ash landfill. This study explores ash use as a landfill cover and in roadway applications. It examines the current direct and indirect economic costs of ash disposal, and examines the technical feasibility and health risks of three potential uses:

1. As Intermediate Cover for Final Landfill Closure (Task 1).

2. As a Landfill Daily Cover (Task 2).

3. As Partial Replacement for Aggregate in Asphalt for Road Paving (Task 3).

This ash reuse study began as a cooperative effort between the City and County of Honolulu (City) and the National Renewable Energy Laboratory (NREL). *Utilization of Ash from Municipal Solid Waste Combustion, Phase I (NREL subcontract No. XAR-3-1322)* provided biological, chemical, and civil soil engineering tests on the ash. The major significance of this study was the use of combined ash, rather than just bottom ash, which was the subject of previous MWC ash studies. Combined ash re-use is important because modern MWC facilities are designed to produce combined ash for disposal. The use of bottom ash only reduces the beneficial cementitious properties of the combined ash, because the excess free lime from the scrubber is found only in the fly ash, thus making certain re-use options less technically feasible.

a. Summary of Phase I Results

The results of Phase I of the study completed at the end of 1994 showed that:

1. All ash samples collected and analyzed quarterly from December 1989 until March 1994 (more than 400 samples taken over almost 6 years) have passed EPA's Toxicity Characteristic Leachate Procedure (TCLP) test.

2. There was no enrichment of any of the trace metals (Al, Ca, Cd, Cu, Fe, Pb, Hg, and Si) in the smaller sieve size fractions. This is based on duplicate sampling of combined ash collected over a 5-day period that was separated into seven sieve size fractions ranging from sieve size #4 to smaller than #200. The samples were then chemically analyzed for the eight trace metals.

3. Three ash mixtures (H-POWER fly ash, three parts H-POWER fly ash to one part sewage sludge, and one part H-POWER combined ash to one part Waipahu Incinerator combined ash) were examined using the Falling Head Permeability test (Das, 1986). All ash mixtures exhibited very low coefficients of hydraulic permeability, from 1.16 x 10^{-6} to 4.36 x 10^{-6} cm/s. The lowest permeability mixture was the mixture of one part combined ash from H-POWER to one part Waipahu Incinerator combined ash. However, none of these permeability mixtures examined H-POWER combined ash by itself.

4. All but one of the ash mixtures tested exhibited greater erosion and cracking resistance during drying than currently used landfill cover material.

5. MWC combined ash chemical analysis, hydraulic permeability, and erosion resistance indicate that this ash is a viable alternative for a landfill cover.

6. MWC ash size fractions and chemical analysis show combined ash to be a viable alternative for landfill cover and for certain road construction applications.

b. Identification of Phase II General Areas of Investigation

From a plant operation standpoint, combined ash is the simplest and least costly form of ash to use. For these reasons the Phase II study focused on combined ash. After examination and discussion of the Phase I results with other City and Hawaii Department of Health (HDOH) officials, the beneficial uses that appeared most appropriate to carefully examine are the three listed in the opening paragraph of this section. Another use that was considered but not further studied at this time, was use as a soil amendment material to stabilize clay soils on embankments which are subject to slides. Mixing with sewage sludge and compost as a soil amendment for agriculture uses was also considered but rejected at this time. This Phase II study was designed to collect data to determine if any of these uses were economically and technically feasible and would offer an acceptably low environmental and health risk to workers and the public.

The Phase II study was organized into six general areas of investigation to support evaluation of the proposed uses. The general areas of investigation supporting each proposed use were:

1. Updating combined ash TCLP data from the Phase I study.

2. Analyzing sufficient additional ash samples for total chemistry data to develop a valid statistical model of the total chemistry, then updating the total chemistry data from the Phase I study.

3. Preparing health risk assessments for each proposed use based on the total chemistry analysis data gathered.

4. Updating civil engineering soil tests on the combined ash using some new ash mixtures.

5. Developing economic data that would facilitate an estimate of possible cost savingsassociated with each beneficial use.

6. Gathering airborne fugitive dust and metal data that result from the ash uses in the field.

c. Summary of Similar Studies

The only studies found by searching the literature which address the use of combined ash for landfill cover were:

1. Keith E. Forrester, "State-of-the-Art in Refuse-to-Energy Facility Ash Residue Handling, Reuse, Landfill Design and Management - A Summary."[(2)]

2. Lee E. Koppelman and Edith G. Tanenbaum, "The Potential for Beneficial Use of Waste-to-Energy Ash."[(3)]

Forrester examined combined ash field leachates and fugitive dust levels at ash landfills from mass burn facilities and found that fugitive dust levels met all health standards established for workers and the public. He also found that field leachates were at worst only slightly above EPA's primary drinking water standards. He then reviewed combined ash uses from nine Wheelabrator Environmental System facilities, pointing out that three of those facilities (Saugus, Pinellas County, and Bridgeport) had active studies under way in 1989 using combined ash as daily cover over unlined MSW landfills. Results of those studies confirmed that the use of combined ash as daily cover reduced complaints about odors, wind-blown MSW, and vectors.

Forrester reported results of falling head permeability studies on the combined ash and field leachate analysis data. However, there were no comparison data with natural soils used for daily cover, and there were no reported shear strength tests, no shrink swell tests (Atterberg Limits) and no tests for cracking on drying as were done in the H-POWER Phase II tests. In addition, no RDF facilities were studied as compared to the mass burn facilities where the proportion of fly ash and bottom ash differs from those of mass burn facilities.

Although Forrester considered the health impacts of field monitored fugitive dust levels, he did not do a complete health risk assessment, which would require considering all pathways of exposure using approved EPA and state guidance for health risk assessments. Finally, because Forrester's study was done before EPA proposed criteria for final closure of MSW landfills, it did not examine the specific use of combined ash as intermediate cover for the final closure of a landfill.

Still, the observations and conclusions are in complete agreement with all the observations and conclusions of this Phase II study. One of those conclusions was that waste-to-energy ash should be viewed as a civil engineering material. Focus should be on developing ash into a useful material for either low permeable layered landfill use or as an aggregate substitute.

The Koppelman and Tanenbaum study provides a general review by the Long Island Regional Planning Board of ash recycling potential. This study occurred when New York's Part 360 Landfill Regulations severely constrained ash landfilling on Long Island. The physical information collected from five mass burn facilities in New York included elemental analysis; a series of leaching tests, including TCLP; and engineering tests including size gradation, bearing capacity, density, swell potential, water solubility, and compressive strength. A field demonstration included in the study showed that the use of combined ash as a daily cover material was technically feasible and acceptable from a health and safety standpoint. However, no quantitative health risk assessments were done, and none of the facilities studied were RDF facilities. The Planning Board, a quasi-political organization, made the following interesting recommendation:

> "In a landfill environment the use of combined ash in an unbound aggregate form as daily or intermediate cover, or the use of treated ash as a landfill cover or as a grout material for landfill stabilization was judged to be a suitable strategy for ash utilization that is projected to result in no significant adverse environmental impact."

II. REPORT ORGANIZATION, AREAS OF INVESTIGATION AND KEY SUMMARY RESULT

a. Updated TCLP Test Data

Appendix A provides an update of the combined ash chemistry data as reported in the Phase I report. Table 1 in Appendix A contains all TCLP test results from December 1989 to July 1998 and routine test results for 2,3,7,8-TCDD and 2,3,7,8-TCDF. Statistical analyses accompanying the TCLP data are also reported in Appendix A. Summarized below is a comparison of the averages for TCLP data reported in the Phase I report and the averages for TCLP to July 1998:

TABLE 1: UPDATED TCLP TEST DATA COMPARISON

Leachate Element	Average TCLP results from 12/89 to 3/94 (reported in Phase I report) in mg/L	Average TCLP results from 12/89 to 7/98 in mg/L	EPA TCLP Standard In mg/L	EPA Drinking Water Standard in mg/L
Arsenic	0.397	0.260	5.000	0.050
Barium	0.745	0.699	100.000	1.000
Cadmium	0.166	0.166	1.000	0.010
Chromium	0.048	0.035	5.000	0.050
Lead	0.709	0.508	5.000	0.050
Mercury	0.003	0.002	0.200	0.002
Selenium	0.156	0.107	1.000	0.010
Silver	0.056	0.038	5.000	0.050

These TCLP data show evidence of a decreasing trend in leachate results for all trace metal TCLP elements. Four of the trace metals (barium, chromium, mercury, and silver) are below EPA's drinking water standards and the others are well below the TCLP limits. Individual plots of these data over time, showing the decreasing trend in TCLP leachate concentrations, are provided in Appendix A.

Conclusion: The combined ash TCLP test results continue to show a trend of decreasing trace metal leachate concentrations. This is significant in that it indicates a continuing reduction of these heavy metals in our environment. Because there has been no change in the source of MSW within the community, we believe this probably reflects a general trend throughout the environment within the United States. Known elements of this reduction include the removal of lead from paint, the reduction in the mercury content of batteries and fluorescent bulbs, and the elimination of lead in gasoline.

b. Updated Total Lead Data

Total chemistry data for certain trace metals in H-POWER's combined ash were reported in the Phase I report. The HDOH focused on lead as its main health risk concern for the proposed uses. This was caused by one Phase I sample, which showed an unusually high lead content, discussed below. Such concern motivated the City to conduct further sampling and analysis for total lead and other trace metals, and report these new data in this report. The results of these additional total chemistry combined ash data based on 68 samples gathered from March 1995 until April 1998 are presented in Appendix B. In addition to total metal testing, two combined ash samples were analyzed for all 2,3,7,8-substituted dioxin and furan congeners to obtain useful data for risk assessment purposes. These data are also presented in Appendix B.

The average lead concentration in combined ash from the Phase I sieve size analysis, taken from one sample, was 2,155 mg/kg. The average lead concentration in combined ash in mixture 3a and 3b from the Phase I report, representing just one sample, was 9,490 mg/kg. The average lead concentration in combined ash from the 68 new samples collected from March 1995 to April 1998 was 2,221 mg/kg. The 68 additional samples were collected using the EPA-approved procedures for sampling used for the regular TCLP testing, and thus represent a valid sample of the actual ash from this facility.

This focus on lead occurred because duplicate laboratory aliquots from one actual combined ash mixture (mixtures 3a and 3b) sample reported an average value of 9,490 ppm in the Phase I report. This is a much higher lead concentration than typically occurs in combined ash from an MWC, although it was not recognized as such when the Phase I report was prepared.

There are several likely sources of lead in MSW. A principal source is lead solder from electronic circuit boards. From time to time these drops of solder show up as spikes in ash samples. Lead melts at 327□C (621□F) and boils at 1,620□C (2,948 □F). Given the density of lead, it is more likely to end up in the bottom ash than to appear in the precipitator with the fly ash.

Sampling in Phase I was very limited because only one of the nine mixtures being investigated was H-POWER combined ash. That mixture consisted of one composite combined ash sample from which duplicate subaliquots were taken for separate chemical analysis. Sample 3b likely had a drop of lead solder from a discarded electronic device. The anomalous nature of sample 3b is seen by examining the total sieve size analysis data in Appendix B2 of the Phase I report. These data show total lead values for combined ash sieved into seven separate size fractions. Their weighted average was 2,155 mg/kg. This compares well with the average of 68 new combined ash samples not sieve sized.

Conclusion: Additional data comprising a valid sample indicate that total lead in H-POWER combined ash is in the range of 890 ppm to 5,100 ppm, with a mean concentration of 2,221 ppm and an upper 95% confidence interval of 2,449 ppm.

c. New Health Risk Assessments for Potential Beneficial Uses

In order to analyze the potential health risk from chemicals in the combined ash from the three proposed beneficial uses, health risk assessments were requested by HDOH. These were conducted by Ogden Environmental and Energy Services (OEES).

All natural substances, including soil and water, contain very minute quantities of various chemicals. Human exposure to such chemicals is thus ever present, and its significance depends largely on the exposure concentration level, the relative toxicity of the chemical, and the duration of the exposure. The concentrations of most trace metals in the combined ash are higher than in natural soil, but this study indicates low health risks from the proposed uses. Reasons for this are the low fugitive dusting characteristics of the proposed uses, coupled with the relative inaccessibility of the ash to humans because of engineered and institutional controls associated with the proposed uses, and the relatively low toxicity characteristics of the trace metals in the ash because of low bioavailability.

The risk assessments all follow the four-step approach recommended by the National Research Council (NRC). Those steps are:

1. Hazard Identification
2. Toxicity Assessment
3. Exposure Assessment
4. Risk Characterization

Hazard identification involves the identification of nine trace metals as well as polychlorinated dioxins and furans as compounds of potential concern (CPC) in the ash. The identification of these CPCs will be applicable in the health risk assessment of all three proposed beneficial uses.

Toxicity assessment involves establishing the level of exposure (dose) for each CPC that is associated with specific adverse health effects; both carcinogenic and noncarcinogenic. In all use scenarios the same EPA-verified dose response criteria were used, except for lead, where there are no EPA criteria. Lead dose-response effects were evaluated by using the California DTSC blood lead model.

Exposure assessment takes into account who is likely to be exposed, for how long, and in what manner. This assessment is different for each proposed use, because the exposure situations are different for each proposed method.

Risk characterization combines the results of the exposure assessments with the results of the toxicity assessments. From this combination we then derive quantitative estimates of the potential for adverse health effects as a result of exposure to the ash. A number of conservative assumptions are incorporated into these calculations, which usually result in the risks being considerably overestimated.

The application of the California DTSC lead model estimated an upper 99th percentile blood lead concentration of 3.41 µg Pb/dL or lower for children, well below the acceptable benchmark level of 10 µg Pb/dL for children. Background exposure accounted for blood lead levels of 1.9 µg /dL for children, and site exposures accounted for blood lead levels of 1.5 µg/ dL or less. The 99th percentile of blood lead levels for workers during construction activities was projected to be at 7.3 µg Pb/dL or less, well below the adult lead acceptable benchmark level of 25 µg /Pb/dL for men and 10 µg Pb/dL for women of childbearing age. Background exposures accounted for blood lead levels of 1.0 µg /dL for adults, and site exposures accounted for blood lead levels of 6.3 µg /dL or less. Most of the site exposures resulted from the assumption that workers and members of the public routinely ingested pure ash.

Noncarcinogenic risk assessment for other metals of concern and dioxins/furans resulted in estimated hazard indices of 0.6 and below, which are below the EPA regulatory concern hazard index ratio of 1.0. In addition, the estimated daily intake of dioxins and furans were 0.30 pg/kg/day or less of 2,3,7,8-TCDD equivalents for all workers receptors and 0.14 pg/kg/day or less for all members of the public for all beneficial use scenarios. These values are significantly less than EPA's estimate of the public's daily intake from background exposures, which is 1-3 pg/kg/day (EPA, 1994).

The estimated excess lifetime cancer risks from all beneficial uses were 5×10^{-5} or below for workers and $4x10^{-6}$ or below for members of the public. Most of this risk (55-70%) is due to arsenic, which has been decreasing in TCLP leachates. Thus, all lifetime cancer risks for members of the public are well within EPA's acceptable risk range of $1x10^{-4}$ to $1x10^{-6}$ for members of the public. Although EPA's risk range used in the Superfund program may not be administratively applicable to the use of H-POWER combined ash in beneficial uses, this risk range is being provided to provide context for the risk assessment results. As a comparison point for worker risks, Travis et al. (1987) found that the individual excess lifetime risk at which federal agencies always acted to reduce worker risk was approximately $4x10^{-3}$ and the individual excess lifetime risk level considered to be *de minimis* was approximately $1x10^{-4}$. Additionally, many OSHA standards are set at exposure levels associated with individual excess lifetime risks in excess of $1x10^{-3}$. In fact, if workers were exposed to airborne arsenic at the Hawaii OSHA (HIOSH) standard, their lifetime cancer risk would be $4x10^{-2}$. These risk comparisons demonstrate that no adverse health effects are anticipated from any of the proposed beneficial uses.

Appendix G presents selected summary tables from the risk assessment reports that provide results for each exposure pathway. As shown in these tables, the soil ingestion pathway is a major pathway for both noncarcinogenic and carcinogenic risk. This is an exposure pathway that is greatly overestimated by assuming hypothetical behaviors that cannot and will not occur in reality. For instance, it is assumed in the risk assessment that workers will ignore HIOSH regulations, remove their personal protective gear and actually ingest pure ash on a regular basis. Similarly, trespassers or landfill visitors are assumed to gain access to prohibited areas and intentionally ingest pure ash repeatedly many times a year over the course of many years. While such unrealistic assumptions are commonly made in the practice of risk assessment, it must be realized that they define the risks under high-end or worst case conditions and do not reflect the risks under expected exposure conditions. Risks posed by inhalation of airborne ash are also greatly overestimated, because the risk assessment ignored the air monitoring data, which showed no increase in respirable dust downwind of the ash-handling activities and no detectable metals in respirable dust samples. Instead, the risk assessment was extremely health-protective and assumed, contrary to empirical fact, that the respirable dust was 100% ash-derived and thus contained ash-derived metals. Even with this conservative assumption, the assumed arsenic concentration was below the OSHA standard by a factor of 600 or more and we assumed lead concentration was below the OSHA standard by a factor of 70 or more.

<u>Conclusion</u>: No adverse health effects are anticipated from either of the two proposed beneficial uses as a landfill cover based on detailed health risk assessments conducted for each proposed use. A health risk assessment for the beneficial use of combined ash as a partial substitute for aggregate in asphalt will be executed when environmental testing data are available.

d. Updated Civil Engineering Soil Tests

To evaluate the best final intermediate cover material for closure of the Waipahu Landfill, the Civil Engineering Department at the University of Hawaii performed soil engineering tests, that are discussed in the Phase I report. The tests carried out were modified Proctor compaction tests and falling head permeability tests on three ash mixtures as defined in Phase I. Only one mixture involved H-POWER combined ash.

The Phase II engineering investigations concentrated on three new combinations of H-POWER combined ash screened to remove all 1-cm (3/8-in.) and larger material. These were:

1. 80% screened combined ash with 20% Ameron quarry waste fines.

2. 90% screened combined ash with 10% Ameron quarry waste fines.

3. 100% screened combined ash.

A baseline was established using Mililani soil, a lateritic silt soil excavated throughout Oahu from previous sugarcane and pineapple fields; it is often used as landfill construction material.

Tests were performed to measure permeability and compressive strength and to characterize the swell and cracking potential of the three combined ash mixtures as well as the baseline native soil samples. These tests and their results are described fully in Appendix C. Ideal civil engineering properties for landfill cover material are:

1. Low hydraulic permeability coefficients, which restricts water penetrating the cover to preclude production of metal-containing leachate.

2. Ability to control moisture levels to optimize compaction.

3. Ability to compact in the field with conventional commercial compactors to maximum dry density levels.

4. Relatively high compressive and shear strengths for erosion resistance and low maintenance as tractors, trucks, and other heavy equipment run over of the cover material.

5. Low swell rate when material becomes saturated with rainwater.

6. Low potential for cracking as the cover material dries after being saturated with water.

7. Plentiful and inexpensive.

Engineering tests showed the 90% H-POWER combined ash with 10% Ameron quarry waste fines mixtures and 100% combined ash mixtures both had very low permeability coefficients, good compressive and shear strengths, and both displayed excellent performance in shrinkage cracking tests following air drying.

Hawaii Administrative Rules 11-58.1-17 (a) (2) specify a permeability coefficient no larger than 1×10^{-5} cm/s for the infiltration layer of the final cover in closure of a landfill. There are no equivalent criteria for landfill daily cover, but clearly a low permeability material helps in this application as well. The 90% H-POWER combined ash with 10% Ameron quarry waste fines mixtures and the 100% combined ash mixtures had permeability coefficients of 2 x 10^{-8} cm/s and 3 x 10^{-8} cm/s, respectively, well below the state infiltration layer criteria. The swell test results were low for both mixtures (4.9% and 1.4%, respectively), but the qualities that made the real difference in showing the superior nature of these two mixtures, compared to the Mililani soil, were cracking resistance and costs. These cracking resistance tests are critical, because cracking would allow a direct flow path for rainwater, irrigation water, or water used to control fugitive dusting to migrate into the solid wastes disposed in the landfill under the daily cover.

Conclusion: The civil engineering soil tests show that the 90% H-POWER combined ash with 10% Ameron quarry waste fines and the 100% combined ash mixtures far exceed the Hawaii criteria for landfill final cover, and, from a civil engineering standpoint, are much better than Mililani soil because of the much lower potential for the ash to crack upon drying. Further, this material is excellent for daily cover material, exceeding the characteristics of soil.

e. Economic Data Relating to Beneficial Use

The direct economic savings in the use of H-POWER combined ash for the closure of the Waipahu Landfill can be approximated. It is estimated to cost about $15-$20/tonne ($14-$18/ton) to deliver Mililani soil to the Waipahu Landfill for use as final infiltration layer material. It presently costs the City $17.98/tonne ($16.31/ton) to dispose of the combined ash in the Waimanalo Gulch Landfill. The added cost of delivery of ash to the Waipahu site instead of to the Waimanalo Gulch Landfill is approximately $3.30/tonne ($3/ton). There is therefore a direct differential saving of about $28 for every ton of H-POWER combined ash used for the Waipahu Landfill closure.

Combined ash has a maximum dry compaction density of 1,360-1,380 kg/m^3 (85-86 lb/ft^3 or 2,308 lbs/yd^3). The Waipahu Landfill has a surface area of 0.174 km^2 (43 acres), and assuming an average depth of 61 cm (24 in.) for the infiltration layer, about 106,275 m^3 (139,000 yd^3) of closure material would be needed for this layer. That translates to a need for about 145,190 tonnes (160,044 tons) of combined ash for the closure, which translates to a potential cost saving of more than $4 million dollars for the use of combined ash in place of Mililani soil. In addition, there are savings associated with avoiding the need to site a new ash monofill in 10 years. The cost for purchasing land is estimated to be $5 million for a 32,380-$m^2$ (8-acre) site, $1.5 million to design and permit the new site, and $3.5 million for building roads, constructing a liner, installing monitoring wells, and making other capital improvements at the new ash monofilll. This avoided cost element is estimated to be $10,000,000.

The economics for use of the combined ash for Waimanalo Gulch Landfill daily cover are not as compelling as for its use for Waipahu Landfill closure. Conservatively speaking, the value of selling material from the quarry operation in the landfill, currently used as daily cover, is assumed to be only $1.10/tonne ($1/ton). The principal cost savings are the potential savings $17.98/tonne ($16.30/ton) from avoiding landfilling the ash in the ash monofill, and avoiding the need to purchase, design, permit, and construct a new lined ash monofill. In this beneficial use alternative the future avoided cost is assumed to be $10 million. This results in an assumed cost saving of almost $38 million over a 15-year period, the projected remaining life of the H-POWER facility for this use.

Table 2 summarizes the estimated economic benefits of the proposed use of combined ash for the intermediate final cover of the Waipahu Landfill closure to the current ash monofill disposal approach:

TABLE 2: COST ANALYSIS FOR THE USE OF COMBINED ASH IN WAIPAHU LANDFILL CLOSURE

Cost Element	**Costs Assuming Current Ash Monofill Disposal Approach Continues and No Ash Used for Closure**	**Costs If Ash Used as Intermediate Cover for Waipahu Landfill Closure**
Cost of natural Mililani soils used for intermediate level cover at $8.80/tonne ($8/ton)	$1,000,000	N.A.
Cost of transport of soil to the landfill at $8.80/tonne ($8/ton)	$1,000,000	N.A.
Added cost to transport ash to Waipahu instead of to Waimanalo at $3.30/tonne ($3/ton)	N.A.	$480,000
Cost to dispose of ash at Waimanalo landfill at $17.98/tonne ($16.30/ton)	$2,610,318	N.A.
Avoided cost to site, purchase and permit a new ash monofill in 10 years	$10,000,000	N.A. (if use as daily cover at Waimanalo Landfill also allowed)
Total costs	$14,610,318	$480,000
Net saving for using ash		$14,130,318

Table 3 summarizes the estimated economic benefits of the proposed use of combined ash for daily cover of the Waimanalo Gulch Landfill compared to continuing the current ash monofill disposal approach:

TABLE 3: COST ANALYSIS FOR THE USE OF COMBINED ASH AS WAIMANALO LANDFILL DAILY COVER

Cost Element	**Costs Assuming Current Ash Monofill Disposal Approach Continues and No Ash Used for Daily Cover Over 15 Year Period**	**Costs If Ash Used as Intermediate Cover for Waimanalo Landfill Closure**
Sale of present soils used for daily cover at \$1.1/tonne (\$1/ton)	\$1,650,000	N.A.
Cost to dispose of ash at Waimanalo landfill over 15 year period at \$7.72 /tonne (\$7/ton)	\$11,235,000	N.A.
Avoided cost to site, purchase and permit a new ash monofill in 10 years	\$10,000,000	N.A.
Total costs	\$22,885,000	
Net savings for using ash over 15 year period		\$22,885,000

Conclusion: It is far less costly to use combined ash for the Waipahu Landfill closure and the Waimanalo Gulch Landfill daily cover in these two proposed applications, than to use native soil or quarry materials as originally planned, or as currently being used.

f. Ambient Fugitive Dust Levels Caused by Ash Use in the Field

Combined ash currently produced by H-POWER contains average moisture levels around 30% to 35%. The combined ash has therefore not created any fugitive dusting problems as it is trucked to Waimanalo Gulch Landfill and dumped for final disposal. Still there was a question by officials of Waste Management Inc., HDOH, and the operators of the Waimanalo Gulch Landfill, about the ambient dust levels in various places as fresh ash as well as mined ash is stockpiled, pushed, compacted, and run over by heavy landfill equipment. With approval from the HDOH, a 6-day fugitive dust study program was conducted at the Waimanalo Gulch Landfill in July 1996. This study is discussed in Section III, Task 2, and described in more detail in Appendix D of this report.

MSW Being Compacted over Previous Day's Alternate Daily Cover

The study coincided with an operational feasibility test using combined ash as daily cover by Waste Management Inc., personnel, and it examined handling of ash for this purpose at the landfill. A meteorological monitoring station was placed on a nearby hill to measure wind speed and direction. Three ambient air monitoring stations were set up around the area where the daily cover was to be placed at the landfill. One station was upwind; the other two were downwind. The pumps were calibrated to record the volume of air collected over time. A filter and pump were used to monitor for total dust, another for respirable dust, and a third for measuring total metals. In addition, other air monitors were placed on people working in the area and inside the cabs of the landfill equipment that was used to place and compact daily cover. Other monitors were periodically run at various places in the landfill to measure hexavalent chromium, mercury, and respirable silica dust.

All fugitive dust results were below OSHA exposure limits. In fact, no metals were detected in any dust samples except for a low level of nickel in two samples. Mercury was detected in several samples, but mass balance calculations and the results of a second air monitoring program demonstrated that the mercury detected during the demonstration was unrelated to the use of H-POWER combined ash as alternate daily cover (Appendix D8).

As noted in Section III, worst-case metal concentrations over the workday were estimated for risk assessment purposes by assuming that all the respirable dust was derived from combined ash, even though ash-related metals were not detected during the monitoring program. All noncarcinogenic hazard indices and estimated cancer risks were below regulatory levels of concern. In addition, estimated levels of blood lead were below regulatory benchmarks. For further details on this study and how risks were estimated conservatively from the measured levels of airborne dust, see Appendix D.

Conclusion: Fugitive dust levels created at the landfill from all operations show no risk levels that exceed any EPA or OSHA levels established to protect workers and the general public. This is the case whether fresh H-POWER combined ash or drier, mined combined ash already disposed in the monofill at the landfill as daily cover is used. The use of combined ash for daily cover thus appears to be completely acceptable from this standpoint.

III. PROPOSED BENEFICIAL USES

The objective of the Phase II study was to select and test possible alternatives to landfilling of H-POWER combined ash. As previously indicated, this study investigated the following three proposed uses:

Task 1 - H-POWER combined ash used as final intermediate cover material for closure of the Waipahu Landfill.

Task 2 - H-POWER combined ash used as daily landfill cover at the Waimanalo Gulch Landfill.

Task 3 - H-POWER combined ash used as partial replacement for natural aggregate in asphalt concrete.

Task 1 - H-POWER combined ash used as final intermediate cover material for closure of the Waipahu Landfill.

a. Waipahu Landfill History

Since 1993, the City has been planning the final closure of the Waipahu Landfill located in the area of Oahu shown in Appendix D5, Figure 1. The landfill began in the late 1950s as an area where MSW was disposed by open burning. When EPA banned the practice of open burning, the landfill was temporarily shut down as new landfills were opened on the island. In the early 1970s, the Waipahu Incinerator was constructed next to the closed landfill. It had a capacity of 544 tonnes (600 tons) of MSW per day. The Waipahu Incinerator operated continuously until the H-POWER waste-to-energy facility came on line in May 1990. At that time, the Waipahu Incinerator operated on a reduced load basis of less than 270 tonnes (300 tons) of MSW per day to burn "international waste" arriving on the island. Ash produced by the incinerator was disposed in the reopened Waipahu Landfill. From the early 1970s until 1992 the Waipahu Landfill received only ash produced by the Waipahu Incinerator. When the Waipahu Landfill reached capacity in 1992, ash from the Waipahu Incinerator was disposed in the Waimanalo Gulch Landfill.

Final closure of the Waipahu Landfill will require application of a final cover that would protect the area and allow use of the land in the future. The purpose of the final cover is to minimize moisture infiltration into the landfill, minimize and manage the formation of leachate, minimize erosion on the landfill, and manage and direct rainfall runoff and other surface water away from the landfilled solid waste.

Natural red-brown lateritic silt from Mililani is the most common soil on the island, and it is the standard material used for the final cover of landfills in Hawaii. This soil has the Unified Soil Classification System (USCS) designation of ML or MH (Anderson and Hee, 1995).

Initially, the City's plan for final closure of the landfill was to use this Mililani soil for the final cover material. Mililani soil costs approximately \$8.80/tonne (\$8/ton) plus trucking, which can add another estimated \$7-\$11/tonne (\$6-\$10.00/ton).

b. Regulatory Landfill Closure Requirements

HDOH regulations for closure of solid waste disposal facilities (§ 11-58-17 (a) (2)), specify that two layers be used in the final cover of a closed landfill. The top layer is called the erosion control layer. It must have a minimum thickness of 15 cm (6 in.) and be able to sustain plant growth. The next layer, the one nearest the stored MSW, is called the infiltration layer. It must be at least 46 cm (18 in.) thick. It is generally assumed that natural soil that can meet permeability coefficients no greater than 1×10^{-5} cm/s will be used for this second layer.

The same HDOH regulations also state that the director may approve an alternative material for the infiltration layer final cover. That material must also have a permeability coefficient no greater than 1 x 10^{-5} cm/s. If a waste material improves on this permeability criterion and provides other superior soil engineering properties, such as reduced cracking on drying after moisture saturation, or can significantly reduce total project costs, there is good reason for proposing it. Such is the case with the proposed use of either 100% H-POWER combined ash or a mixture of 90% H-POWER combined ash with 10% Ameron quarry waste fines.

As a result of the Task 1 engineering studies, final cover material for the landfill consisting of a 61-cm (24-in.) infiltration layer of H-POWER combined ash beneath an 46-cm (18-in.) erosion layer of Mililani soil is now being proposed. This cover exceeds the regulatory requirements as will be detailed below.

c. Engineering Tests on Ash Mixtures

Ash was chosen as an infiltration-inhibiting layer material because of its superior permeability properties, found from the Phase I engineering studies. Approximately 106,080 m^3 (138,746 yd^3) of ash would be required. The ash would require screening to remove all ferrous and nonferrous metals. The water content of the ash would be approximately 30%-35%.

While the Phase I studies were underway, the City retained the Civil Engineering Department at the University of Hawaii to investigate various ash mixtures (Appendix C). These investigations examined soil engineering properties of mixtures of combined ash from H-POWER and quarry fines from Ameron and Grace Pacific Corporation (Grace Pacific) quarries for use as a final infiltrative layer cover material. These engineering tests investigated not only the important coefficient of permeability for these mixtures but other engineering properties that are important for the infiltration layer (intermediate layer) of a landfill's final cover. These properties are permeability, shear strength, Atterberg limits, physical cracking, the Modified Proctor test, and grain size analysis.

Permeability

Permeability indicates the ability of a material, at its optimum density, to allow water to migrate through it at some fixed head of pressure measured in units of cm/s. The permeability of a soil sample is the rate that water is able to flow through it. The Falling Head Permeability Test (Das, 1986) is used to determine the coefficient of permeability (k) measured in cm/s. A soil sample was compacted in five layers at 95% maximum dry density at the optimum plus 2% moisture content. A 22.7 kPa (3.3 psi) confining vertical stress was applied to the top of the sample to represent expected field conditions. The sample was saturated with water and a hydraulic head applied causing water to flow through it. The volume of water that flowed through the sample was measured for 2 to 3 days. The coefficient of permeability was calculated for each mixture.

Mixtures of 80% ash and 20% Ameron fines (80-20), 90% ash and 10% Ameron fines (90-10) and 100% ash were tested. Mililani soil was also tested as a baseline material. The 90%-10% mixture had a coefficient of permeability equal to the Mililani soil of 2×10^{-8} cm/s with a vertical confining stress of 157.2 kPa (22.8 psi). All the ash mixtures tested achieved a moist coefficient of permeability of less than, or equal, to 3×10^{-8} cm/s and thus met the Hawaii Administrative Rule's lower limit of 1×10^{-5} cm/s. The coefficients of permeability achieved are representative of field conditions.

Shear Strength

Shear strength indicates the amount of load that can be applied to a soil before failure. It is the measure of the maximum shear stress that a soil can withstand. The shear strength of a sample is the amount of horizontal stress that sample is able to withstand before it undergoes horizontal displacement. The Direct Shear Test is used to determine the cohesion intercept (c) measured in kN/m^3 and the friction angle (f) measured in degrees. Each sample was compacted in five layers to 95% maximum dry density at optimum plus 2% moisture content. Each sample was then subjected to a constant horizontal strain of 0.75 mm/min. Horizontal displacement and shear stress were recorded and plotted, and the maximum shear strength of each mixture was determined. The 90%-10% mixture had the highest shear strength of 92.5 kPa at a friction angle of 33^o. The Mililani soil had a shear strength of 53.4 kPa at a friction angle of 36^o. The 100% H-POWER combined ash had a shear strength of 23.3 kPa at a friction angle of 56^o.

Atterberg Limits

Atterberg limit indicates limiting behavior or critical stages in soil behavior pertaining to plasticity, cohesion, and shrinkage. They measure moisture contents at which the soil behaves as a liquid or plastically. Free swell is the amount of volumetric expansion that will occur to a sample when water is added to it. The method used to determine swell potential is the Direct Free Swell Test (ASTM D-4546). Each sample was compacted in five layers to 95% maximum dry density at optimum plus 2% moisture content. The sample was immersed in water and allowed to swell freely. The change in volume was measured over a period of 5 days, and the maximum swell potential was determined. The Mililani soil had the lowest swell potential of 0.44 %. The 90%-10% mixture had a swell potential of 4.9%, the 100% combined ash had a swell potential of 1.4%.

Physical Cracking

Physical cracking indicates the tendency of a material that has become saturated with moisture to physically crack as the material dries. Such cracking then opens up direct pathways for water penetration. After the swell test was performed, the samples were allowed to dry and were observed for shrinkage cracks. After drying, the Mililani soil showed substantial cracking. The ash mixtures showed negligible to no cracking.

Modified Proctor Test

Modified Proctor test determines a relationship between dry density of the soil and moisture content. The optimum moisture-density relationship obtained is used to specify field fill compaction and preparation of laboratory test samples. A compaction test was used to determine the maximum dry density and the optimum water content of a soil sample. The method used to determine these values was the Modified Compaction Test (ASTM D-1557). A soil sample was compacted in five high-density layers by dropping a 10-pound hammer 25 times from a height of 1.5 feet to achieve a standard compaction energy. The moisture content and moist unit weight were determined, varied, and plotted for each sample, and the maximum dry density of each sample was calculated. The Mililani soil reached a maximum dry density value of 1,497.7 kg/m^3 at an optimum water content of 31.5%. The 90%-10% mixture had a maximum dry density of 1406.4 kg/m^3 at an optimum water content of 27.5%.

Grain Size Analysis

Grain Size Analysis indicates the range and quantities of varying sizes within a soil sample; it is used to classify the soil and predict soil behavior. The ash used for the Phase II test mixtures consisted only of combined ash from H-POWER. This combined ash consists of a ratio of 60% bottom ash and 40% fly ash. The bottom ash was sieved with a #4 (4.75) sieve and then mixed with the fly ash. Quarry fines came from the Ameron cement quarry. Ameron fines originate from crushing and grading blue rock and have a powder-like fineness. Ameron fines are classified as a fine silt with plasticity index 2.6 and USCS designation ML. Grain sieve analyses were performed on both fine materials.

d. Engineering Test Conclusions

Using the above engineering tests, the university found that either the 100% H-POWER combined ash or a mixture of 90% H-POWER combined ash with 10% Ameron quarry waste fines were both superior to the Mililani soil. This is because these ash mixtures did not incur shrinkage cracking after exposure, as did the Mililani soil. Withstanding shrinkage and cracking is a major engineering advantage since dryness cracking can void the primary regulatory criterion of this cover layer.

Other advantages of the combined ash mixtures are:

1. Saves approximately $14 million dollars (See Subsection II (e) and Table 2 of this report).

2. Conserves about 76,455 m^3 (100,000 yd^3) of Mililani soil.

3. Extends the life of the Waimanalo Gulch Landfill ash monofill by about 2.5 years and, if combined with subsequent use of ash as daily cover, would indefinitely defer the need for a new ash monofill.

4. Reduces truck traffic to the Waimanalo Gulch Landfill.

5. Helps the City reach EPA- and HDOH-mandated recycling objectives.

e. Health Risk Assessment of Ash in the Waipahu Landfill Closure

The chief concern of the HDOH regarding the potential use of the combined ash as the intermediate layer of the final cover was whether the proposed use would have adverse health effects either to workers during the construction phase or to the general public.

To answer the concern, the City, with the assistance of OEES, completed a detailed health risk assessment to provide further assurance that H-POWER combined ash is a safe material. *Risk Assessment of the Beneficial Use of H-Power Combined Ash in the Final Cover for the Waipahu Landfill Closure* (December 1997) [(4)] is the result of this work. A summary from this risk assessment follows.

The approach adopted in the health risk assessments is consistent with the approach recommended by the National Research Council (NRC). EPA, OSHA, and many other federal and state regulatory agencies have adopted the NRC risk assessment approach. In accordance with the NRC recommendations, the risk assessment was organized into the following four steps:

1. Hazard Identification
2. Toxicity Assessment
3. Exposure Assessment
4. Risk Characterization

Hazard Identification

Compounds of potential concern to human health, detected in H-POWER combined ash, were selected for a quantitative risk assessment. The CPCs include arsenic, barium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and polychlorinated dioxins and furans.

Toxicity Assessment

The toxicity assessment determines the relationship between the magnitude of exposure for each CPC (dose) and the occurrence of specific health effects for a potential receptor (response). The risk assessments include an evaluation of potentially carcinogenic and potentially noncarcinogenic effects. The risk assessments used the most current EPA verified dose-response criteria. In the case of lead, there is no EPA verified reference dose. Therefore, the risks posed by lead exposure were evaluated separately using the California DTSC blood lead model and toxicity benchmarks defined by the Centers for Disease Control (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR).

Exposure Assessment

In exposure assessment, the potential human receptors are identified based on characteristics of the site, the surrounding area, and specific details of the project. In addition, the magnitude and frequency of the receptors' potential exposure to CPCs is quantified.

For intermediate cover in the final closure of the Waipahu Landfill, exposures were assessed for the closure period during which the combined ash would be delivered to the landfill, spread, compacted, and covered with a growth vegetation layer of Mililani soil. In addition, exposures were assessed for the post-closure period. The potential receptors have been identified as:

1. A worker who stockpiles and spreads ash for the final intermediate cover and uses no personnel protective equipment (PPE) and thus has ash ingestion, dermal contact, and dust inhalation.

2. A child who trespasses onto the landfill as closure construction activities occur and who ingests ash, has dermal contact with ash, and inhales some ash dust, plus contacts and ingests leachate from the landfill.

3. A child resident who lives at the closest residence to the landfill and who also has the same routes of exposures (ingestion, dermal contact, and inhalation) as the above individuals but does not ingest landfill leachate.

A recreational user of the closed (or redeveloped) landfill and West Loch of Pearl Harbor who has the same three routes of exposure and also eats fish that are assumed to have bioaccumulated ash-related chemicals. The user also contacts and incidentally ingests surface water and incidentally contacts and ingests sediment.

Risk Characterization

Risk characterization combines the results of the exposure assessment with the results of the toxicity assessment. The combination of these two results derives quantitative estimates of the potential for adverse health effects as a result of the potential exposures to H-POWER combined ash. The risk characterization estimated the potential for carcinogenic and noncarcinogenic effects for each receptor, and for each potential exposure pathway identified in the exposure assessment. The risks from each exposure pathway are summed to obtain an estimate of total risk.

Because the construction details for landfill closure have not yet been defined, four potential exposure scenarios were identified for the possible use of the ash material in the final cover. These scenarios were:

1. No stockpiling
2. Stockpiling
3. Uncovered
4. Post closure

The first scenario (no stockpiling) assumed that the ash would be delivered to the Waipahu Landfill 5 days per week during daylight hours only. The ash would be spread and compacted and covered with soil at the end of the day. During the nighttime hours the ash would be stored in trailers at the H-POWER facility. At this rate, the landfill infiltration layer would be complete in 3.02 years.

The second scenario (stockpiling) assumed that the ash would be delivered to the Waipahu Landfill 7 days per week during daylight hours. The ash would be continually spread, compacted, and covered with soil during the day. During the night hours the ash would be stored in trailers at H-POWER. On the weekends the ash would also be stockpiled at the landfill. Approximately 269 m^3 (352 yd^3) of ash would accumulate over the weekend. The ash piles would reach a height of about 1.53 m (5 ft.) and cover an area of about 176 m^2 (211 yd^2). At this rate the landfill infiltration layer would be complete in 2.16 years.

The third scenario (uncovered) assumed that the ash would be delivered in the same manner as in the no stockpile scenario. After the ash has been spread and compacted, it would not be covered with soil immediately at the end of each day. At this rate the landfill infiltration layer would be complete in 3.02 years.

The fourth scenario evaluated post closure exposures such as dirt bike racing in the area, fishing along the bank edges, and likely other uses.

The risk assessment assumed that the dust was totally ash-derived, and the worst-case ash-derived metal concentrations were derived from the total metals content of H-POWER combined ash. The risk assessment results were dominated by the assumptions that potential receptors would directly ingest and have dermal contact with H-POWER combined ash using this very conservative approach toward risk assessment. Although risk assessors commonly make such assumptions, construction and landfill workers must adhere to strict requirements under the applicable OSHA standards for arsenic, cadmium, and lead, concerning personal hygiene practices and the use of personal protective equipment. Thus, assuming that workers will violate federal and state OSHA laws is a very health-protective approach to human health risk assessment.

Conclusions of Health Risk Assessment

In all cases, with all receptors and ash use scenarios, estimated blood lead concentrations were less than 25 µg/dL for adult male workers and 10 µg/dL for non workers assumed to be young children or female adults of childbearing age.

The 99th percentile blood lead level was conservatively estimated to be 5.2 µg Pb/dL for on-site workers involved in constructing the final cover (receptor 1). Background exposures accounted for blood lead levels of 1.0 µg /dL for workers, and site exposures accounted for blood lead levels of 5.2 µg/dL. Most of the site exposures resulted from the assumption that workers routinely ingested pure ash. The 99th percentile blood lead levels for the trespassing child when it is assumed that there is ash stockpiling at the landfill (receptor 2) was conservatively estimated to be 3.4 µg Pb/dL. The 99th percentile for a nearby child resident (receptor 3) was conservatively estimated to be 1.9 µg Pb/dL. The 99th percentile blood lead levels for the West Loch recreational user (receptor 4) was conservatively estimated to have a 99th percentile blood lead level of 1.94 µg Pb/dL. Background exposures accounted for blood lead levels of 1.9 µg /dL for children, and site exposures accounted for blood lead levels of 1.5µg /dL or less. Most of the site exposures resulted from the assumption that members of the public routinely ingested pure ash. In the case of the West Loch recreator, almost all of this blood lead level (>99%) is due to background exposures and not to exposures to combined ash.

Estimated noncarcinogenic hazard indices for all receptors were all less than 0.3, which is less than the regulatory level of concern of 1.0. In addition, the estimated daily intake of dioxins and furans were 0.21 pg/kg/day or less of 2,3,7,8-TCDD equivalents for all worker receptors and 0.14 pg/kg/day or less for all members of the public. These values are significantly less than EPA's estimate of the public's average daily intake from background exposures, which is 1-3 pg/kg/day (EPA, 1994).

The maximum estimated excess lifetime cancer risk for the construction worker was conservatively estimated to be 3.0×10^{-6}, and the trespassing child was conservatively estimated to have a maximum lifetime cancer risk of 2.0×10^{-6} assuming the uncovered ash stockpiling scenario. The nearby child resident had a maximum calculated lifetime cancer risk of 1.8×10^{-8}, and the West Loch recreational user had a maximum lifetime cancer risk of 2.0×10^{-6}.

The estimated lifetime cancer risks for all receptors was less than 3×10^{-6}. Most of this risk (56-70%) was due to arsenic, which has been decreasing in TCLP leachates. Thus, all lifetime cancer risks for members of the public are well within EPA's acceptable risk range of 1×10^{-4} to 1×10^{-6} for members of the public. Although EPA's risk range used in the Superfund program is not administratively applicable to the use of H-POWER combined ash in beneficial uses, this risk range is being provided to provide context for the risk assessment results. As a comparison point for worker risks, Travis et al. (1987) found that the individual excess lifetime risk at which federal agencies always acted to reduce worker risk was approximately 4×10^{-3} and the individual excess lifetime risk level considered to be *de minimis* was approximately 1×10^{-4}. Additionally, many OSHA standards are set at exposure levels associated with individual excess lifetime risks in excess of 1×10^{-3}. In fact, if workers were exposed to airborne arsenic at the

HIOSH standard, their lifetime cancer risk would be $4x10^{-2}$. These risk comparisons demonstrate that no adverse health effects are anticipated from the proposed beneficial use.

f. Summary of Task Studies

It is thus concluded that the proposed use of either 100% H-POWER combined ash or a mixture of 90% H-POWER combined ash with 10% Ameron blue coral quarry waste fines for application as the intermediate layer final cover of the Waipahu Landfill closure will:

1. Be a factor of over 100 below the State permeability criterion for this cover layer, thus further protecting the public from the waste material in the landfill.

2. Not be a cover that is subject to the extensive physical shrinkage cracking that Mililani soil experiences, and that has other superior soil engineering properties.

3. Be significantly lower in cost (~$14 million; see Table 2 in Section II (e)) than other competing materials.

4. Satisfy all EPA, OSHA, and state health standards and have no adverse health effects from chemicals in the ash.

Task 2 - H-POWER combined ash used as daily landfill cover at the Waimanalo Gulch Landfill.

a. Background Information on the Waimanalo Gulch Landfill

The Waimanalo Gulch Landfill is a large landfill on the leeward side (west) of Oahu (Appendix D5, Figure 1). It is currently the only legal active MSW landfill on this island and the only ash monofill on any of the Hawaiian Islands. The landfill is owned by the City and is operated by Waste Management Inc. It is fully permitted and complies with all current state and EPA landfill standards. The landfill is divided into two portions, an ash monofill section at the bottom and an MSW section above, each lined and each with run on and runoff controls, as well as monitoring wells to monitor for potential leachate leakage from the lined portion of the landfill. The landfill operates daily from about 7:00 a.m. until 3:30 p.m., and then landfill personnel place about 15-25 cm (6-10 in.) of daily cover over the area where MSW was received during the day. The material used for daily cover can come from several sources, but most is from quarrying operations in the upper portion of the landfill. This material is placed over the MSW and is compacted to restrict the amount of wind-blown MSW, as well as to restrict birds, rats, and other vermin from gaining access to the MSW. It is estimated that about 20%-30% of the volume of the landfill is composed of cover material. Allowing ash to be used for daily cover material will significantly extend the life of the landfill.

b. Study Objectives

This task examines the beneficial use of H-POWER combined ash as daily landfill cover material at the Waimanalo Gulch Landfill. The task investigations were divided into two parts. The first was a field study and demonstration to examine the possibility of using combined ash as an alternate daily cover material. This field study and demonstration had two objectives. One was to determine the operational feasibility of the use of combined ash as daily cover material instead of the native soil materials currently used. The other objective was to gather fugitive dust and metal monitoring data. Such data are needed to determine whether the fugitive dust and airborne metals are created by the whole range of operational activities associated with placing, pushing, and compacting ash in place of natural soils as daily cover materials.

The HDOH approved a written protocol for this test (Appendix D1). The test demonstration involved using H-POWER combined ash as daily cover on the landfill working face for a period of 6 days in July 1996. Air samples were taken 24 hours per day to determine whether exposure to airborne fugitive dust particles from this operation would be a concern when working with ash and as the ash sits overnight.

The second activity of this task was performance of a health risk assessment[5] to ensure that this beneficial use did not have any adverse health effects to landfill workers, the public when using the landfill, or nearby residents.

c. Field Test Methodology and Results

Several ash-specific handling activities were selected for study because they had the greatest potential for generating ash-derived fugitive dust. The monitored activities were:

1. Pushing and compacting fresh MSW on the previous day's alternative daily cover (ADC).

2. Pushing and compacting fresh MSW on MSW.

3. Pushing and compacting H-POWER combined ash on MSW to create the day's ADC.

4. Mining H-POWER combined ash from the ash monofill.

5. Dumping ash at base of working face to be used as ADC.

To monitor fugitive dust concentrations generated during these activities, air samples were collected at various locations in the landfill (Appendix D7). Sampling stations were located on workers, in the cabs of landfill equipment, at landfill locations upwind and downwind of the working face, and in the ash monofill when ash handling work was actually being performed. More than 100 air samples were collected and more than 400 analyses were performed. Separate samples were collected for each specific ash handling activity. In addition to samples taken when landfill employees were working, samples were also collected during the delivery of ash to the landfill from H-POWER, as well as overnight while the landfill was not in operation. A meteorological station was set up near the working face to collect wind speed and direction data. Appendix D details how the daily cover demonstration test was designed and executed.

Air samples were analyzed for concentrations of total and respirable dust, total and respirable metals (including arsenic, barium, chromium, cadmium, lead, nickel, selenium, and silver), respirable crystalline silica, hexavalent chromium, and total mercury (particulate and elemental vapor). Total and respirable dust concentrations ranged from 50 to 1,400 $\mu g/m^3$ and 30 to 840 $\mu g/m^3$, respectively. From 10 samples collected inside equipment cabs, the average ratio of respirable dust to total dust was 0.38. From 30 outdoor ambient samples collected, the average ratio of respirable dust to total dust collected was 0.24. No arsenic, barium, chromium, cadmium, lead, selenium, or silver was detected in any of the total or respirable dust samples collected. Nickel was detected in two total dust samples (at the detection limit of 0.0002 $\mu g/m^3$) but not in any respirable dust samples. Mercury was detected in several samples, but mass balance calculations and the results of a second air monitoring program demonstrated that the mercury detected during the demonstration program was unrelated to the use of H-POWER combined ash as an alternate daily cover material (Appendix D8). No correlation was found between dust levels downwind of the working face and wind speed and direction.

No dust was observed while equipment was running over the alternative daily cover or when alternative daily cover was being constructed.

The use of ash by landfill operators appeared to pose no special problems in use as daily cover material compared to the normal material used. It appeared that the ash penetrated farther into the top layer of the MSW and thus required much more material to obtain a top layer at least 15 cm (6 in.) thick compared to quarry fines.

d. Field Test Conclusions

In this field test task, more than 100 samples were collected and more than 400 chemical analyses were performed. No arsenic, barium, chromium, cadmium, lead, selenium, or silver were found in any of the air samples analyzed. Negligible amounts of nickel were found in two samples. Mercury was detected in several samples, but was found to be unrelated to the H-POWER combined ash. No dust was observed to originate from the ash daily cover. There was no correlation between dust levels and wind speed and direction throughout the demonstration period. From this demonstration it has been determined that H-POWER combined ash is not a significant source of airborne dust when ash is used as a landfill daily cover material. However, in the interest of producing conservative estimates of health risk, worst-case concentrations of metals in respirable dust were derived assuming that the measured respirable dust was all ash derived.

e. Health Risk Assessment Evaluation

The HDOH's chief concern in using H-POWER combined ash as a daily cover was the potential for adverse health effects caused by the constituents in fugitive dust. Compared with normal soils used for daily cover, H-POWER combined ash has higher concentrations of some metals, notably lead.

The City, with the assistance of OEES, completed a detailed health risk assessment to provide further assurance that H-POWER combined ash is a safe material. *Risk Assessment of the Beneficial Use of H-POWER Combined Ash in the Daily Cover of the Waimanalo Gulch Landfill Closure* (January 1997) [5] is the result of this work.

The approach to the health risk assessment for landfill daily cover usage is the same as that outlined in Task 1 for using combined ash as final intermediate cover for the Waipahu Landfill closure. As above, in accordance with the NRC recommendations, the risk assessment was organized into the following four steps:

1. Hazard Identification
2. Toxicity Assessment

3. Exposure Assessment
4. Risk Characterization

Hazard Identification

Compounds of potential concern to human health, detected in H-POWER combined ash, were selected for a quantitative risk assessment. The CPCs include arsenic, barium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and polychlorinated dioxins and furans.

Toxicity Assessment

The risk assessment includes an evaluation of potentially carcinogenic and potentially noncarcinogenic effects. The risk assessment used the most current EPA-verified dose-response criteria. In the case of lead, the risks were evaluated by separately using the California DTSC blood lead model and toxicity benchmarks defined by the CDC and the ATSDR.

Exposure Assessment

For daily cover, the exposures were assessed for daily use of the combined ash. Five types of potential receptors were identified:

1. An on-site worker assumed to be pushing and compacting ash over the previous day's ash cover without the use of PPE.

2. An on-site worker who is responsible for mining the ash that was previously disposed in the ash portion of the landfill who also does not use PPE.

3. An adult female visitor to the landfill who is of childbearing age or is actually pregnant, and who ingests and has dermal contact with ash and inhales on-site dust while at the landfill.

4. A child who accompanies the adult visitor and who resides in the nearby neighborhood southwest of the landfill. It is assumed that this child is exposed to the dust during the day and at night at his or her nearby residence. While at the landfill, the child is assumed to breathe on-site dust, ingest, and dermally contact ash, and ingest and dermally contact leachate from stockpiled ash.

5. Another child who lives in the nearest neighborhood and breathes ash-derived dust at home 24 hours a day and ingests ash assumed to be tracked home by parents who visit the landfill.

Risk Characterization

Risk characterization combines the results of the exposure assessment with the results of the toxicity assessment. The quantitative estimates of the potential for adverse health effects as a result of the potential exposures to H-POWER combined ash are derived from such a combination. The risk characterization estimated the potential for carcinogenic and noncarcinogenic effects for each receptor and for each potential exposure pathway identified in the exposure assessment. The risks from each exposure pathway are summed to obtain an estimate of total risk.

To provide at least 15 cm (6 in.) of compacted daily cover, it was assumed that 46 cm (18 in.) of uncompacted combined ash would need to be spread over an area up to 1,150 m^3 (12,350 ft^2) each day for six days a week. Such a volume of ash is about 460 m^3 (600 yd^3), approximately twice the volume of ash H-POWER produces per day. It is therefore assumed that some of the landfilled ash would need to be mined to provide the additional required amount of cover material.

If current ash delivery practices for combined ash continue, each trailer load will continue to be stockpiled pending placement of the daily cover at the end of the day. This means there will be no incremental increase in exposures over current exposures.

Although no metals were detected in the dust samples, the risk assessment assumed that the dust was totally ash-derived, and the ash-derived metal concentrations were derived from the total metals content of H-POWER combined ash. It was also assumed that the potential receptors would have dermal contact with as well as direct ingestion of H-POWER combined ash. Although risk assessments commonly make such health protective assumptions, construction and landfill workers must adhere to strict OSHA requirements for personal hygiene requirements and practices, including the use of PPE, to control their exposures to arsenic, cadmium, and lead. Thus, assuming that all workers will always violate OSHA hygienic and PPE regulations is a very conservative health protective approach to human health risk assessment.

Conclusions of Health Risk Assessment

In all cases with all receptors and ash use scenarios, estimated blood lead concentrations were less than 25 µg/dL for adult male workers and 10 □g/dL for nonworkers assumed to be young children or women of childbearing age.

The 99th percentile blood lead level was conservatively estimated to be 6.7 µg Pb/dL for on-site workers involved in daily cover and MSW placement activities and 7.3 µg Pb/dL for on-site workers involved in the ash mining activity. Background exposures accounted for blood lead levels of 1.0 µg /dL for adults, and site exposures accounted for blood lead levels of 6.3 µg /dL or less. Most of the site exposures resulted from the assumption that workers routinely ingested pure ash. The 99th percentile blood lead levels for the child identified as receptor 4 was conservatively estimated to be 3.4 µg Pb/dL, and the off-site child identified as receptor 5 was found to have a blood lead level of 1.9 µg Pb/dL. Background exposures accounted for blood lead levels of 1.9 μg /dL for children, and site exposures accounted for blood lead levels of 1.5 μg /dL or less. Most of the site exposures resulted from the assumption that children routinely ingested pure ash. The 99th percentile for the adult pregnant female identified as receptor 3 was conservatively estimated to have an upper 99th percentile blood lead level of 1.8 μg Pb/dL. Almost all the blood lead for receptor 5 is due to background exposures and not exposures to combined ash.

Estimated hazard indices were all less than 0.6, which is less than the regulatory level of concern of 1.0. In addition, the estimated daily intakes of dioxins and furans were 0.30 pg/kg/day or less of 2,3,7,8-TCDD equivalents for all worker receptors and 0.14 pg/kg/day or less for all members of the public. These values are significantly less than EPA's estimate of the public's average daily intake from background exposures, which is 1-3 pg/kg/day (EPA, 1994).

Maximum estimated excess lifetime cancer risk for the on-site worker were conservatively estimated to 3×10^{-5} to 5×10^{-5}, and estimated lifetime cancer risks for adult and child receptors were both 4×10^{-6}. Most of this risk (55-66%) was due to arsenic, which has been decreasing. Although 40-53% of total worker risk was due to inhalation of assumed levels of airborne arsenic, these levels were 700-1500 times less than the HIOSH standard. In addition, all lifetime cancer risks for members of the public are well within EPA's acceptable risk range of 1×10^{-4} to 1×10^{-6} for members of the public. Although EPA's risk range used in the Superfund program may not be administratively applicable to the use of H-POWER combined ash in beneficial uses, this risk range is being provided to provide context for the risk assessment results. As a comparison point for worker risks, Travis et al. (1987) found that the individual excess lifetime risk at which federal agencies always acted to reduce worker risk was approximately 4×10^{-3} and the individual excess lifetime risk level considered to be *de minimis* was approximately 1×10^{-4}. Additionally, many OSHA standards are set at exposure levels associated with individual excess lifetime risks in excess of 1×10^{-3}. In fact, if workers were exposed to airborne arsenic at the HIOSH standard, their lifetime cancer risk would be $4 x10^{-2}$. These risk comparisons demonstrate that no adverse health effects are anticipated from the proposed beneficial use.

f. Summary of Task Studies

It is thus concluded that the proposed use of H-POWER combined ash for application as the daily cover at the Waimanalo Gulch Landfill will:

1. Be a workable daily cover material requiring a greater amount of cover to attain a compacted depth of at least 15 cm (6 in.). This is due to the tendency of the ash to penetrate somewhat into the top layer of the MSW.
2. Extend the life of the MSW portion of the Waimanalo Gulch Landfill by allowing that portion to expand into the area reserved for ash. At the same time, the need for another ash monofill in 10 years will be obviated.

3. Improve the engineering properties of the daily cover. Combined ash, as reported in Section III, Task 1, has been found to have less potential for erosion on the open face of the landfill and less potential for leachate production than quarried soil, which is currently being used for daily cover.

4. Significantly lower costs of the ash monofill by more than $22 million over 15 years, which is the assumed remaining life of the H-POWER facility. About 45% of this saving is due to obviating the need to site a new ash monofill in 10 years.

5. Satisfy all EPA, OSHA, and state health standards and have no adverse health effects from chemicals in the ash to either landfill workers, neighboring residents, or those who come to the landfill to drop off trash.

Up-Ramp to Tipping Floor At H-POWER Paved with Ash-Amended Asphalt

Task 3 - H-POWER combined ash used as partial replacement for natural aggregate in asphalt concrete.

a. Introduction

The purpose of Task 3 is to construct a test road section that incorporates H-POWER combined ash as a partial replacement for the natural aggregate component in asphaltic concrete. The initial efforts involved designing an asphalt mix that incorporated H-POWER combined ash and satisfied State of Hawaii Department of Transportation (HDOT) and City and County of Honolulu specifications for asphaltic concrete pavement. Next, a location for the test road pavement was selected with the approval of the HDOH. The site selected included the up-ramp leading to and the down-ramp from the MSW tipping floor of the H-POWER facility. The above photo shows the ash-amended asphalt on the up-ramp. Note that the light colored material is MSW that has fallen off of trucks. No ash was visible in the asphalt mixture. Detailed plans for this test pavement installation, testing, and monitoring were developed. A sample of typical ash was taken, screened, and tested to ensure that its characteristics were typical of H-POWER ash.

The initial plan was to prepare test asphalt with approximately 8%-10% combined ash substituted for the natural aggregate (Appendix E1). A laboratory test mix was designed that met all specifications for asphaltic cement pavement using an oven-dried sample of combined ash (Appendix E2). Later, however, it was determined that the asphalt batch plant could not produce the asphalt cement with the stockpiled, screened, combined ash because there was high moisture present. A test conducted on April 16, 1998 found that the ash had an initial moisture level of 35%. This moisture level of the stockpiled, screened, combined ash was too high to add into the batch plant and have a usable product. The screened combined ash was allowed to air dry in the storage trailer to reduce the moisture level. On August 18, 1998, three samples from different sections of the screened combined ash pile were taken for moisture testing purposes. The results yielded by these samples indicated that the ash moisture had only been reduced to 25%-30%. This was still more moisture than could be removed in the batch plant even using the maximum heating of the other aggregate in the asphalt mix. The maximum moisture content that could be accommodated with a 10% ash mix was approximately 10%.

Accordingly, a revised mix was developed with the assistance of Grace Pacific using approximately 3% ash instead of 8%-10%. In fact, as noted below, the asphalt as prepared contained 5.5% ash. To prepare for the October 11, 1998 paving, the total amount of ash in the storage trailer was reduced from the initial 11 tons of screened combined ash to 3.08 tons on October 7, 1998. As ash was being loaded into the metering bin at the Grace Pacific facility, a sample was taken for moisture testing. The ash appeared to have dried considerably during the 4 days between October 7, 1998 the date the ash was reduced to 3.08 tons and October 11, 1998 the morning of asphalt production. The moisture content of the ash sample taken on October 11, 1998 was 17.5%.

This would indicate that the ash moisture can be reduced to more usable levels for asphalt production when the ash is allowed to dry in smaller piles. This theory is further supported by an earlier moisture test performed on July 2, 1998. A sample of ash was skimmed off the top of the screened ash pile. This sample of ash was found to have a moisture content of 10.9%. A long-term solution to the problem of producing sufficiently dry ash for asphalt batch plant is currently under investigation, as discussed below.

Two main components make up H-POWER combined ash. The fly ash and bottom ash combine at a ratio of approximately 70% bottom ash and 30% fly ash to make H-POWER combined ash. The moisture levels in the fly ash currently are 18% to 30% as it exits the H-POWER pugmill. Water is added to the fly ash in the pugmill to control fugitive dusting of the combined ash as it is handled at the H-POWER facility and Waimanalo Gulch Landfill. Bottom ash has moisture levels 30% to 45%.

The fly ash is collected dry from the facility's two electrostatic precipitators (ESP) as well as the facility's two spray dry absorbers (SDA). Transported from the ESP and the SDA in enclosed conveying lines, the fly ash is wetted in pugmills before to being combined with the bottom ash portion. The fly ash is a highly absorbent material, and its moisture content can vary greatly. The moisture level of the fly ash is largely dependent on the operator's setting of the water flow to the pugmill.

Bottom ash is wet because of the design of the boilers, because it falls off the traveling grates into a quench water tank. It is then removed from this tank with a traveling submerged scraping conveyor that deposits the saturated ash onto a rubber conveyor belt. The bottom ash is then conveyed to the ash tower, then to the bottom ash metals recovery system (BAMRS). The bottom ash is processed in the BAMRS through two ferrous metals removal magnets, a finger screen to remove oversized objects, a Bivitec screen to screen the ash to 3/8-in., and an eddy current separator to remove nonferrous metals. As this bottom ash exits the BAMRS it contains very few metals of any kind, and the BAMR can be modified so that the inert material all passes through the 3/8-in. screen. This material is then returned to the ash tower where it is mixed with the fly ash that exits the pugmill. The resultant combined ash from this facility thus is smaller than 3/8 in. and contains a great deal of fine material. This moisture content as the facility is presently configured, is 30% to 35%.

If a sufficient market can be developed for the combined ash to be used as an aggregate, bottom and fly ash likely can be combined in some form of mixer where the dry properties of the fly ash, combined with the very wet properties of the bottom ash, will result in a much lower total moisture content in the final combined ash material. However, such a mixing device has not yet been designed or built.

Task 3 involves a number of subtasks to construct the test road. The subtasks include the selection of a test road location, design of the asphalt mix using H-POWER combined ash, construction of the test road, evaluation of leachate quality from the test road, and completion of a health risk assessment to demonstrate that H-POWER combined ash is safe to use as an aggregate component in asphalt concrete. Physical performance monitoring of the test road to ensure that it meets HDOT and City specifications for asphaltic concrete pavement is also included in the proposed studies.

b. Selection of a Test Road Location

Selection of the test road location was a critical subtask. After consideration of several locations, the H-POWER MSW tipping floor up-ramp was selected as the ideal location of the test road for the following reasons:

1. The ramp experiences heavy traffic, 6 days a week, 11 months of the year.

2. Traffic is monitored at the facility's scale house, which will provide accurate records of the total amount and weight of the trucks using the ramp.

3. The ramp requires a repaving of the wearing course.

4. All monitoring and observation of the test road is on the facility's site.

5. The down-ramp will be used as a control, repaving the wearing course with the same asphalt mix using natural aggregate.

Appendix E3 contains detailed drawings of both ramps, and displays the up-ramp, paved with the ash-amended asphalt, and the down-ramp, which is paved with regular asphalt and serves as a control.

c. Design of an Asphalt Mix

As of August 18,1998, the moisture content of three samples taken from the screened ash pile was 25% to 30%. Based on these results, and with the cooperation of Grace Pacific, the test mix was formulated to contain 3% combined ash that is screened to smaller than 1 cm (3/8-in.). This mix design meets or exceeds all HDOT specifications for asphalt concrete pavement.

d. Paving of a Test Road

On October 11, 1998, the up- and down-ramps at the H-POWER MSW tipping floor were paved with a minimum 5-cm (2-in.) thick wearing surface. The 2.8 tonnes (3.08 tons) of screened combined ash was transported from the H-POWER facility to the Grace Pacific facility in an ash storage trailer equipped with a tarp cover to prevent fugitive dust problems. Representatives from H-POWER followed the ash trailer from H-POWER to Grace Pacific. No dusting was observed during transportation.

The ash was dumped from the ash trailer into a front end loader, where it was then dumped into Grace Pacific's metering bin for recycled asphalt. A total of 2.17 tonnes (2.4 tons) of screened combined ash were dumped into the metering bin. The Grace Pacific plant operator ran approximately 0.45 tonnes (0.5 tons) of the screened ash through the heated mixing chamber, and the resulting asphalt was found to have insufficient oil and was deemed too dry for use. The plant operator stopped production at that point and adjusted the flow of oil to the aggregate. The remaining 1.7 tonnes (1.9 tons) of screened combined ash was then fed into the heated mixing chamber with the other standard Grace Pacific aggregates, and production resumed.

The asphalt residue that had insufficient levels of oil was taken to the H-POWER facility in a standard Grace Pacific asphalt truck. Its weight was 12.2 tonnes (13.44 tons). This asphalt residue was taken from the H-POWER facility in an ash trailer and disposed at the Waimanalo Gulch Landfill ash monofill.

A total of 30.1 tonnes (34.17 tons) of ash-amended asphalt were put in place as a wearing topcoat on the up-ramp to the H-POWER tipping floor. Approximately 1.7 tonnes (1.9 tons) of H-POWER screened combined ash at approximately 17.5% moisture content were included in the asphalt that was placed on the up-ramp. This indicates that the asphalt is approximately a 5.5% ash mix. This is a higher level of ash than the design mix was estimated to contain. The higher level of ash proved to be a workable mix in part because its moisture content dropped sharply when the ash was allowed to dry as a smaller pile.

The paving operations were normal in all respects. On the morning of the asphalt paving, Grace Pacific workers swept the pre-existing pavement with heavy-duty brushes. Then they applied a bonding reagent to the surface of the ramp to be paved. (A bonding reagent is normally applied to the pre-existing surface to ensure that the new wearing coat bonds to the foundation.) The ash-amended asphalt was laid in place with a Grace Pacific asphalt laying machine. The asphalt was leveled by hand with the use of leveling scrapers. Then a primary compactor made several passes over the ash-amended wearing coat. A Grace Pacific asphalt kneading machine then made several passes over the asphalt. Several passes were then made by a final compactor. The paving and compaction procedures were duplicated for both the test and control mixes.

Core samples of the control and the ash-amended asphalt were tested to ensure *in-situ* compaction met HDOT specifications. Two core samples from each asphalt type were tested for compaction density. The results of Grace Pacific's testing on these cores are listed in Table 4:

TABLE 4: GRACE PACIFIC SPECIFIC GRAVITY TEST

Sample Number	**Sample Thickness**	**Weight In Air**	**Saturated Weight In Air**	**Weight In Water**	**Bulk Specific Gravity**	**Reference Bulk Specific Gravity**	**Percent of Max. Comp. Density**
#	*inches*	*grams*	*grams*	*grams*	%	*grams*	%
1 ASH	2	889.9	890.8	537	2.515	2.671	94.2
2 ASH	1 ¼	539.1	539.7	328.2	2.549	2.671	95.4
3 REG.	2 5/8	1186.5	1189.7	715.3	2.501	2.742	91.3
4 REG.	3	1310.8	1313.1	789.6	2.504	2.742	91.4

The HDOT specification for asphalt compaction is 91% of maximum theoretical compaction density. The maximum compaction specific gravity of the ash mix was calculated to be 2.671. The maximum compaction specific gravity of the Grace Pacific control mix was calculated to be 2.74. All four asphalt core samples tested were in compliance with HDOT specifications on asphalt compaction density. Photograph documentation of the cores were taken as shown below. As the results of Construction Engineering Labs' engineering tests indicate, fewer voids were visible in the ash-amended cores than in the control cores.

Control Asphalt Cores Taken from Down-Ramp

Ash Amended Asphalt Cores Taken from Up-Ramp

Grace Pacific also conducted CPN Nuclear Field Testing to verify compaction density. Six readings were taken for each mix to further ensure *in-situ* compaction density. The results of the October 11 CPN Nuclear Field Testing are given in Table 5:

TABLE 5: GRACE PACIFIC CPN NUCLEAR FIELD TEST

Location	**Compaction**	**Density**		**Location**	**Compaction**	**Density**
Up-Ramp	*Wet lb/ft³*	*%*		**Down-Ramp**	*Wet lb/ft³*	*%*
Ash	157.3	94.4		Control	156.3	91.5
Ash	158.4	95.0		Control	155.9	91.2
Ash	160.1	96.0		Control	156.4	91.5
Ash	156.5	93.9		Control	156.9	91.8
Ash	157.2	94.3		Control	155.8	91.2
Ash	155.2	93.1		Control	157.1	91.9
Average	157.45	94.5			156.4	91.5

The theoretical maximum compaction densities of the two asphalt mixes were determined by Grace Pacific. The theoretical maximum compaction density of the ash-amended asphalt was found to be 166.7 wet lb/ft³. The theoretical maximum compaction density of the control mix asphalt was found to be 170.9 wet lb/ft³.

Representatives from Construction Engineering Labs were present on the morning of asphalt production. They took samples from both the test and control mixes as the asphalt was loaded from the asphalt silo into the trucks and formed eight cores for engineering tests as well as 30 additional cores for lysimeter (leachate) testing. The cores are 4 in. in diameter and 2-2 ½ in. high. They were compacted by dropping a 10-pound hammer 75 times from a height of 18 in. Thus, a standard compaction energy was applied to all cores. The core preparation followed ASTM testing method D1559. Half these cores were ash-amended and the other half standard asphalt mixes. The results of the engineering tests on the eight cores are listed in Table 6:

TABLE 6: ENGINEERING TESTS ON ASH AND CONTROL MIXES

Sample		**Specific Gravity**				**Mix Properties**				
Location	Mix	Rice	Lab	TSR	Voids	VMA	Voids	Flow	Stability	Oil
		Max	Compacted	(%)	(%)	(%)	Filled	(1/100in.		(%)
Control Mix	4	2.74	2.586	91.3	5.4	18.1	70	12	3547	5.0
			2.599							
			2.594							
			2.593							
Average			*2.593*							
Ash Mix	4	2.67	2.562	87.5	4.1	16.2	74	11	2664	4.8
			2.558							
			2.565							
			2.562							
Average			2.562							

The procedure to determine the specific gravity for the asphalt cores follows the ASTM D2726 test procedure. Rice Max is the specific gravity of a given asphalt mix at its maximum compaction density. The Rice Max and Lab Compaction specific gravity test results indicate that the control mix is a slightly denser material than the ash-amended mix, because the ash is replacing aggregate material that has a higher specific gravity. The control mix was compacted to an average 94.6% of maximum density; the ash-amended mix displayed a 95.9% average compaction density. A higher compaction density in the ash-amended asphalt has been recognized in the drilled core sampling, the nuclear field testing, and in the cores prepared by Construction Engineering Labs.

The number of unfilled spaces in the asphalt core are called voids. The voids test gives a percentage of voids in the compacted asphalt mix in comparison to the theoretical maximum compaction density. The voids test procedures follow the ASTM D2041 test method. Fewer voids were found in the ash mix than in the control mix. This is caused by the ash aggregate's ability to fill voids during asphalt compaction.

An excellent indicator of the ability of the ash to fill voids is the Voids in Mineral Aggregate (VMA) test. This test accounts for the voids that are found in the aggregate. The results of this test indicate that fewer voids are found in the ash aggregate than in the standard Grace Pacific aggregate. The results of the Voids Filled test indicate that the ash aggregate has a better physical ability to fill voids in an asphalt mix. Overall, the ash has a positive effect on reducing voids in the compacted asphalt mix.

The Resistance to Plastic Flow (Flow) test measures the horizontal displacement that occurs when a vertical compression stress is applied to the surface of the core. The Flow test procedures are the same as ASTM test D1559. The horizontal deflection is measured and recorded in units of 1/100 in. Results of this test indicate that the ash has a positive effect in slightly reducing the amount of flow that occurs in the asphalt core.

Stability is a measurement of the asphalt core's strength under compression. The HDOT minimum criterion for stability is 2,000 PSI. The procedures for determining stability follow the ASTM D1559 test method. Both the ash-amended and control mixes surpass HDOT criteria for asphalt stability.

The Tensile Strength Ratio (TSR) test is an indicator of the oil's ability to bond with the aggregate after water penetration and heated drying. The TSR test procedures follow the ASTM D4867 test method. The asphalt core is first immersed in water until a 55% to 80% saturation level is reached. The core is then conditioned at 140□F for 24 hours. The stability of the core is then compared to a core with a similar level of voids. The TSR percentage indicates how much of the original stability the asphalt core withholds.

TABLE 7: SIEVE ANALYSIS FOR ASPHALT AGGREGATE

Sample Information		**Sieve Analysis % Passing**										
Location	Mix	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Control Mix	4		100	90	79	60	38	23	16	12	9	6
Ash Mix	4		100	90	83	63	40	25	18	13	10	8
State Asphalt Mix 4 Specification			100	85-100	72-88	48-66	32-48	21-37	15-27	9-21	6-16	4-10
State Asphalt Mix 4 Ash Tolerance				85-94	72-87	51-65	36-44	21-29	15-21	9-17	6-13	5-9

The Sieve Analysis test gives the particulate size distribution of the aggregates used in asphalt production. The State Asphalt Mix 4 Specification and Tolerance establishes a range for aggregate size distribution used in asphalt. As shown in Table 7, both the control and ash aggregate mixes passed the sieve analysis test. The results indicate that the ash aggregate mix has a larger fraction of smaller particles than the control mix. This explains why fewer voids were observed in the ash-amended asphalt mix than in the control asphalt mix.

e. Evaluation of Leachate Quality

HDOH expressed concerns about the health and environmental impacts of using H-POWER combined ash in road construction. One particular concern is the potential leaching of the metals contained in the ash from the roadway. To address HDOH concerns about leachate quality, the City, in cooperation with OEES, developed a work plan to evaluate the leachate quality from roadway materials containing H-POWER combined ash (Appendix F).

The work plan will perform the following tests to measure total metals, pH, and hardness:

1. Total Metals and Synthetic Precipitation Leachate Procedure on crushed, 3/8-in. sieved asphalt cores.

2. Standard monolith tank test on intact cores, as executed by EPA in the MITE program using distilled water.

3. Surface runoff testing of asphalt:
   Nine-month bimonthly testing period.
   Periodic biological testing for toxicity to aquatic organisms.

4. On-site bench scale tests to simulate long-term weathering (impact of physical deterioration, sunlight, and periodic wetting):
   Nine month testing period.
   Periodic biological testing for toxicity to aquatic organisms.

Down-Ramp Soil Testing

Up-Ramp Soil Testing Area

f. Health Risk Assessment

When leachate quality test results are available, a human health and environmental risk assessment will be performed on the manufacture, use, demolition and disposal of ash-amended asphalt. The risk assessment will be performed in accordance with a scope of work approved by the HDOH.

g. Physical Performance Monitoring

Ash-amended and test asphalt will be observed visually for wear over the lifetime of the pavement to determine the effect of ash on its engineering performance. Failure of either pavement will be documented verbally and photographically if they occur.

Acknowledgments:

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Forrest Hammann, Hawaiian Bitumuls & Paving
Lamont Dahlquist, Honolulu Resource Recovery Venture
Glenn Murata, Honolulu Resource Recovery Venture
Ray Rossetti, Waste Management Inc.
Dr. Leslie Au, Hawaii Department of Health
Gary Siu, Hawaii Department of Health
Hawaii Department of Transportation
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Henry Kitaoka, Grace Pacific
George Komatsu, Grace Pacific
Chris Steele, Grace Pacific
Frank Doyle, City & County of Honolulu
Karen Chung, City & County of Honolulu
Wilma Namumnart, City & County of Honolulu

References:

(1) Colin M. Jones, P.E., R. Michael Hartman, Denton Kort, and Neil Rapues, *Utilization of Ash From Municipal Waste Combustion, Final Report Phase I, NREL Subcontract No. XAR-3-1322*, 1995.

(2) Keith E. Forrester, *State-of-the-Art in Refuse-to-Energy Facility Ash Residue Handling, Reuse, Landfill Design and Management-A Summary, Presented at EPRI Conference on MSW as a Utility Fuel*, October 11-12, 1989, Springfield Mass.

(3) Lee E. Koppelman and Edith G. Tanenbaum, *The Potential for Beneficial Use of Waste-to-Energy Ash*.

(4) Ogden Environmental and Energy Services, *Risk Assessment of the Beneficial Use of H-POWER Combined Ash in the Final Cover for the Waipahu Landfill Closure*, December 18, 1997.

(5) Ogden Environmental and Energy Services, *Risk Assessment of the Beneficial Use of H-POWER Combined Ash in the Daily Cover of the Waimanalo Gulch Landfill*, January 9, 1997.

(6) Travis, C.C. et al. 1987. *Cancer Risk Management*. Environmental Science and Technology 21(5):415-420.

(7) U.S. Environmental Protection Agency. 1994. *Estimating Exposure to Dioxin-Like Compounds.* EPA/600/6-88/005Cb.

Appendix A

TCLP Analysis Data for H-POWER Ash
As Submitted to HDOH

Appendix A

Appendix A contains the complete H-POWER TCLP data for all ash testing conducted from December 1989 through March 1998. These TCLP tests were conducted using an EPA approved sampling technique, and using the EPA approved laboratory procedures for TCLP tests. Table 1 contains the data.

Figures 1 through 8 are plots showing this data on a logarithmic scale. These plots show the computer generated trend analysis. Statistical analysis of this data is also included.

Of great interest here is the downward trend shown for each of these heavy metals with the exception of Barium. We believe this downward trend reflects such a trend in the environment. Hawaii has very little industry. As a consequence, the municipal solid waste and commercial waste collected here and brought to the H-POWER facility should represent a good sampling of the typical household waste from the United States. If this, in fact, is the case, then we can certainly be pleased that the efforts to reduce the amount of these heavy metals used in society, has in fact, been successful in reducing the amount found in the environment. Such efforts as the reduction in the amount of mercury in alkaline batteries and fluorescent lamps has clearly reduced the amount of mercury found in waste. Likewise, the efforts to reduce the lead in paints and other common household materials has proven successful in reducing the lead found in our environment.

TCLP ANALYSIS DATA FOR H-POWER COMBINED ASH AS SUBMITTED TO HDOH

		Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
EPA TCLP STD MG/L		5	100	1	5	5	0.2	1	5
Dec-89		1.64	0.4	0.34	0.005	1.88	0.003	0.64	0.03
Feb-90		1.23	0.21	0.09	0.05	0.64	0.00062	0.42	0.03
Jun-90		1.42	0.06	0.16	0.03	0.4	0.008	0.44	0.03
Jul-90		1.72	0.19	0.16	0.02	1.22	0.00056	0.28	0.02
Aug-90		1.47	1.82	0.23	0.22	1.49	0.001	0.72	0.02
Sep-90		0.77	0.41	0.21	0.04	0.92	0.002	0.35	0.05
Oct-90	**	0.407	1.53	0.017	0.02	0.23	0.003	0.1	0.02
Nov-90		0.28	0.18	0.28	0.04	1.08	0.02	0.08	0.05
Dec-90		0.1	0.07	0.29	0.04	2.73	0.0008	0.04	0.06
Jan-91		0.1	0.09	0.21	0.03	0.54	0.004	0.04	0.03
Feb-91	**	0.2	1.45	0.02	0.02	0.52	0.0008	0.08	0.05
Mar-91		0.07	0.18	0.18	0.03	0.25	0.01	0.05	0.05
Apr-91		0.065	0.042	0.118	0.032	0.0635	0.00095	0.047	0.04
May-91		0.042	0.074	0.102	0.029	0.152	0.0033	0.033	0.016
Jun-91		0.5	8.05	0.142	0.5	0.74	0.00068	0.1	0.5
Jul-91		0.133	0.045	0.117	0.033	0.102	0.002	0.034	0.044
Aug-91	**	0.12	0.88	0.02	0.02	0.33	0.005	0.08	0.19
Sep-91		0.15	0.13	0.12	0.03	0.16	0.0003	0.27	0.03
Dec-91		0.1	0.07	0.24	0.026	0.8	0.0016	0.047	0.018
Mar-92		0.08	0.1	0.08	0.01	0.08	0.00099	0.04	0.02
May-92		0.1	0.25	0.19	0.02	0.181	0.00016	0.1	0.01
Aug-92		0.09	0.12	0.3	0.028	2.08	0.0007	0.06	0.04
Dec-92		0.09	0.106	0.47	0.045	1.73	0.0034	0.0662	0.0392
Mar-93		0.05	0.89	0.23	0.01	0.34	0.00505	0.05	0.04
Jun-93		0.05	0.89	0.21	0.01	0.58	0.0038	0.05	0.05
Sep-93		0.05	1.14	0.01	0.01	0.26	0.00134	0.05	0.05
Dec-93		0.05	0.89	0.05	0.01	0.25	0.0015	0.05	0.05
Mar-94		0.02	0.6	0.076	0.01	0.101	0.001	0.05	0.005
Jun-94		0.02	0.34	0.219	0.011	0.092	0.0018	0.02	0.004
Sep-94		0.02	0.6	0.149	0.007	0.16	0.001	0.02	0.004
Nov-94		0.02	0.57	0.226	0.004	0.08	0.0015	0.02	0.004
Mar-95		0.02	0.75	0.012	0.004	0.12	0.0003	0.02	0.004
May-95		0.02	0.75	0.198	0.005	0.06	0.0015	0.02	0.004
Aug-95		0.03	0.66	0.405	0.024	0.45	0.0006	0.02	0.004
Nov-95		0.02	0.63	0.506	0.004	0.52	0.0005	0.02	0.004
Mar-96		0.02	0.6	0.186	0.025	0.07	0.0012	0.02	0.004
Jun-96		0.02	0.49	0.094	0.007	0.06	0.0006	0.02	0.004
Sep-96		0.02	0.62	0.071	0.01	0.05	0.0005	0.02	0.004
Dec-96		0.02	0.47	0.117	0.004	0.03	0.00056	0.02	0.004
Mar-97		0.021	0.7	0.005	0.004	0.021	0.00026	0.021	0.006
Jun-97		0.036	0.63	0.229	0.02	0.153	0.00084	0.02	0.004
Sep-97		0.021	0.62	0.163	0.018	0.058	0.0004	0.021	0.004
Dec-97		0.021	0.74	0.021	0.004	0.535	0.0006	0.021	0.004
Mar-98		0.021	0.72	0.042	0.004	0.055	0.0003	0.021	0.004
Jul-98		0.022	0.72	0.48	0.008	0.129	0.00054	0.022	0.004
AVERAGE		0.255	0.699	0.173	0.034	0.500	0.002	0.105	0.037
COUNT		45.000	45.000	45.000	45.000	45.000	45.000	45.000	45.000
MIN		0.020	0.042	0.005	0.004	0.021	0.000	0.020	0.004
MAX		1.720	8.050	0.506	0.500	2.730	0.020	0.720	0.500
STDS		0.469	1.195	0.127	0.078	0.620	0.003	0.163	0.077
VARS		0.220	1.427	0.016	0.006	0.384	0.000	0.027	0.006

N.B. STATISTICAL ANALYSIS USES BUILT IN QUATTRO PRO FUNCTIONS FOR GENERATION, AND ASSUMES A GAUSSIAN DISTRIBUTION

** Trimester testing using water leachate per EPA Method SW924

Maximum values of three batches tested as reported in ABB ltr dated 1/31/91

Table 1

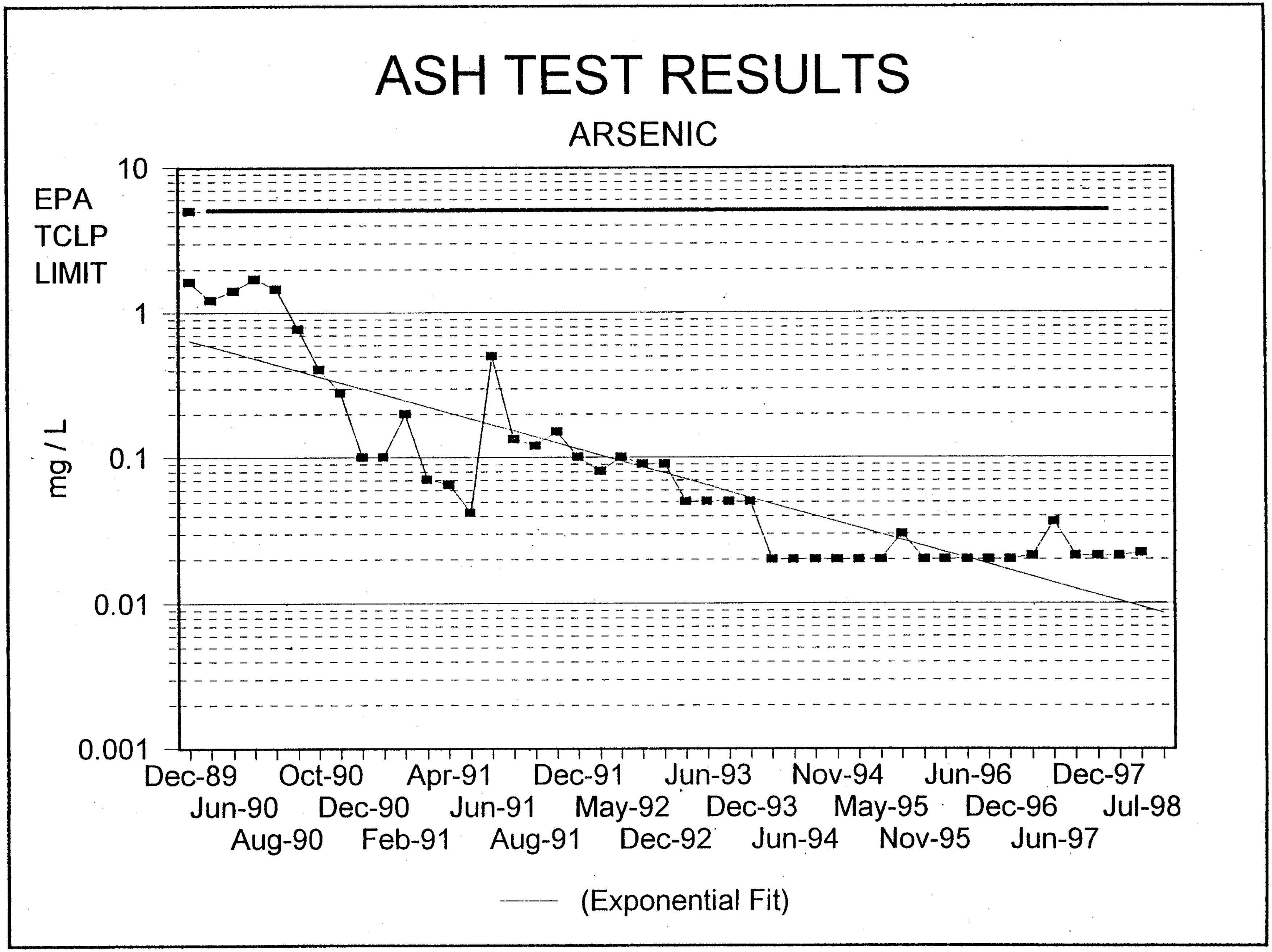

ASH TEST RESULTS
ARSENIC
EPA
TCLP
LIMIT
mg / L
10
1
0.1
0.01
0.001
Dec-89
Jun-90
Aug-90
Oct-90
Dec-90
Feb-91
Apr-91
Jun-91
Aug-91
Dec-91
May-92
Dec-92
Jun-93
Dec-93
Jun-94
Nov-94
May-95
Nov-95
Jun-96
Dec-96
Jun-97
Dec-97
Jul-98
(Exponential Fit)

Figure 1

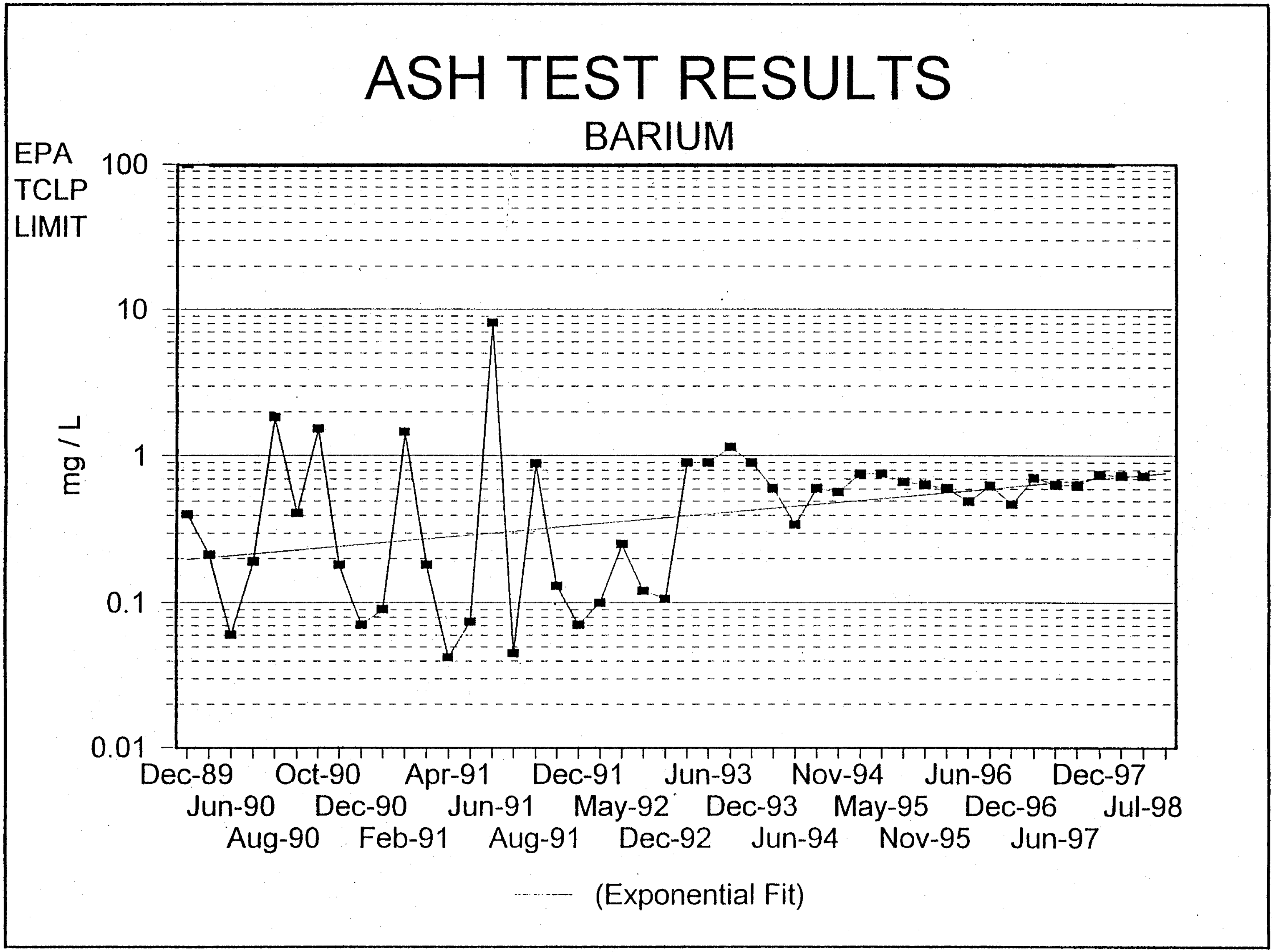

ASH TEST RESULTS
BARIUM
EPA
TCLP
LIMIT
100
10
1
0.1
0.01
mg / L
Dec-89
Jun-90
Aug-90
Oct-90
Dec-90
Feb-91
Apr-91
Jun-91
Aug-91
Dec-91
May-92
Dec-92
Jun-93
Dec-93
Jun-94
Nov-94
May-95
Nov-95
Jun-96
Dec-96
Jun-97
Dec-97
Jul-98
(Exponential Fit)

Figure 2

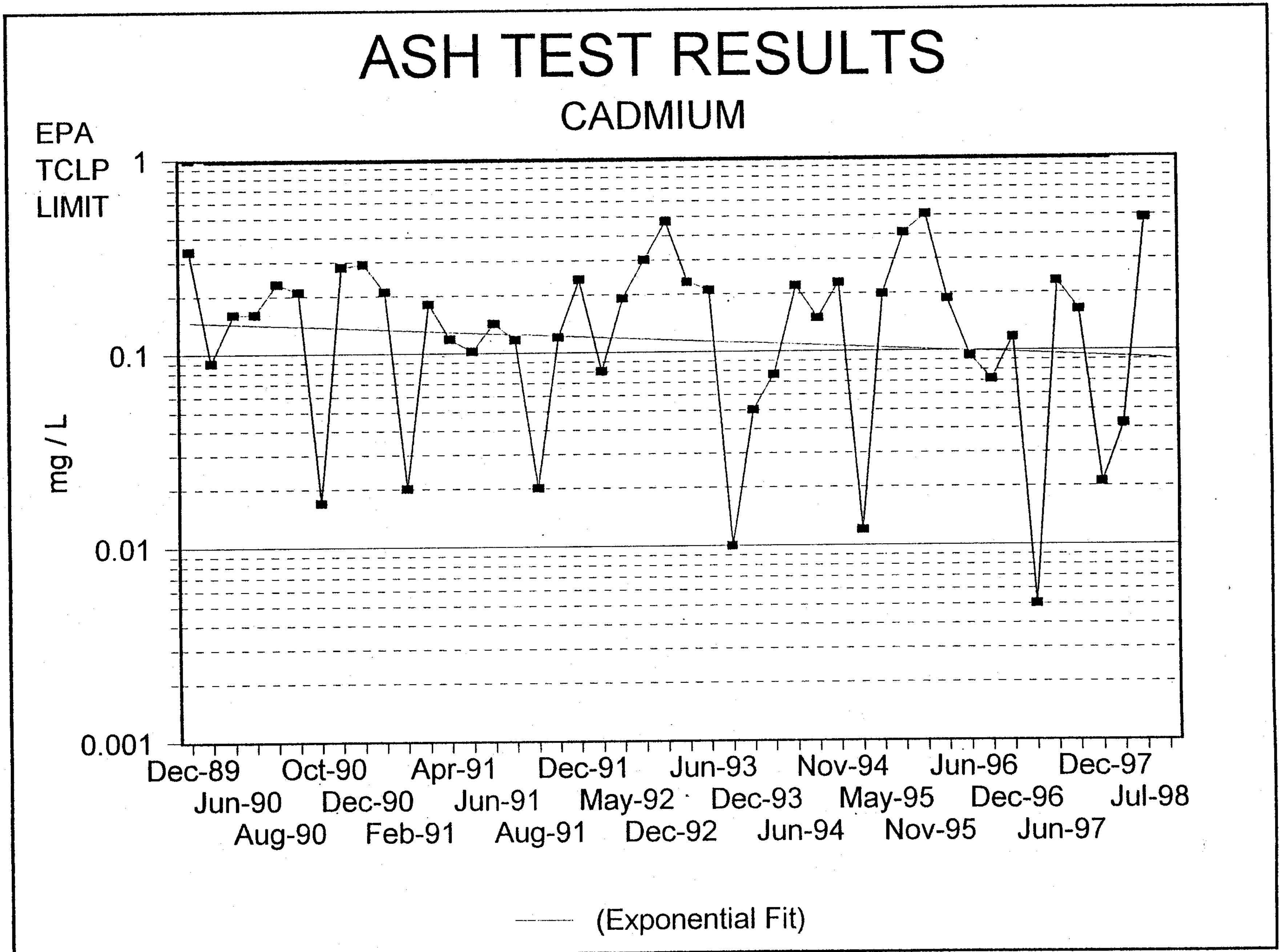

ASH TEST RESULTS
CADMIUM
EPA
TCLP
LIMIT
1
0.1
0.01
0.001
mg / L
Dec-89
Jun-90
Aug-90
Oct-90
Dec-90
Feb-91
Apr-91
Jun-91
Aug-91
Dec-91
May-92
Dec-92
Jun-93
Dec-93
Jun-94
Nov-94
May-95
Nov-95
Jun-96
Dec-96
Jun-97
Dec-97
Jul-98
(Exponential Fit)

Figure 3

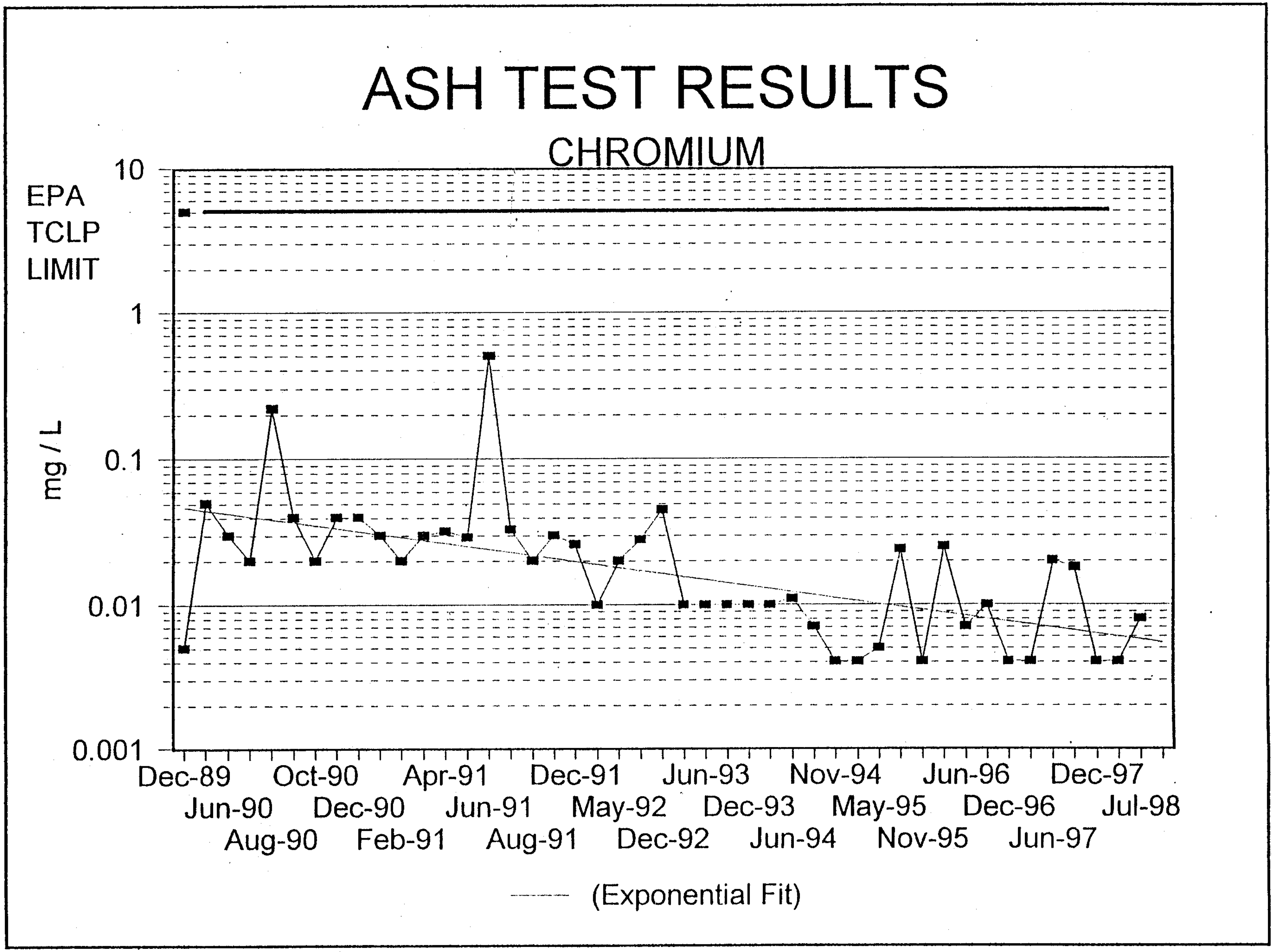
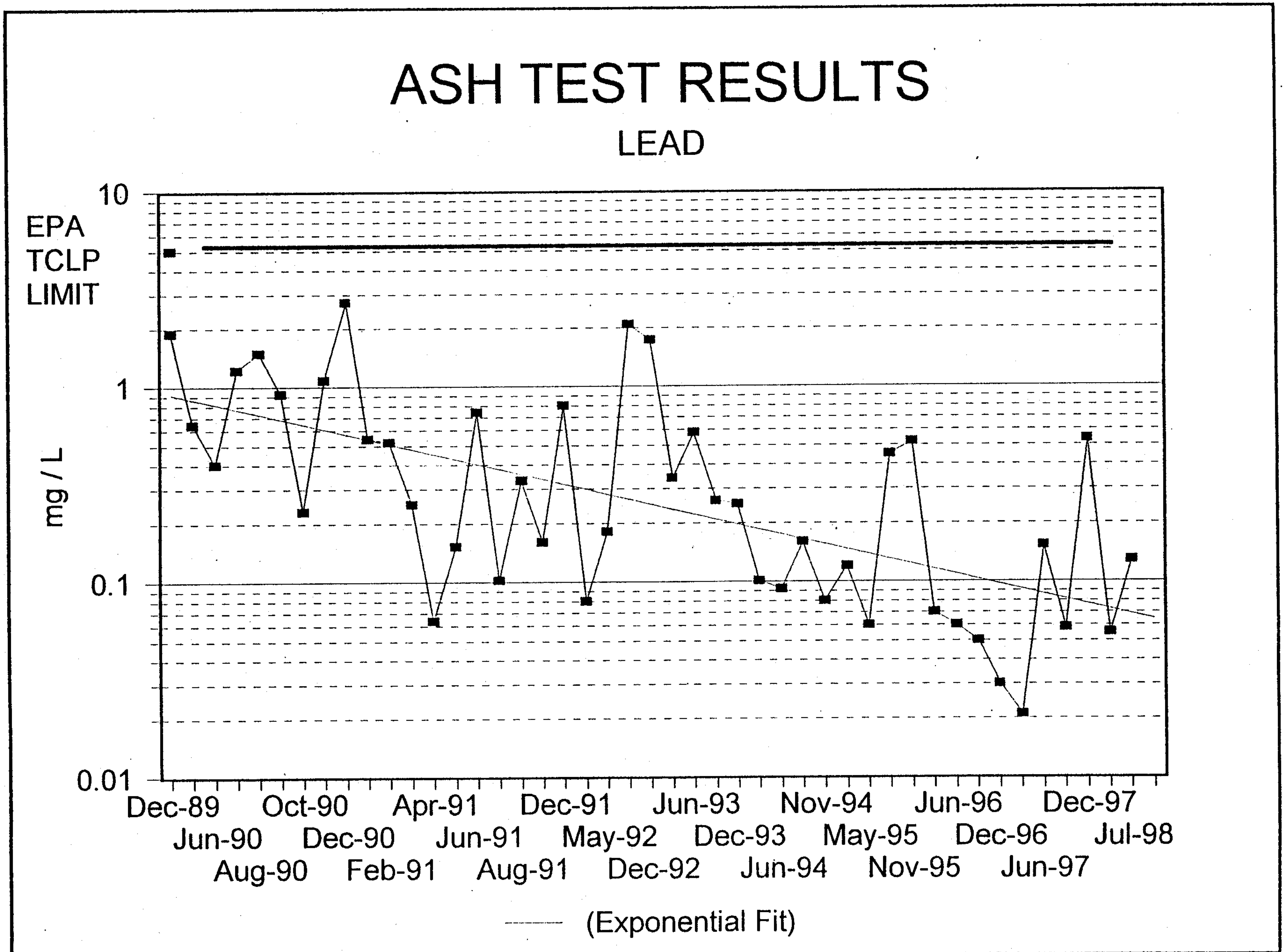
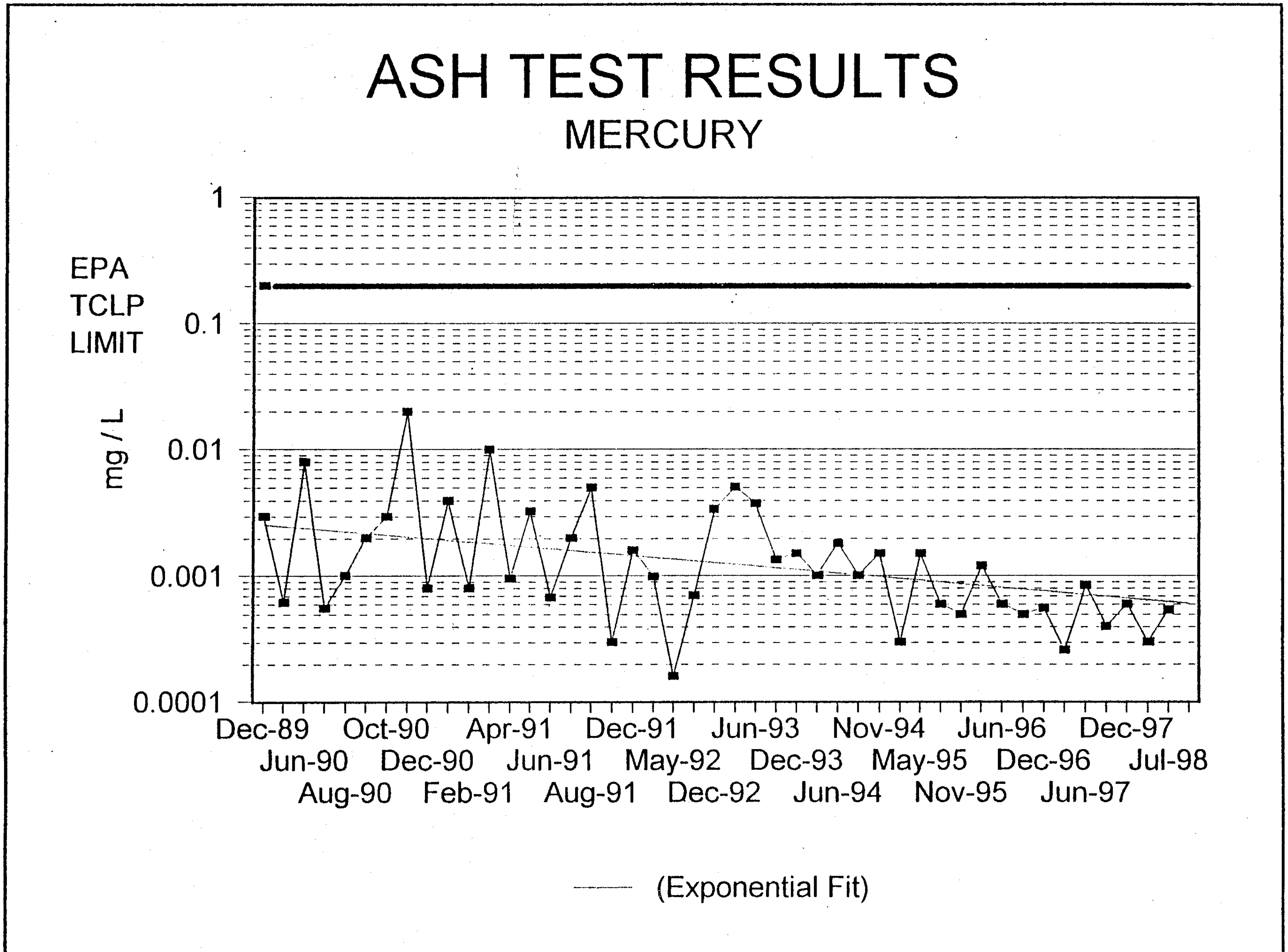

ASH TEST RESULTS
CHROMIUM
EPA
TCLP
LIMIT
mg / L
10
1
0.1
0.01
0.001
Dec-89
Jun-90
Aug-90
Oct-90
Dec-90
Feb-91
Apr-91
Jun-91
Aug-91
Dec-91
May-92
Dec-92
Jun-93
Dec-93
Jun-94
Nov-94
May-95
Nov-95
Jun-96
Dec-96
Jun-97
Dec-97
Jul-98
(Exponential Fit)

Figure 4



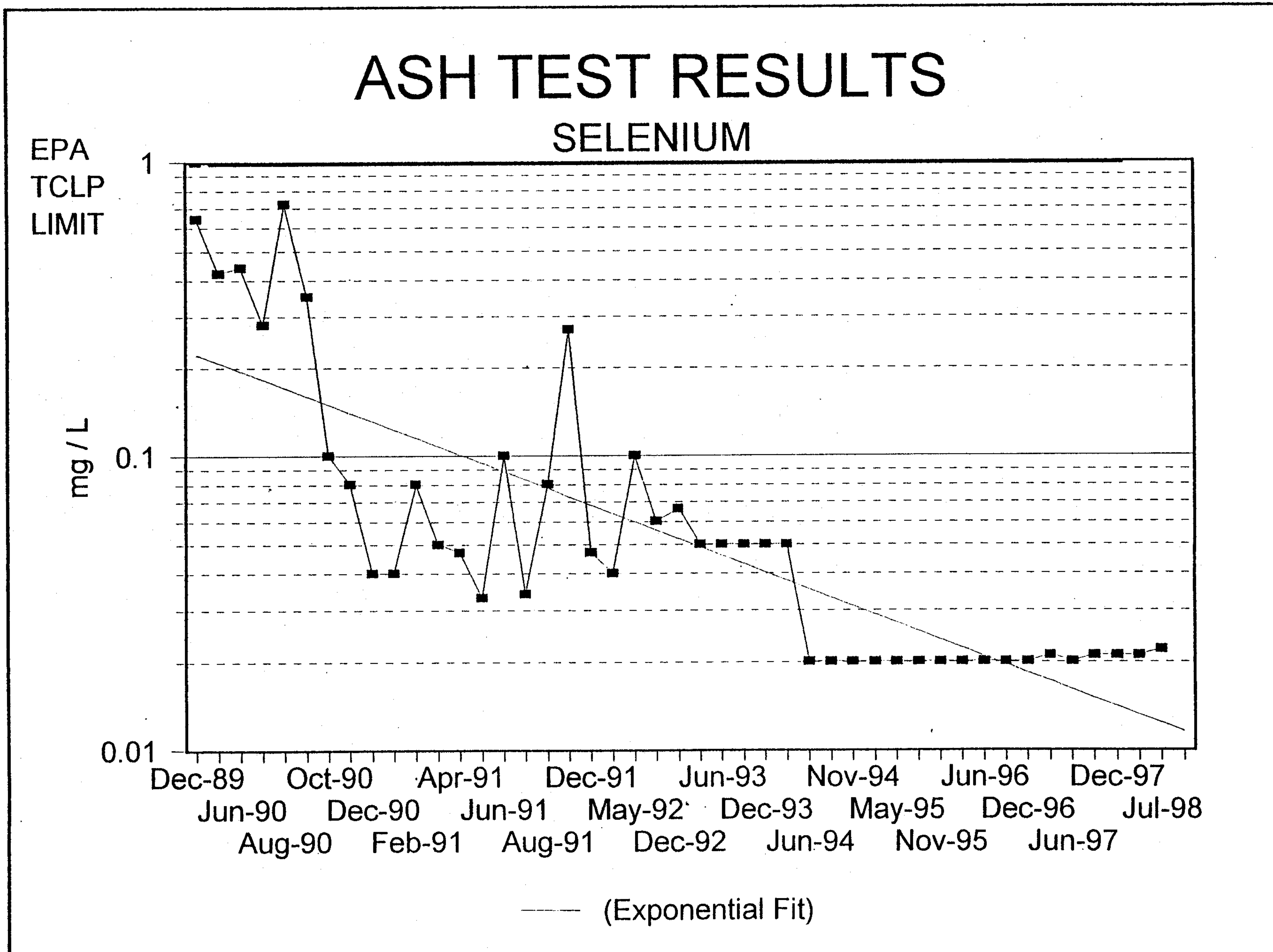
ASH TEST RESULTS
LEAD
EPA
TCLP
LIMIT
mg / L
10
1
0.1
0.01
Dec-89
Jun-90
Aug-90
Oct-90
Dec-90
Feb-91
Apr-91
Jun-91
Aug-91
Dec-91
May-92
Dec-92
Jun-93
Dec-93
Jun-94
Nov-94
May-95
Nov-95
Jun-96
Dec-96
Jun-97
Dec-97
Jul-98
(Exponential Fit)

Figure 5



ASH TEST RESULTS
MERCURY
EPA
TCLP
LIMIT
mg / L
1
0.1
0.01
0.001
0.0001
Dec-89
Jun-90
Aug-90
Oct-90
Dec-90
Feb-91
Apr-91
Jun-91
Aug-91
Dec-91
May-92
Dec-92
Jun-93
Dec-93
Jun-94
Nov-94
May-95
Nov-95
Jun-96
Dec-96
Jun-97
Dec-97
Jul-98
(Exponential Fit)

Figure 6



ASH TEST RESULTS
SELENIUM
EPA
TCLP
LIMIT
1
0.1
0.01
mg / L
Dec-89
Jun-90
Aug-90
Oct-90
Dec-90
Feb-91
Apr-91
Jun-91
Aug-91
Dec-91
May-92
Dec-92
Jun-93
Dec-93
Jun-94
Nov-94
May-95
Nov-95
Jun-96
Dec-96
Jun-97
Dec-97
Jul-98
(Exponential Fit)

Figure 7

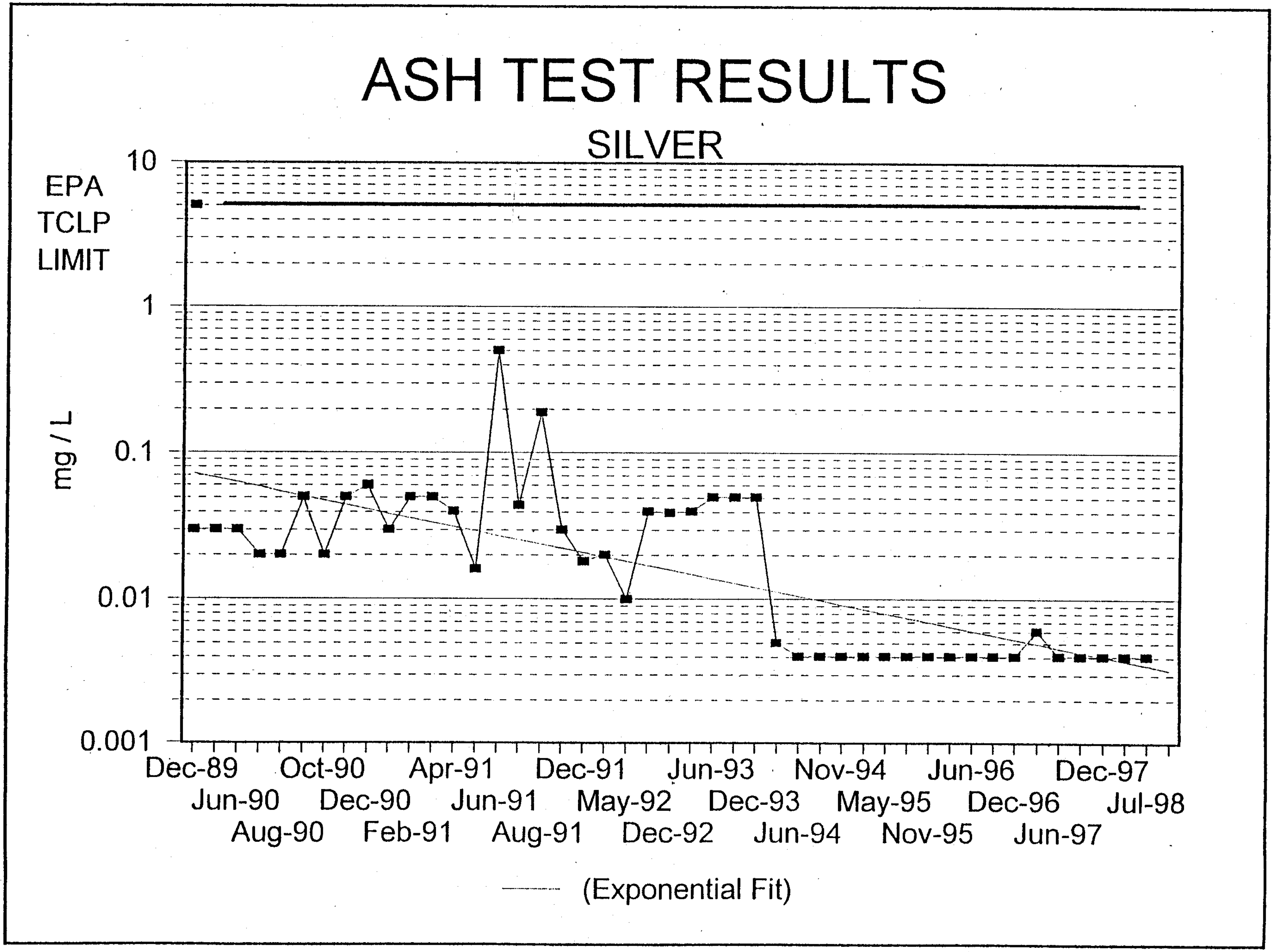

ASH TEST RESULTS
SILVER
EPA
TCLP
LIMIT
mg / L
10
1
0.1
0.01
0.001
Dec-89
Jun-90
Aug-90
Oct-90
Dec-90
Feb-91
Apr-91
Jun-91
Aug-91
Dec-91
May-92
Dec-92
Jun-93
Dec-93
Jun-94
Nov-94
May-95
Nov-95
Jun-96
Dec-96
Jun-97
Dec-97
Jul-98
(Exponential Fit)

Figure 8

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ashtclp.PDW

COLUMN NAME:	ARSENIC
Number of rows:	44
Number of valid points:	44
Number of missing points:	0
Number of negative values:	0
Number of positive values:	44
Number of zero values:	0
Minimum value:	0.020000000
Maximum value:	1.72000000
Inter range value:	1.70000000
Median:	0.057500000
Sum of row value:	11.44700000
Sum of absolute value:	11.44700000
Arithmetic mean:	0.26015909
Geometric mean:	0.079868808
Quadratic mean:	0.53537555
Harmonic mean:	0.041903806
Absolute mean:	0.26015909
Sum of squares:	12.61158700
Variance:	0.22403595
Standard deviation:	0.47332436
Absolute deviation:	0.32252583
Standard error:	0.071356332

95 percent confidence interval:
[0.11625533, 0.40406285]
99 percent confidence interval:
[0.067846488, 0.45247169]

Coefficient of variance:	181.93650642
Skewness:	2.25162493
Coefficient of skewness:	0.40637450
Kurtosis:	3.78393660
Coefficient of Kurtosis:	6.78393660

Percentiles:

10 percentile:	0.020000000
25 percentile:	0.020250000
50 percentile:	0.057500000
75 percentile:	0.14575000
90 percentile:	1.18400000

Quartiles:

First quartile:	0.020250000
Second quartile:	0.057500000
Third quartile:	0.14575000
Inter quartile:	0.12550000

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----Mon Jul 13 11:32:30 1998

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ashtclp.PDW

COLUMN NAME:	BARIUM
Number of rows:	44
Number of valid points:	44
Number of missing points:	0
Number of negative values:	0
Number of positive values:	44
Number of zero values:	0
Minimum value:	0.042000000
Maximum value:	8.05000000
Inter range value:	8.00800000
Median:	0.58500000
Sum of row value:	30.75700000
Sum of absolute value:	30.75700000
Arithmetic mean:	0.69902273
Geometric mean:	0.37351188
Quadratic mean:	1.38406681
Harmonic mean:	0.20234945
Absolute mean:	0.69902273
Sum of squares:	84.28820100
Variance:	1.46019439
Standard deviation:	1.20838504
Absolute deviation:	0.51880372
Standard error:	0.18217090

95 percent confidence interval:
[0.33164010, 1.06640536]
99 percent confidence interval:
[0.20805355, 1.18999190]

Coefficient of variance:	172.86777506
Skewness:	5.47340457
Coefficient of skewness:	-0.46280992
Kurtosis:	33.45394245
Coefficient of Kurtosis:	36.45394245
Percentiles:	
10 percentile:	0.070000000
25 percentile:	0.14250000
50 percentile:	0.58500000
75 percentile:	0.74750000
90 percentile:	1.11500000
Quartiles:	
First quartile:	0.14250000
Second quartile:	0.58500000
Third quartile:	0.74750000
Inter quartile:	0.60500000

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----Mon Jul 13 11:34:55 1998

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ashtclp.PDW

COLUMN NAME:	CADMIUM
Number of rows:	44
Number of valid points:	44
Number of missing points:	0
Number of negative values:	0
Number of positive values:	44
Number of zero values:	0
Minimum value:	0.0050000000
Maximum value:	0.50600000
Inter range value:	0.50100000
Median:	0.16000000
Sum of row value:	7.30500000
Sum of absolute value:	7.30500000
Arithmetic mean:	0.16602273
Geometric mean:	0.11212170
Quadratic mean:	0.20365942
Harmonic mean:	0.051595327
Absolute mean:	0.16602273
Sum of squares:	1.82499500
Variance:	0.014237186
Standard deviation:	0.11931968
Absolute deviation:	0.092206612
Standard error:	0.017988118

95 percent confidence interval:
[0.12974623, 0.20229922]
99 percent confidence interval:
[0.11754291, 0.21450254]

Coefficient of variance:	71.86948425
Skewness:	0.89633385
Coefficient of skewness:	-0.097520661
Kurtosis:	0.90878313
Coefficient of Kurtosis:	3.90878313

Percentiles:

10 percentile:	0.017300000
25 percentile:	0.077000000
50 percentile:	0.16000000
75 percentile:	0.22825000
90 percentile:	0.29900000

Quartiles:

First quartile:	0.077000000
Second quartile:	0.16000000
Third quartile:	0.22825000
Inter quartile:	0.15125000

----Created by Colin M. Jones with PSI-Plot
----Mon Jul 13 11:37:30 1998

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ashtclp.PDW

COLUMN NAME:	CHROMIUM
Number of rows:	44
Number of valid points:	44
Number of missing points:	0
Number of negative values:	0
Number of positive values:	44
Number of zero values:	0
Minimum value:	0.0040000000
Maximum value:	0.50000000
Inter range value:	0.49600000
Median:	0.020000000
Sum of row value:	1.52300000
Sum of absolute value:	1.52300000
Arithmetic mean:	0.034613636
Geometric mean:	0.016561154
Quadratic mean:	0.085379500
Harmonic mean:	0.010754901
Absolute mean:	0.034613636
Sum of squares:	0.32074500
Variance:	0.0062332193
Standard deviation:	0.078950740
Absolute deviation:	0.031486570
Standard error:	0.011902272

95 percent confidence interval:
[0.010610418, 0.058616855]
99 percent confidence interval:
[0.0025357980, 0.066691475]

Coefficient of variance:	228.09143529
Skewness:	5.28401294
Coefficient of skewness:	-0.10112360
Kurtosis:	29.88450235
Coefficient of Kurtosis:	32.88450235

Percentiles:

10 percentile:	0.0040000000
25 percentile:	0.0077500000
50 percentile:	0.020000000
75 percentile:	0.030000000
90 percentile:	0.040000000

Quartiles:

First quartile:	0.0077500000
Second quartile:	0.020000000
Third quartile:	0.030000000
Inter quartile:	0.022250000

----Created by Colin M. Jones with PSI-Plot
----Mon Jul 13 11:40:14 1998

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ashtclp.PDW

COLUMN NAME:	LEAD
Number of rows:	44
Number of valid points:	44
Number of missing points:	0
Number of negative values:	0
Number of positive values:	44
Number of zero values:	0
Minimum value:	0.021000000
Maximum value:	2.73000000
Inter range value:	2.70900000
Median:	0.25000000
Sum of row value:	22.36350000
Sum of absolute value:	22.36350000
Arithmetic mean:	0.50826136
Geometric mean:	0.25298960
Quadratic mean:	0.79951307
Harmonic mean:	0.12918615
Absolute mean:	0.50826136
Sum of squares:	28.12573025
Variance:	0.38974947
Standard deviation:	0.62429918
Absolute deviation:	0.44876446
Standard error:	0.094116643

95 percent confidence interval:
[0.31845706, 0.69806566]
99 percent confidence interval:
[0.25460740, 0.76191533]

Coefficient of variance:	122.83034446
Skewness:	1.93093307
Coefficient of skewness:	0.38376384
Kurtosis:	3.50837232
Coefficient of Kurtosis:	6.50837232

Percentiles:

10 percentile:	0.055300000
25 percentile:	0.083000000
50 percentile:	0.25000000
75 percentile:	0.62500000
90 percentile:	1.46300000

Quartiles:

First quartile:	0.083000000
Second quartile:	0.25000000
Third quartile:	0.62500000
Inter quartile:	0.54200000

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Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ashtclp.PDW

COLUMN NAME:	MERCURY
Number of rows:	44
Number of valid points:	44
Number of missing points:	0
Number of negative values:	0
Number of positive values:	44
Number of zero values:	0
Minimum value:	0.00016000000
Maximum value:	0.020000000
Inter range value:	0.019840000
Median:	0.0010000000
Sum of row value:	0.098010000
Sum of absolute value:	0.098010000
Arithmetic mean:	0.0022275000
Geometric mean:	0.0012100646
Quadratic mean:	0.0040455180
Harmonic mean:	0.00077679496
Absolute mean:	0.0022275000
Sum of squares:	0.00072011350
Variance:	0.00001166968
Standard deviation:	0.0034160913
Absolute deviation:	0.0020021591
Standard error:	0.00051499514

95 percent confidence interval:
[0.0011889133, 0.0032660867]
99 percent confidence interval:
[0.00083953551, 0.0036154645]

Coefficient of variance:	153.35987801
Skewness:	3.80335166
Coefficient of skewness:	0.62790698
Kurtosis:	17.36785075
Coefficient of Kurtosis:	20.36785075

Percentiles:

10 percentile:	0.00030000000
25 percentile:	0.00060000000
50 percentile:	0.0010000000
75 percentile:	0.0027500000
90 percentile:	0.0049000000

Quartiles:

First quartile:	0.00060000000
Second quartile:	0.0010000000
Third quartile:	0.0027500000
Inter quartile:	0.0021500000

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Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ashtclp.PDW

COLUMN NAME:	SELENIUM
Number of rows:	44
Number of valid points:	44
Number of missing points:	0
Number of negative values:	0
Number of positive values:	44
Number of zero values:	0
Minimum value:	0.020000000
Maximum value:	0.72000000
Inter range value:	0.70000000
Median:	0.047000000
Sum of row value:	4.69120000
Sum of absolute value:	4.69120000
Arithmetic mean:	0.10661818
Geometric mean:	0.053245670
Quadratic mean:	0.19435262
Harmonic mean:	0.036521981
Absolute mean:	0.10661818
Sum of squares:	1.66200944
Variance:	0.027019587
Standard deviation:	0.16437636
Absolute deviation:	0.10789421
Standard error:	0.024780668

95 percent confidence interval:
[0.056643202, 0.15659316]

99 percent confidence interval:
[0.039831750, 0.17340461]

Coefficient of variance:	154.17291299
Skewness:	2.52677112
Coefficient of skewness:	0.10000000
Kurtosis:	5.96188700
Coefficient of Kurtosis:	8.96188700
Percentiles:	
10 percentile:	0.020000000
25 percentile:	0.020000000
50 percentile:	0.047000000
75 percentile:	0.080000000
90 percentile:	0.34300000
Quartiles:	
First quartile:	0.020000000
Second quartile:	0.047000000
Third quartile:	0.080000000
Inter quartile:	0.060000000

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Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ashtclp.PDW

COLUMN NAME:	SILVER
Number of rows:	44
Number of valid points:	44
Number of missing points:	0
Number of negative values:	0
Number of positive values:	44
Number of zero values:	0
Minimum value:	0.0040000000
Maximum value:	0.50000000
Inter range value:	0.49600000
Median:	0.020000000
Sum of row value:	1.64820000
Sum of absolute value:	1.64820000
Arithmetic mean:	0.037459091
Geometric mean:	0.016225506
Quadratic mean:	0.085619884
Harmonic mean:	0.0088201873
Absolute mean:	0.037459091
Sum of squares:	0.32255364
Variance:	0.0060654318
Standard deviation:	0.077880882
Absolute deviation:	0.033696074
Standard error:	0.011740985

95 percent confidence interval:
[0.013781139, 0.061137043]
99 percent confidence interval:
[0.0058159380, 0.069102244]

Coefficient of variance:	207.90916191
Skewness:	5.25266281
Coefficient of skewness:	0.17948718
Kurtosis:	30.45780969
Coefficient of Kurtosis:	33.45780969

Percentiles:

10 percentile:	0.0040000000
25 percentile:	0.0040000000
50 percentile:	0.020000000
75 percentile:	0.043000000
90 percentile:	0.050000000

Quartiles:

First quartile:	0.0040000000
Second quartile:	0.020000000
Third quartile:	0.043000000
Inter quartile:	0.039000000

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Appendix B

Total Chemistry Analysis of H-POWER Ash

Appendix B

Appendix B contains the total chemistry analysis of a series of ash samples for heavy metals. This data reflects tests done on the same statistical samples used for the TCLP studies during one year, as well as a few additional samples, and is believed to now present a statistically valid sample for the ash. The Phase I total chemistry testing covered only one grab sample of bottom ash and one grab sample of combined ash. HDOH expressed concerns about the total lead chemistry, particularly samples 2B and 3B, in the Phase I Report. These sub-samples had lead values of 14,748 ppm and 15,809 ppm respectively. Upon review of the Phase I total lead chemistry results, mixtures reported as 2A and 2B were in fact laboratory duplicates of the same sample, yet the reported levels for these laboratory duplicates of the same sample were 828 ppm and 14,748 ppm. Sub-samples 3A and 3B were likewise laboratory duplicates of the same sample and they had results of 3,172 ppm and 15,809 ppm respectively. It was because of this wide spread in the analysis results of duplicates from the laboratory that additional total chemistry analyses were conducted during the Phase II study, and the samples analyzed were the same samples taken for the EPA-required TCLP tests. In addition, the ability to correlate the total chemistry data with the TCLP data might provide useful information.

The following observations regarding the total chemistry analysis included in the Phase I Report require additional interpretation:

1. The trace metal lead concentrations by sieve size for two grab samples, Table 1 in Appendix B2, Phase I Report, shows interesting results. The bottom ash #8 sieve showed a reading of 25,000 ppm. With combined ash, the #16 size showed 5,400 ppm, and the -200 showed 5,500 ppm. While this is interesting, it is not indicative of the total lead in these samples. In reality, drops of lead from solder in electronic circuit boards or other components will show up from time to time, and these drops of solder may well show up as spikes.

2. Lead melts at a temperature of 621^{o} F, and boils at a temperature of 2948^{o} F. Therefore, given the density of lead, the lead is far more likely to end up in the bottom ash than in the precipitator. Further, it is noted that the alloys of lead frequently used in solder, while having slightly lower melting temperatures than pure lead, have higher boiling points.

In 1995 after publication of the Phase I Report, two additional grab samples of combined ash were collected and analyzed. One sample was also fractionated and analyzed. The single reading with high lead levels, a reading of 8,600 mg/kg or ppm, comes from a sieve 16 sub-sample. The aggregate sample from which this came analyzed at 1,400 ppm. Each of these individual sieve samples are not included in the statistical analysis because this is not a correct statistical procedure. The sample from which the individual sieve samples were drawn is included in the statistical analysis, and this sample is referred to as sample A-1.

The high of all the individual lead samples taken from 1995 to date is 5,100 ppm, and the low is 890 ppm. There are a total of 68 separate samples that have been analyzed for lead, representing what must be considered a reasonable statistical sample. A complete statistical description for the lead data is included in this report.

Discussions of this data would be incomplete without mentioning the fact that while these heavy metals may be of concern to society as a whole when found in the environment, the real risks are associated with the compounds of these metals which are in a form that can be absorbed by animal or plant life. Today, as in the past, we continue to use many of these materials safely for many useful purposes. The Risk Assessments conducted in the course of the preparation of this report confirm this conclusion.

TOTAL CHEMICAL ANALYSIS OF H-POWER ASH

H-POWER SAMPLE NO.	TYPE	LAB SAMPLE NO.	CADMIUM mg/Kg	CHROMIUM mg/Kg	Copper mg/Kg	LEAD mg/Kg	NICKEL mg/Kg	SODIUM mg/Kg	Aluminum mg/Kg	ARSENIC mg/Kg	BARIUM mg/Kg	MERCURY mg/Kg	SELENIUM mg/Kg	SILVER mg/Kg	ZINC mg/Kg	%SOLIDS
A-1	03/20/95	2927	13	62		1400	57	18000								98.9%
A-2	03/20/95	2928	15	54		1300	49	15000								98.5%
5	03/20/95	3064	34	63		3400	51	21000								65.0%
6	03/20/95	3065	23	58		1700	72	18000								69.1%
7	03/20/95	3066	29	77		2300	60	20000								68.3%
8	03/20/95	3067	29	60		1800	600	17000								71.3%
9	03/20/95	3068	28	65		1800	58	19000								68.9%
10	03/20/95	3069	27	76		2400	74	22000								69.1%
11	03/20/95	3070	22	69		2100	58	15000								68.4%
12	03/20/95	3071	37	63		4500	88	19000								61.7%
13	03/20/95	3072	21	66		1600	60	16000								67.9%
14	03/20/95	3073	22	61		3100	47	17000								68.4%
15	03/20/95	3074	18	70		5100	49	18000								63.0%
16	03/20/95	3075	23	84		1800	90	18000								60.6%
17	03/20/95	3076	19	67		3800	64	17000								72.8%
18	03/20/95	3077	14	57		1000	51	16000								70.2%
5	06/08/95	7911	20	75		1000	66	17000								70.7%
6	06/08/95	7912	19	65		2200	51	17000								71.5%
7	06/08/95	7913	18	74		1200	62	21000								71.4%
8	06/08/95	7914	26	68		1700	69	17000								67.8%
9	06/08/95	7915	17	77		1200	69	18000								71.2%
10	06/08/95	7916	30	64		2600	73	19000								73.8%
11	06/08/95	7917	11	36		890	39	9800								76.0%
12	06/08/95	7918	10	140		960	50	14000								72.2%
13	06/08/95	7919	28	130		4000	100	20000								79.7%
14	06/08/95	7920	26	72		2100	64	25000								72.3%
15	06/08/95	7921	30	77		1600	56	23000								63.7%
16	06/08/95	7922	24	54		1200	58	17000								68.4%
17	06/08/95	7923	33	73		2300	58	22000								76.1%
18	06/08/95	7924	35	72		2200	96	20000								75.7%
1	09/07/95	8650	37	62		3300	69	24000								72.9%
2	09/07/95	8651	35	78		3800	96	23000								75.6%
3	09/07/95	8652	43	68		3500	70	21000								73.7%
4	09/07/95	8653	34	53		1800	77	18000								71.2%
5	09/07/95	8654	32	43		3200	40	15000								76.2%
6	09/07/95	8655	30	58		2100	67	21000								74.7%
7	09/07/95	8656	38	140		3700	89	26000								73.0%
8	09/07/95	8657	29	61		2900	60	21000								73.4%
9	09/07/95	8658	33	69		2100	85	20000								73.3%
10	09/07/95	8659	36	61		2600	72	26000								73.0%
11	09/07/95	8660	51	62		3800	66	23000								75.7%
12	09/07/95	8661	36	69		3300	91	24000								73.0%
13	09/07/95	8662	32	49		3100	75	19000								75.6%
14	09/07/95	8663	25	47		2200	44	15000								76.2%
1	12/18/95	6865	22	50		1400	57	18000		49	290	9.6	0.5	6		69.80%
2	12/18/95	6866	24	54		1700	51	19000		42	300	8.8	0.5	5		64.10%
3	12/18/95	6867	21	83		2100	61	19000		43	240	8.5	0.6	6		76.20%
4	12/18/95	6868	24	36		1400	41	17000		46	240	8.6	0.8	4		67.50%

TOTAL CHEMICAL ANALYSIS OF H-POWER ASH

H-POWER SAMPLE NO.	TYPE	LAB SAMPLE NO.	CADMIUM mg/Kg	CHROMIUM mg/Kg	Copper mg/Kg	LEAD mg/Kg	NICKEL mg/Kg	SODIUM mg/Kg	Aluminum mg/Kg	ARSENIC mg/Kg	BARIUM mg/Kg	MERCURY mg/Kg	SELENIUM mg/Kg	SILVER mg/Kg	ZINC mg/Kg	%SOLIDS
5	12/18/95	6869	28	47		2100	55	20000		31	270	9.6	0.5	4		78.50%
6	12/18/95	6870	23	48		1200	66	20000		33	290	12	0.7	4		72.90%
7	12/18/95	6871	15	42		890	41	15000		28	260	10	0.5	3		69.70%
8	12/18/95	6872	30	60		2300	51	20000		37	130	11	0.5	7		71.50%
9	12/18/95	6873	25	61		3100	61	18000		77	760	9.4	0.5	5		71.40%
10	12/18/95	6874	21	45		2600	47	15000		44	240	9.4	0.8	7		72.80%
11	12/18/95	6875	25	56		1700	50	22000		52	260	9.1	1.5	6		73.00%
12	12/18/95	6876	39	56		2500	68	18000		47	330	12	1.2	11		71.50%
13	12/18/95	6877	29	46		2200	41	19000		42	290	17	1	9		73.20%
14	12/18/95	6878	24	65		1600	58	20000		34	610	11	0.8	5		68.20%
8	04/03/98		32	51	840	1700	64		30000	69	370	11	0.7	5	2900	
9	04/03/98		22	43	380	1200	41		30000	50	270	8.6	1.1	4	2400	
10	04/03/98		24	41	330	2000	37		20000	53	230	8.5	1.2	3	2100	
11	04/03/98		34	60	510	3400	66		57000	80	410	8.5	1.1	6	3200	
12	04/03/98		20	47	940	1200	53		26000	52	260	8.6	1.6	9	2300	
13	04/03/98		24	53	550	1500	54		33000	68	420	6.2	1.2	6	2100	
15	04/03/98		23	51	670	1500	62		56000	50	260	7.6	0.9	6	2900	
16	04/03/98		25	61	8400	1500	65		32000	55	390	5.2	2.3	7	2400	
17	04/03/98		42	57	3600	2300	74		28000	98	380	8.9	2.8	10	3300	
18	04/03/98		34	60	1500	2300	50		35000	100	470	5.6	1.6	8	3100	
		AVERAGE	26.8	63.6	1772.0	2221.2	69.9	18996.6	34700.0	53.3	332.1	9.4	1.0	6.1	2670.0	0.7
		VAR	62.3	368.9	5722416.0	875431.0	4408.6	9511022.6	134210000.0	362.1	17158.2	5.4	0.3	4.3	190100.0	0.0
		VARS	63.2	374.4	6358240.0	888497.1	4474.4	9677882.6	149122222.2	377.9	17904.2	5.7	0.3	4.5	211222.2	0.0
		STD	7.9	19.2	2392.2	935.6	66.4	3084.0	11584.9	19.0	131.0	2.3	0.6	2.1	436.0	0.1
		STDS	8.0	19.3	2521.6	942.6	66.9	3110.9	12211.6	19.4	133.8	2.4	0.6	2.1	459.6	0.1
		MAX	51	140	8400	5100	600	26000	57000	100	760	17	2.8	11	3300	98.90%
		MIN	10	36	330	890	37	9800	20000	28	130	5.2	0.5	3	2100	60.60%
		COUNT	68	68	10	68	68	58	10	24	24	24	24	24	10	58

TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	CADIMUM
Number of rows:	68
Number of valid points:	68
Number of missing points:	0
Number of negative values:	0
Number of positive values:	68
Number of zero values:	0
Minimum value:	10.00000000
Maximum value:	51.00000000
Inter range value:	41.00000000
Median:	25.50000000
Sum of row value:	1822.00000000
Sum of absolute value:	1822.00000000
Arithmetic mean:	26.79411765
Geometric mean:	25.56683240
Quadratic mean:	27.93269221
Harmonic mean:	24.23263477
Absolute mean:	26.79411765
Sum of squares:	53056.0000000
Variance:	63.24056190
Standard deviation:	7.95239347
Absolute deviation:	6.37024221
Standard error:	0.96436936

95 percent confidence interval:
[24.86922835, 28.71900695]
99 percent confidence interval:
[24.23736235, 29.35087295]

Coefficient of variance:	29.67962437
Skewness:	0.32416753
Coefficient of skewness:	0.34883721
Kurtosis:	0.32341104
Coefficient of Kurtosis:	3.32341104

Percentiles:

10 percentile:	15.20000000
25 percentile:	22.00000000
50 percentile:	25.50000000
75 percentile:	32.75000000
90 percentile:	36.90000000

Quartiles:

First quartile:	22.00000000
Second quartile:	25.50000000
Third quartile:	32.75000000
Inter quartile:	10.75000000

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TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	CHROMIUM
Number of rows:	68
Number of valid points:	68
Number of missing points:	0
Number of negative values:	0
Number of positive values:	68
Number of zero values:	0
Minimum value:	36.00000000
Maximum value:	140.00000000
Inter range value:	104.00000000
Median:	61.00000000
Sum of row value:	4322.00000000
Sum of absolute value:	4322.00000000
Arithmetic mean:	63.55882353
Geometric mean:	61.30689057
Quadratic mean:	66.39742199
Harmonic mean:	59.43621588
Absolute mean:	63.55882353
Sum of squares:	299786.000000
Variance:	374.39947322
Standard deviation:	19.34940498
Absolute deviation:	12.26211073
Standard error:	2.34646002

95 percent confidence interval:
[58.87526974, 68.24237732]
99 percent confidence interval:
[57.33784190, 69.77980516]

Coefficient of variance:	30.44330261
Skewness:	2.32204916
Coefficient of skewness:	0
Kurtosis:	7.45641326
Coefficient of Kurtosis:	10.45641326
Percentiles:	
10 percentile:	43.20000000
25 percentile:	53.00000000
50 percentile:	61.00000000
75 percentile:	69.00000000
90 percentile:	77.00000000
Quartiles:	
First quartile:	53.00000000
Second quartile:	61.00000000
Third quartile:	69.00000000
Inter quartile:	16.00000000

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TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	LEAD
Number of rows:	68
Number of valid points:	68
Number of missing points:	0
Number of negative values:	0
Number of positive values:	68
Number of zero values:	0
Minimum value:	890.00000000
Maximum value:	5100.00000000
Inter range value:	4210.00000000
Median:	2100.00000000
Sum of row value:	151040.000000
Sum of absolute value:	151040.000000
Arithmetic mean:	2221.17647059
Geometric mean:	2037.19821451
Quadratic mean:	2410.19830768
Harmonic mean:	1868.53128529
Absolute mean:	2221.17647059
Sum of squares:	395015800.000
Variance:	888497.102722
Standard deviation:	942.60124269
Absolute deviation:	742.00692042
Standard error:	114.30719078

95 percent confidence interval:
[1993.01836303, 2449.33457815]
99 percent confidence interval:
[1918.12296462, 2524.22997656]

Coefficient of variance:	42.43702629
Skewness:	0.83819285
Coefficient of skewness:	0.094339623
Kurtosis:	0.27162478
Coefficient of Kurtosis:	3.27162478

Percentiles:

10 percentile:	1200.00000000
25 percentile:	1500.00000000
50 percentile:	2100.00000000
75 percentile:	2825.00000000
90 percentile:	3680.00000000

Quartiles:

First quartile:	1500.00000000
Second quartile:	2100.00000000
Third quartile:	2825.00000000
Inter quartile:	1325.00000000

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TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	NICKEL
Number of rows:	68
Number of valid points:	68
Number of missing points:	0
Number of negative values:	0
Number of positive values:	68
Number of zero values:	0
Minimum value:	37.00000000
Maximum value:	600.00000000
Inter range value:	563.00000000
Median:	60.50000000
Sum of row value:	4754.00000000
Sum of absolute value:	4754.00000000
Arithmetic mean:	69.91176471
Geometric mean:	62.38700342
Quadratic mean:	96.41729159
Harmonic mean:	59.48324222
Absolute mean:	69.91176471
Sum of squares:	632148.000000
Variance:	4474.43985953
Standard deviation:	66.89125398
Absolute deviation:	21.57352941
Standard error:	8.11175605

95 percent confidence interval:
[53.72063188, 86.10289753]
99 percent confidence interval:
[48.40571515, 91.41781426]

Coefficient of variance:	95.67953872
Skewness:	7.64044563
Coefficient of skewness:	-0.013333333
Kurtosis:	61.24838143
Coefficient of Kurtosis:	64.24838143
Percentiles:	
10 percentile:	41.00000000
25 percentile:	51.00000000
50 percentile:	60.50000000
75 percentile:	69.75000000
90 percentile:	88.90000000
Quartiles:	
First quartile:	51.00000000
Second quartile:	60.50000000
Third quartile:	69.75000000
Inter quartile:	18.75000000

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TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	SODIUM
Number of rows:	58
Number of valid points:	58
Number of missing points:	0
Number of negative values:	0
Number of positive values:	58
Number of zero values:	0
Minimum value:	9800.00000000
Maximum value:	26000.0000000
Inter range value:	16200.0000000
Median:	19000.0000000
Sum of row value:	1101800.00000
Sum of absolute value:	1101800.00000
Arithmetic mean:	18996.5517241
Geometric mean:	18735.4786112
Quadratic mean:	19245.2591565
Harmonic mean:	18455.8866933
Absolute mean:	18996.5517241
Sum of squares:	21482040000.0
Variance:	9677882.63763
Standard deviation:	3110.92954559
Absolute deviation:	2382.99643282
Standard error:	408.48506151

95 percent confidence interval:
[18178.5744985, 19814.5289498]
99 percent confidence interval:
[17907.9918731, 20085.1115752]

Coefficient of variance:	16.37628550
Skewness:	0.038636775
Coefficient of skewness:	0
Kurtosis:	0.59631311
Coefficient of Kurtosis:	3.59631311

Percentiles:

10 percentile:	15000.0000000
25 percentile:	17000.0000000
50 percentile:	19000.0000000
75 percentile:	21000.0000000
90 percentile:	23000.0000000

Quartiles:

First quartile:	17000.0000000
Second quartile:	19000.0000000
Third quartile:	21000.0000000
Inter quartile:	4000.00000000

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----Mon Jul 13 15:47:11 1998

TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	ARSENIC
Number of rows:	68
Number of valid points:	24
Number of missing points:	44
Number of negative values:	0
Number of positive values:	24
Number of zero values:	0
Minimum value:	28.00000000
Maximum value:	100.00000000
Inter range value:	72.00000000
Median:	49.50000000
Sum of row value:	1280.00000000
Sum of absolute value:	1280.00000000
Arithmetic mean:	53.33333333
Geometric mean:	50.36907706
Quadratic mean:	56.62670159
Harmonic mean:	47.79532058
Absolute mean:	53.33333333
Sum of squares:	76958.0000000
Variance:	377.88405797
Standard deviation:	19.43924016
Absolute deviation:	14.47222222
Standard error:	3.96801828

95 percent confidence interval:
[45.12486214, 61.54180453]
99 percent confidence interval:
[42.19377402, 64.47289264]

Coefficient of variance:	36.44857530
Skewness:	1.14250514
Coefficient of skewness:	0.34065934
Kurtosis:	0.81523295
Coefficient of Kurtosis:	3.81523295
Percentiles:	
10 percentile:	31.20000000
25 percentile:	42.00000000
50 percentile:	49.50000000
75 percentile:	64.75000000
90 percentile:	79.70000000
Quartiles:	
First quartile:	42.00000000
Second quartile:	49.50000000
Third quartile:	64.75000000
Inter quartile:	22.75000000

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----Mon Jul 13 15:48:39 1998

TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	BARIUM
Number of rows:	68
Number of valid points:	24
Number of missing points:	44
Number of negative values:	0
Number of positive values:	24
Number of zero values:	0
Minimum value:	130.00000000
Maximum value:	760.00000000
Inter range value:	630.00000000
Median:	290.00000000
Sum of row value:	7970.00000000
Sum of absolute value:	7970.00000000
Arithmetric mean:	332.08333333
Geometric mean:	311.26357957
Quadratic mean:	356.98389319
Harmonic mean:	293.24877245
Absolute mean:	332.08333333
Sum of squares:	3058500.00000
Variance:	17904.1666667
Standard deviation:	133.80645226
Absolute deviation:	96.11111111
Standard error:	27.31312769

95 percent confidence interval:
[275.58182403, 388.58484264]
99 percent confidence interval:
[255.40621537, 408.76045130]

Coefficient of variance:	40.29303456
Skewness:	1.78314186
Coefficient of skewness:	0.52941176
Kurtosis:	3.98299361
Coefficient of Kurtosis:	6.98299361

Percentiles:

10 percentile:	231.00000000
25 percentile:	260.00000000
50 percentile:	290.00000000
75 percentile:	387.50000000
90 percentile:	465.00000000

Quartiles:

First quartile:	260.00000000
Second quartile:	290.00000000
Third quartile:	387.50000000
Inter quartile:	127.50000000

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----Mon Jul 13 15:52:20 1998

TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	MERCURY
Number of rows:	68
Number of valid points:	24
Number of missing points:	44
Number of negative values:	0
Number of positive values:	24
Number of zero values:	0
Minimum value:	5.20000000
Maximum value:	17.00000000
Inter range value:	11.80000000
Median:	9.00000000
Sum of row value:	225.70000000
Sum of absolute value:	225.70000000
Arithmetic mean:	9.40416667
Geometric mean:	9.15272190
Quadratic mean:	9.67369716
Harmonic mean:	8.90976651
Absolute mean:	9.40416667
Sum of squares:	2245.93000000
Variance:	5.36563406
Standard deviation:	2.31638383
Absolute deviation:	1.54687500
Standard error:	0.47282987

95 percent confidence interval:
[8.42604356, 10.38228977]
99 percent confidence interval:
[8.07677450, 10.73155883]

Coefficient of variance:	24.63146299
Skewness:	1.32182788
Coefficient of skewness:	0.55555556
Kurtosis:	4.27866103
Coefficient of Kurtosis:	7.27866103

Percentiles:

10 percentile:	6.24000000
25 percentile:	8.50000000
50 percentile:	9.00000000
75 percentile:	10.75000000
90 percentile:	11.90000000

Quartiles:

First quartile:	8.50000000
Second quartile:	9.00000000
Third quartile:	10.75000000
Inter quartile:	2.25000000

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----Mon Jul 13 15:54:21 1998

TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	SELENIUM
Number of rows:	68
Number of valid points:	24
Number of missing points:	44
Number of negative values:	0
Number of positive values:	24
Number of zero values:	0
Minimum value:	0.50000000
Maximum value:	2.80000000
Inter range value:	2.30000000
Median:	0.85000000
Sum of row value:	24.90000000
Sum of absolute value:	24.90000000
Arithmetic mean:	1.03750000
Geometric mean:	0.91194312
Quadratic mean:	1.18690775
Harmonic mean:	0.81600195
Absolute mean:	1.03750000
Sum of squares:	33.81000000
Variance:	0.34679348
Standard deviation:	0.58889174
Absolute deviation:	0.43541667
Standard error:	0.12020702

95 percent confidence interval:
[0.78883283, 1.28616717]
99 percent confidence interval:
[0.70003854, 1.37496146]

Coefficient of variance:	56.76064938
Skewness:	1.58403432
Coefficient of skewness:	0.037037037
Kurtosis:	2.67398071
Coefficient of Kurtosis:	5.67398071

Percentiles:

10 percentile:	0.50000000
25 percentile:	0.52500000
50 percentile:	0.85000000
75 percentile:	1.20000000
90 percentile:	1.60000000

Quartiles:

First quartile:	0.52500000
Second quartile:	0.85000000
Third quartile:	1.20000000
Inter quartile:	0.67500000

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----Mon Jul 13 15:57:18 1998

TOTAL CHEMISTRY RESULTS

Descriptive Statistics Report
Data File Name: G:\PSIPLOTW\Ash2.PDW

COLUMN NAME:	SILVER
Number of rows:	68
Number of valid points:	24
Number of missing points:	44
Number of negative values:	0
Number of positive values:	24
Number of zero values:	0
Minimum value:	3.00000000
Maximum value:	11.00000000
Inter range value:	8.00000000
Median:	6.00000000
Sum of row value:	146.00000000
Sum of absolute value:	146.00000000
Arithmetic mean:	6.08333333
Geometric mean:	5.74090674
Quadratic mean:	6.42910051
Harmonic mean:	5.41348978
Absolute mean:	6.08333333
Sum of squares:	992.00000000
Variance:	4.51449275
Standard deviation:	2.12473357
Absolute deviation:	1.61111111
Standard error:	0.43370942

95 percent confidence interval:
[5.18613703, 6.98052963]
99 percent confidence interval:
[4.86576539, 7.30090128]

Coefficient of variance:	34.92712722
Skewness:	0.68251748
Coefficient of skewness:	-0.27272727
Kurtosis:	0.0050054318
Coefficient of Kurtosis:	3.00500543
Percentiles:	
10 percentile:	3.10000000
25 percentile:	4.25000000
50 percentile:	6.00000000
75 percentile:	7.00000000
90 percentile:	9.00000000
Quartiles:	
First quartile:	4.25000000
Second quartile:	6.00000000
Third quartile:	7.00000000
Inter quartile:	2.75000000

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----Mon Jul 13 15:58:40 1998

TOTAL POLYCHLORINATED DIOXIN AND FURAN DATA

H-POWER combined ash has been routinely analyzed for 2,3,7,8-TCDD and 2,3,7,8-TCDF. Use of these data in risk assessment, however, could underestimate the total 2,3,7,8-TCDD Toxic Equivalent (TCDD-TE) concentration, because other congeners of interest might be present. Accordingly, it was arranged to have Triangle Laboratories analyze two recent ash samples for all dioxin and furan congeners. The following tables show the historical and the current dioxin and furan data.

The TCDD-TE concentration for all samples except the most recent two samples is based on 2,3,7,8-TCDD and 2,3,7,8-TCDF. As noted in the table, the mean TCDD-TE concentration is 159 parts per trillion (ppt) and the upper 95% confidence interval of the mean is 557 ppt. The mean of the two samples for which total congener analyses were performed is 426 ppt. This value was used in the risk assessments for Waipahu Landfill and Waimanalo Gulch Landfill.

Calculation of TCDD Toxic Equivalent Concentrations (TCDD-TE) for Two Ash Samples
H-POWER Risk Assessment: Waipahu Landfill and Waimanalo Gulch Landfill

TCDD Congener	TEF	Combined Ash Results (12/9/95) (ppt)	Combined Ash TCDD-TE (ppt)	Combined Ash Results (8/22-25/95) (ppt)	Combined Ash TCDD-TE (ppt)		
2378 TCDD	1	33.4	33.4	28.1	28.1		
12378-PeCDD	0.5	107	53.5	116	58		
123478-HxCDD	0.1	76.8	7.68	71.1	7.11		
123678-HxCDD	0.1	133	13.3	80.6	8.06		
123789-HxCDD	0.1	153	15.3	99.8	9.98		
1234678-HpCDD	0.01	648	6.48	489	4.89		
OCDD	0.001	632	0.632	478	0.478		
2378 TCDF [1]	0.1	263	26.3	189	18.9		
12378-PeCDF	0.05	322	16.1	250	12.5		
23478-PeCDF	0.5	373	186.5	326	163		
123478-HxCDF	0.1	520	52	399	39.9		
123678-HxCDF	0.1	250	25	192	19.2		
234678-HxCDF	0.1	195	19.5	150	15		
123789-HxCDF	0.1	14.3	1.43	15.3	1.53		
1234678-HpCDF	0.01	395	3.95	350	3.5		
1234789-HpCDF	0.01	52	0.52	55.6	0.556		
OCDF	0.001	85.4	0.0854	69.7	0.0697		
Total (ppt)			462		391	426	Average

Notes:
1. Concentrations shown represent results obtained from the DB-225 column used in the analysis.

Calculation of TCDD Toxic Equivalent Concentrations (TCDD TE) from 2,3,7,8-TCDD and 2,3,7,8-TCDF Data
H-Power Risk Assessment: Waipahu Landfill and Waimanalo Gulch Landfill

Sample Date	2,3,7,8-TCDD (ppt)	2,3,7,8-TCDF[1] (ppt)	TCDD TE [2] (ppt)
4/10/92	105	478.4	153
7/23/92	116	527	169
10/25/92	139	522	191
6/17/93	19.4	68.1	26
4/14/93	93.8	483.6	142
11/23/93	28	157.6	44
10/04/93	112	507	163
7/01/94	50.7	339	85
4/06/94	39.4	280	67
9/21/94	74.9	384	113
11/23/94	231	1006	332
3/16/95	2.7	15.5	4
6/05/95	22.6	148.2	37
9/1/95[3]	28.1	189	391
1/96[3]	33.4	263	462
Summary Statistics Using TCDD TEs (ppt)			
MIN:	4	**Lognormal UCL[4]**	
MED:	142	Transformed Data Mean:	4.591
MAX:	462	Transformed Data SD:	1.210
AVG:	159	H Statistic:	3.096
STD:	137	95% UCLM:	557
VAR:	18753		
COUNT:	15		

Notes:
1. Results for 2,3,7,8-TCDF for 4/94, 7/94, 9/94, 8/95, and 1/96 are DB-225 results. Results for other dates are estimated DB-225 results derived from the average DB-5/DB-225 ratio for H-Power ash, which is 0.26.
2. TCDD-TE calculated assuming a TE of 1.0 for 2,3,7,8-TCDD and 0.1 for 2,3,7,8-TCDF.
3. TCDD-TE calculated for all congeners; see Table 2-6.
4. 95% upper confidence limit on the mean calculated in accordance with USEPA guidance, assuming a lognormal distribution.

Appendix C

Engineering Soil Tests on H-POWER Ash Mixtures for Potential Use as a Landfill Cover (September 1995)

Engineering Soil Tests on H-Power Ash Mixtures for Potential Use as a Landfill Final Cover

University of Hawaii

Department of Civil Engineering

Maureen T. Lee

Peter G. Nicholson

Report Prepared for

The City & County of Honolulu

Refuse Department

Under P.O.# AM23734, AV4804, and AV4805

September 1995

EXECUTIVE SUMMARY

In June of 1995, the University of Hawaii completed a preliminary study for the City & County of Honolulu (City) which included engineering soil tests on H-Power Ash mixtures for potential use as a landfill final cover. Due to testing procedures, initial results were conservative. The preliminary test results showed that the ash from the H-Power waste-to-energy facility on the island of Oahu, mixed with quarry waste fines from Ameron HC&D was the best candidate, of a variety of mixtures tested, for use as an alternative to natural soil for the Waipahu ash landfill final cover material. Further testing was requested by the City to better quantify and identify the best ratio of the mixture.

The study included engineering tests performed on four material "blends" of which two were mixtures of ash with quarry fines from Ameron HC&D. The ratios of the two ash-quarry fines mixtures were 80% ash - 20% waste fines and 90% ash - 10% waste fines. Identical tests were also performed on 100% ash and a baseline natural soil that has been proposed for the landfill cover. The baseline soil used was from Mililani and is one of the most abundant and accessible Hawaiian soils, a red-brown lateritic silt, which is currently being excavated throughout Oahu in the development of previous sugar and pineapple fields. This material has been proposed as a landfill construction material.

Tests were performed to quantify permeability, strength, and characterize swell and cracking potential. Procedures used were chosen to reflect field conditions. Relative comparisons were made to determine the best suited material for the landfill cover. Results showed that all materials tested qualified for the landfill cover, although some attributes made certain materials more attractive.

Of all material tested, the 90% H-Power ash -10% Ameron waste fines mixture proved to be the most viable alternative to the natural baseline soil. Both the mix and natural soil had a permeability of $2x10^{-8}$ cm/sec; however, the ash mixture tested stronger and appeared to have a lesser tendency for serious shrinkage cracking. Considering economics and the recycling potential, along with some superior properties, the ash mixture appears to be the best material for the Waipahu ash landfill final cover material.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

In June, 1995, a study was conducted by the University of Hawaii under direction from the City & County of Honolulu, to analyze potential materials including Municipal Solid Waste (MSW) ash for potential use as the bottom layer of the final cover of the Waipahu ash landfill. The study included engineering tests performed on mixtures of ash with two different quarry fines and two different mix ratios. The two quarry fines were from Grace Pacific Corporation and Ameron HC&D. The ratios were 80% ash - 20% waste fines and 50% ash - 50% waste fines. Identical tests were also performed on a baseline natural soil that has been proposed for the landfill cover.

The ash used in the study consisted of 60% ¼-inch screened bottom ash and 40% fly ash by dry weight. This mixture was intended to represent approximate proportions of the ash produced at H-Power. All ash material was air dried. The bottom ash was weighed (60% of total), sieved on the No. 4 sieve (4.75 mm), and then mixed with the fly ash. Standards require tests be performed on soils with grain size less than 4.75 mm. One batch of the ash mixture was made and used for all subsequent tests.

The quarry fines used in the study came from two different quarries operated by Grace Pacific Corporation, and Ameron HC&D. The Grace Pacific fines are wastes from the sieving of dredged coral and appear tan in color and are granular. The material is non-plastic and classifies as SP-SM under the Unified Soil Classification System (USCS). The Ameron fines appear gray in color with almost a powder-like fineness. The Ameron fines are by-products from the crushing and grading of quarried "blue rock." Grain size analyses were performed on both materials. The Ameron fines were determined to be a fine silt with a plasticity index of 2.6, and can be classified as ML under USCS.

The natural soil from Mililani used in the study is one of the most abundant and accessible Hawaiian soils, that has been tested extensively as reported by Hee (1995), and Anderson and Hee (1995). It is a red-brown lateritic silt, with a clay content comprised principally of Kaolinite and halloysite, typically with a ML or MH USCS designation (Anderson and Hee, 1995).

Results showed that each of the ash mixtures tested met technical requirements for the final landfill cover material and that the Ameron waste fines mixture appear to be the most promising alternate material. A summary of results from the previous study is listed in Table 1.

Table 1. Summary of Preliminary Test Results

	Compaction		Permeability		Shear Strength	
Mixture	γ_{dmax}	ω_{opt}	k	Vertical Pressure	ϕ	c
	kg/m^3 *(lb/ft^3)*	%	cm/sec *(ft/min)*	kPa *(psi)*	degrees	kPa *(psi)*
80-20 GP	1448.0 *(90.4)*	23.0	1.1×10^{-6} *(2.2×10^{-6})*	1.23 *(0.18)*	40	66.9 *(9.7)*
50-50 GP	1544.1 *(96.4)*	20.0	6.6×10^{-6} *(1.3×10^{-5})*	1.25 *(0.18)*	40	40.4 *(5.9)*
50-50 AM	1617.8 *(101.0)*	18.0	6.5×10^{-7} *(1.3×10^{-6})*	1.25 *(0.18)*	32	33.9 *(4.9)*
Mililani Soil	1497.7 *(93.5)*	31.5	1.0×10^{-6} *(2.0×10^{-6})*	9.94 *(1.44)*	36	54.3 *(7.9)*

GP = Grace Pacific waste fines
AM = Ameron waste fines

However, test procedures conducted during preliminary studies led to conservative results, using relatively low densities, and producing the upper bounds of permeabilities. Therefore, the city requested further testing on the most promising of ash combinations with the Ameron waste fines which may have potential as a good alternative to the baseline natural soil for the landfill final cover. The selected mixtures were 80% ash - 20% waste fines, 90% ash - 10% waste fines, 100% ash, and the natural soil from Mililani.

The intent of the new study was to perform tests to more closely reflect field conditions and maintain consistency for direct comparisons. Therefore, identical tests were performed on all materials selected. Tests included compaction, permeability, direct shear, and free swell.

To obtain maximum dry density and optimum water content of the materials, the compaction test was executed. This test was done with five layers instead of the previous three, increasing compactive effort by 66%. The permeability tests in this study were performed with an overburden pressure representative of the anticipated average in situ soil overburden. Direct shear tests were performed to determine the shear strength parameters of each material. To observe the maximum swell potential of the materials, free swell tests were performed. Details of each method are discussed in the next section.

TESTING & PREPARATION METHODS

The ash used in this study was prepared as in the previous study, by combining 60% ¼-inch screened bottom ash and 40% fly ash by weight. The quarry fines used in this study were acquired from Ameron HC&D. H-Power ash - waste fines mixtures were prepared based on dry weight. One batch was made for all subsequent tests. The other materials tested included a baseline natural soil from Mililani.

A total of four materials were tested. They include:

- 80% H-Power Ash - 20% Ameron Fines
- 90% H-Power Ash - 10% Ameron Fines
- 100% H-Power Ash
- Mililani Soil

Identical tests were performed on each material. Table 2 is a summary of tests performed.

Table 2. Summary of Tests Performed

Test	Parameters Obtained	Method
Compaction	Dry Density, γ_{dry} Optimum Moisture Content, ω_{opt}	Modified Proctor Test (ASTM D-1557)
Permeability	Coefficient of Permeability, k	Falling Head Permeability (Das, 1986)
Strength	Friction Angle, ϕ Cohesion Intercept, c Shear Strength, τ	Direct Shear Test (ASTM D-3080)
Swell	Swell Potential	One-Dimensional Free Swell (ASTM D-4546)

Details of each test method is described below.

Compaction Test

The compaction test was used to determine the maximum dry density and optimum moisture content of each mixture. The test method used was based on the Proctor test. In the standard Proctor test, a sample is compacted in a 1/30 ft^3 mold in three layers. Each layer is tamped 25 times by a 5.5 lb hammer dropped 1 ft. In the Modified Proctor test, a sample is compacted in a 1/30 ft^3 mold in five layers. Each layer is tamped 25 times by a 10 lb hammer dropped 1.5 ft. It represents a higher compactive energy.

The Modified Proctor test was used in this study, compacted in five layers as opposed to three layers in the previous study to better represent the compactive effort expected in the field. For each mixture, the soil was placed in the compaction mold of a volume of 1/30 ft^3 in five equal layers. Each layer was compacted by the Modified Proctor hammer (10 lb) with 25 blows/layer. Once compacted, the weight was measured and a sample was oven dried to measure the moisture content. This was done for five to seven different moisture contents per mixture to obtain sufficient data to derive the moisture-density relationship for that compactive effort.

Dry density was calculated from moist unit weight (γ) and the moisture content (ω).

$$\gamma_{moist} = \frac{\text{weight of moist soil (lb)}}{\text{volume of mold (ft}^3\text{)}} = \frac{W_2 - W_1}{1/30}$$

where:

$$\gamma_{dry} = \frac{\gamma_{moist}}{1 + \frac{\omega\ (\%)}{100}}$$

$$\omega = \frac{\text{weight of water}}{\text{weight of solids}}$$

Calculated γ_{dry} and ω for each mixture was plotted to obtain the maximum dry density and optimum moisture content. Results can be found in the next section and in Appendix A.

Permeability

The Falling Head permeability test was used to determine the coefficient of permeability, k, of each mixture. While this test method is not an ASTM standard, it is widely used in practice and provides a reasonable estimate of permeabilities achievable. For more accurate determinations, more sophisticated flexible wall permeability tests should be employed. Each mixture was compacted to 95% of the maximum dry density with a moisture content of optimum plus 2% based on the results of the Modified Proctor compaction test. Specimens were compacted in a 2.5 inch diameter, 1 inch high sampling ring in five equal layers. Specimens were tested with 3.3 psi surcharge confining stress to represent average expected field conditions. Tests were performed in an odometer-type apparatus connected to a burette by plastic tubing. The burette was constantly filled with water until the sample was saturated. Once saturated, the burette was filled to a known position and the height was recorded. As the height of the water in the burette fell, time, height and volume change were measured. Measurements were taken for a period of two to three days. Precautions were taken to prevent evaporation by covering (sealing) the top of the burette. k was calculated by the following equation:

$$k = \frac{2.303\,(\Delta V)L}{(h_1 - h_2)\,t\,A} \log\frac{h_1}{h_2}$$

where:

- k = coefficient of permeability
- ΔV = change in volume (measurement of burette)
- L = length of drainage path (height of sample)
- h_1 = initial head (height of water in burette)
- h_2 = head after time, t (height of water in burette)
- t = time
- A = area of sample

Results of multiple permeability tests were averaged and may be found in the next section and Appendix B.

Shear Strength

The direct shear test was used to determine the soil shear strength parameters: cohesion intercept (c), and friction angle (ϕ). Each mixture was compacted to 95% of the maximum dry density and at optimum water content plus 2%. Samples were compacted directly in the test apparatus sampling ring in five equal layers. Samples were sheared under a constant strain rate of 0.75 mm/min. Shear stress and horizontal displacement were recorded. The maximum shear strength was determined from the plots of the two measurements. (See Appendix C). This was repeated for three different confining pressures (vertical stresses): 30.7, 61.7, and 92.7 kPa. Results were plotted to determine the friction angle and cohesion intercept for each soil mixture.

Free Swell Test

The free swell test was based on the ASTM D-4546 Standard Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils, Method A. In this method, each sample was prepared in a consolidometer cell that was 2.5 inches in diameter and one inch in height: compacted to 95% of the maximum dry density and at optimum water content plus 2% in five equal layers. Once the sample was prepared, a dial gage was placed upon the porous stone cap to measure any swell. The sample was then inundated with water and allowed to swell freely. Measurements were taken for five days. Results can be found in the next section and Appendix D.

This test represents the maximum possible swell of each specimen with zero confining (overburden) stress. While this is not representative of actual expected field conditions, it does provide a conservative indication of potential expansive characteristics.

RESULTS

The following is a summary of results obtained from the various tests:

Table 3. Summary of Test Results

	Compaction		Permeability		Shear Strength		Swell
Mixture	γ_{dmax}	ω_{opt}	k	Vertical Pressure	ϕ	c	
	kg/m^3 *(lb/ft^3)*	%	cm/sec (ft/min)	kPa (psi)	degrees	kPa (psi)	%
80-20 AM	1470.5 *(91.8)*	24.5	3 x 10^{-8} *(6 x 10^{-8})*	22.8 *(3.3)*	43	75.0 (10.8)	2.2
90-10 AM	1406.4 *(87.8)*	27.5	2 x 10^{-8} *(4 x 10^{-8})*	22.8 *(3.3)*	33	92.5 (13.4)	4.9
100% Ash	1361.5 *(85.0)*	28.4	3 x 10^{-8} *(6 x 10^{-8})*	22.8 *(3.3)*	56	23.3 (3.4)	1.4
Mililani Soil	1497.7 *(93.5)*	31.5	2 x 10^{-8} *(4 x 10^{-8})*	22.8 *(3.3)*	36	54.3 (7.9)	0.44

Data for the compaction test can be found in Appendix A. Data for the falling head permeability tests can be found in Appendix B. Appendix C contains data of the direct shear tests. Appendix D shows data for the free swell tests.

DISCUSSION

The objective of this study was to determine through soil testing if the H-Power ash mixed with quarry fines of differing ratios would meet the criteria of the landfill cover. According to the Hawaii Administrative Rules 11-58.1-17, Municipal Solid Waste Landfills – Closure and Post-Closure Care. (a) Closure Criteria (Dec. 1993):

> Owners or operators of all MSWLF units must install a final cover system that is designed to minimize infiltration and erosion. The final cover system must be comprised of an erosion layer underlain by an infiltration layer as follows:
>
> 1. Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1×10^{-5} cm/sec, whichever is less, and
> 2. Minimize infiltration through the closed MSWLF by the use of an infiltration layer that contains a minimum eighteen inches of earthen material, and
> 3. Minimize erosion of the final cover by the use of an erosion layer that contains a minimum six inches of earthen material that is capable of sustaining native plant growth.

The December 1993 rule also requires landfill liners to have a maximum permeability of 10^{-7} cm/sec; therefore, for landfills constructed post 1993, landfill covers are also required to have a permeability of 10^{-7} cm/sec. However, the Waipahu Ash Landfill was constructed without a liner and closed prior to when the rule went into effect. The old rule which governs this landfill states that the design of the cover should minimize leachate, handle surface water, and manage leachate. The best guide to achieve these requirements as stated above is to use a material with a maximum permeability of 10^{-5} cm/sec. Tests were performed to determine the permeability of the mixtures.

Tests performed in this study were designed to better model field conditions and further investigate potential mixtures identified in the previous study to use as a material for the final landfill cover. All materials had a permeability of or less than 3×10^{-8} cm/sec. The Hawaii Administrative Rules state that the final cover for Waipahu should have a permeability of no greater than 1×10^{-5} cm/sec as a guide. Therefore, all mixtures met this criteria.

Analysis in the permeability test showed a variability in test results with time. From the data presented in Appendix B, it can be seen that the permeability varied as much as 20% daily; however, due to factors influencing the permeability, these sorts of results are not uncommon. Factors include, particle grain size, mineral content, particle structure, density, discontinuities, temperature, and head of water. In general, permeabilities measured in the laboratory only determine the order of magnitude to be expected based on particular field conditions. Exact permeabilities cannot be measured in the laboratory due to the variability of the factors influencing the permeability in the field. The majority of these factors cannot be modeled or duplicated in the laboratory. However, test results are representative of what magnitude of permeability to expect in the field.

The compaction test performed in this study represented widely accepted standard practice procedures. Results were applied in the preparation of the samples used for the other tests in this study. A minimum compaction specification of 95% of the maximum dry density achieved by the Modified Proctor test is a reasonable expectation, although caution should be exercised in field control inspections due to the nature and composition of the ash.

Direct shear tests performed gave relative shear strength of the soil. Results showed the 90% H-Power ash - 10% Ameron waste fines mixture to be the strongest with a nominal cohesive shear strength of 92.5 kPa. The ash alone was the least strongest. This could be due to the strength of the bonds produced in the ash-fines mixtures. Both mixtures were stronger than the natural Mililani soil.

In the free swell test, all materials swelled slightly. All materials tested showed a slight swell less than 5%. The test was performed conservatively without a confining pressure according to ASTM procedure. Under these test conditions the swell potential results were considered low. Consequently, in the field, where there would be an overburden pressure due to the topsoil, the swell potential would be expected to be insignificant.

While no quantitative shrinkage test was performed, the 100% ash and Mililani soil specimens used in the permeability tests were removed from the sampling rings and observed daily as they air-dried. After three days, the Mililani soil showed substantial vertical shrinkage cracks as shown in the photograph, Figure 1. The ash samples seemed to expand slightly; however, no quantitative measurements were made and no cracks were noted as shown in the photograph, Figure 2. Expansion should not be expected in the field due to the confining pressure created by the surrounding soil. However, cracks in the material can create an open flow path, thereby greatly increasing the permeability and infiltration potential of the soil. A more detailed investigation may be explored in the future to better quantify the cracking potential of the natural soil.

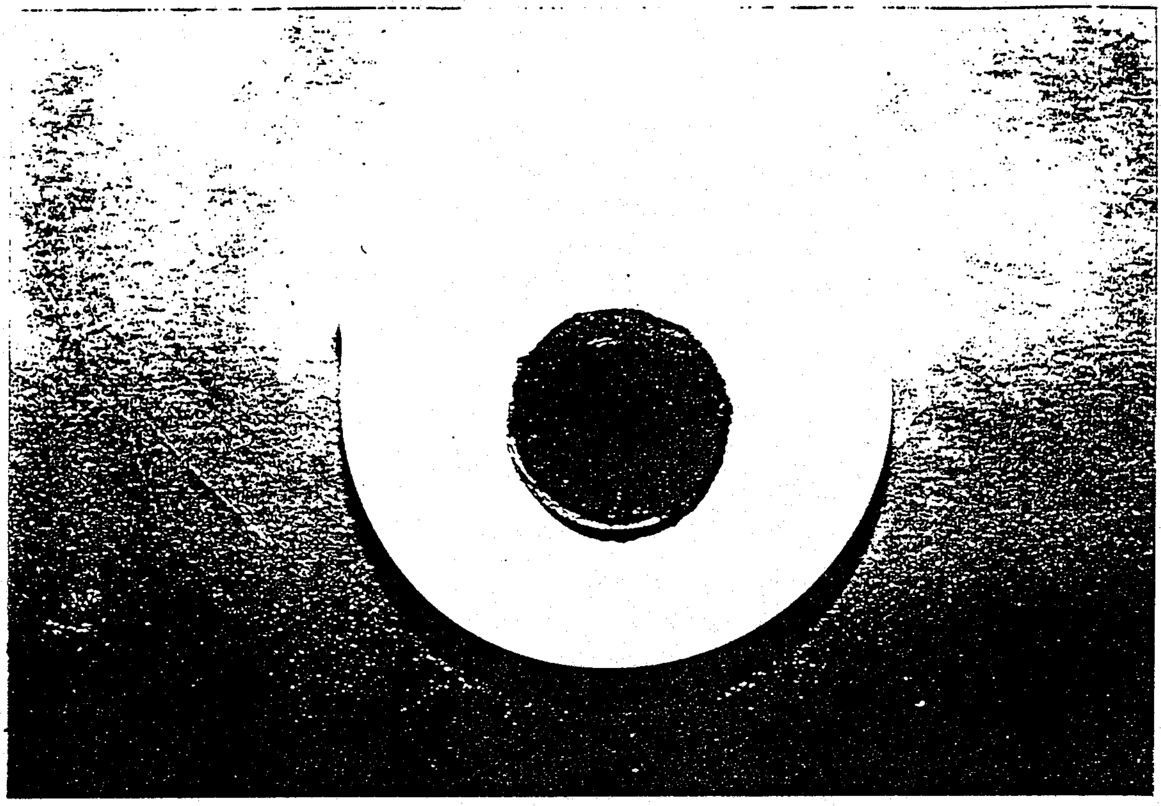


Figure 1. A saturated Mililani soil sample air-dried after 3 days

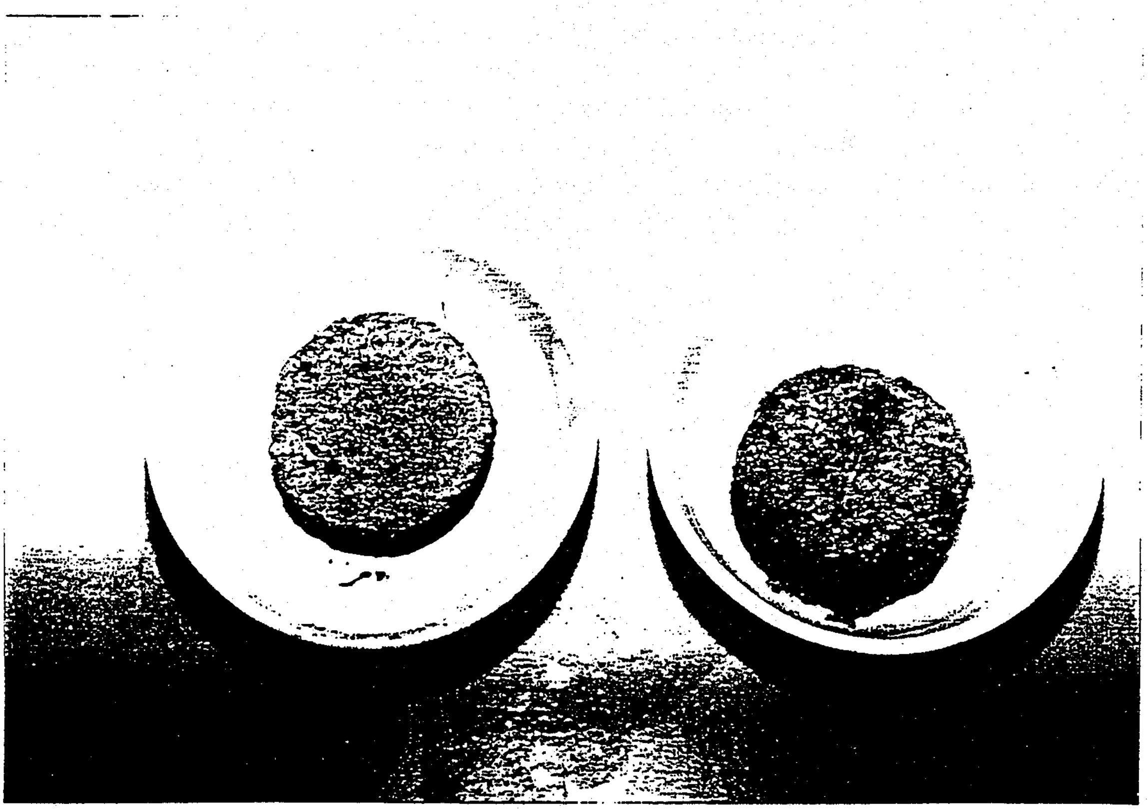


Figure 2. Two saturated 100% H-Power Ash samples air-dried after 5 days

SUMMARY & CONCLUSIONS

The intent of these tests were to investigate the best ratio of H-Power ash mixed with Ameron waste fines and compare the mixtures to 100 % ash and a natural soil from Mililani to select a material that would prove to be a viable alternative to a baseline natural soil for the bottom layer of the Waipahu ash landfill final cover. All materials in the study, 80% ash - 20% waste fines, 90% ash - 10 % waste fines, 100% ash, and the Mililani soil had a permeability less than 1×10^{-7} cm/sec, meeting the criteria stated in the Hawaii Administrative Rules for final landfill covers.

The majority of the test methods used in the analyses were meant to model expected field conditions as closely as possible. Test samples were prepared according to standard practice of 95% of maximum dry density and a moisture content plus 2% of optimum as determined in the compaction tests of this study. Permeability tests were performed with a vertical pressure representative of expected average field conditions. Free swell tests were performed to measure the maximum volume change potential associated with saturation.

Results of the study show that the 90% H-Power ash - 10% Ameron waste fines appear to be the best material for the final landfill cover. When compared to the natural soil from Mililani, the permeabilities were in the same range. However, the observation of the air-dried Mililani specimen showed cracking which could critically affect the permeability adversely.

The direct shear test showed that the 90% H-Power ash -10% waste fines to be the strongest of all materials tested. This is important in support of overburden pressures.

Shrink/swell characteristics observed show nominal/insignificant expansive characteristics. Shrinkage *cracking* of the natural soil could be critical. If drying were to occur during construction of any time later, cracks could develop, increasing the permeability, and allowing water to more easily infiltrate the landfill. However, the 90% H-Power ash - 10% waste fines showed the greatest potential for swell. Due to the nature of the project and concern to prevent landfill infiltration, shrinkage cracks would be more detrimental than a slight swell. Also, with a confining pressure such as the topsoil, swell is expected to be insignificant; however, if it is a concern, then the 80% H-Power ash - 20% waste fines mixture would be the next best candidate for the landfill final cover material.

In conclusion, all materials tested met the requirements of the Hawaii Administrative Rules for the infiltration layer of the cover material for the Waipahu ash landfill closure. The test results show the 90% H-Power ash - 10% Ameron waste fines mixture to be the most viable alternative to the baseline natural soil.

REFERENCES

Anderson, Scott A. and Brandon H. Hee. (1995). "Hydraulic Conductivity of Compacted Lateritic Soil With Bentonite Admixture," Environmental & Engineering Geosciences Journal.

Bowels, Joseph E. Engineering Properties of Soils and Their Measurements, Second Edition. McGraw-Hill Book Company, New York, NY. 1978.

Das, Braja M. Soil Mechanics Laboratory Manual, Second Edition. Engineering Press, Inc., San Jose, CA. 1986.

Hee, Brandon H. (1995), "The Influence of Bentonite Admixture on the Hydraulic Conductivity of Elastic Silts." Masters Thesis, University of Hawaii.

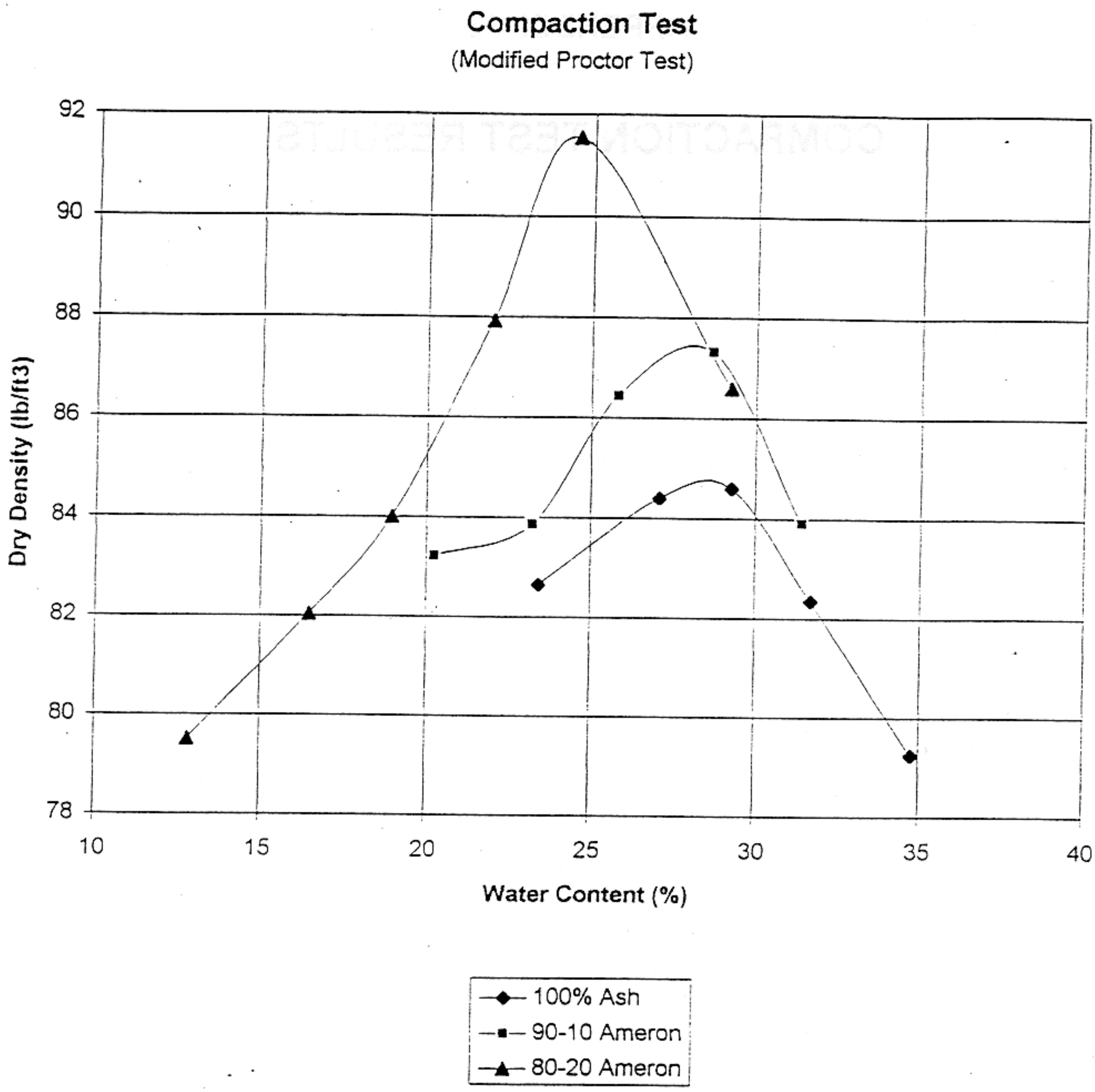
Jones, Colin M., R. Michael Hartman, Denton Kort and Neil Rapues. (1994). "Utilization of Ash From Municipal Solid Waste Combustion, Final Report Phase I." NREL Subcontract No XAR-3-1322.

"Engineering Soil Tests on H-Power Ash Mixtures for Potential Use as a Landfill Final Cover." (June 1995), University of Hawaii Report.

APPENDICES

APPENDIX A:

COMPACTION TEST RESULTS



Mixture	Dry Density (lb/ft3)	w(%)
100 % H-Power Ash	85.0	28.4
90 - 10 Ameron	87.8	27.5
80 - 20 Ameron	91.8	24.5

APPENDIX B:

PERMEABILITY TEST RESULTS

FALLING HEAD PERMEABILITY TEST						1-Aug-95	TO	5-Aug-95		
80% H-Power Ash - 20% AMERON Fines				(Duplicate Test)		Confining Stress = 3.25 psi				
Time	t (sec)	h1	h2	h1-h2	log(h1/h2)	V	del V	K (cm/sec)		
14:00:00	0	90.00	90.00	0.00		0			31-Jul-95	
10:43:00	74580	90.00	88.90	1.10	0.0029700	1.90	1.90	1.27E-08	*Saturation*	
10:51:00	0	90.00	90.00	0.00	0.0000000	0.00	0.00	#DIV/0!	1-Aug-95	
11:23:00	1920	90.00	89.90	0.10	0.0002692	0.20	0.20	5.18E-08		
12:00:00	2220	89.90	89.80	0.10	0.0002693	0.30	0.10	2.24E-08		
12:56:00	3360	89.80	89.70	0.10	0.0002695	0.40	0.10	1.48E-08		
16:28:00	12720	89.70	89.20	0.50	0.0013500	1.20	0.80	3.14E-08		
9:18:00	60600	89.20	87.30	1.90	0.0051686	4.60	3.40	2.82E-08	2-Aug-95	
20:14:00	39360	87.30	86.00	1.30	0.0035722	7.20	2.60	3.35E-08		
11:00:00	51540	86.00	83.70	2.30	0.0063929	11.10	3.90	3.88E-08	3-Aug-95	
11:16:00	960	83.70	83.70	0.00	0.0000000	11.10	0.00	#DIV/0!		
15:24:00	14880	83.70	83.00	0.70	0.0019645	12.40	1.30	4.53E-08		
17:06:00	6120	83.00	82.70	0.30	0.0008447	12.90	0.50	4.25E-08	3.43E-08	Average

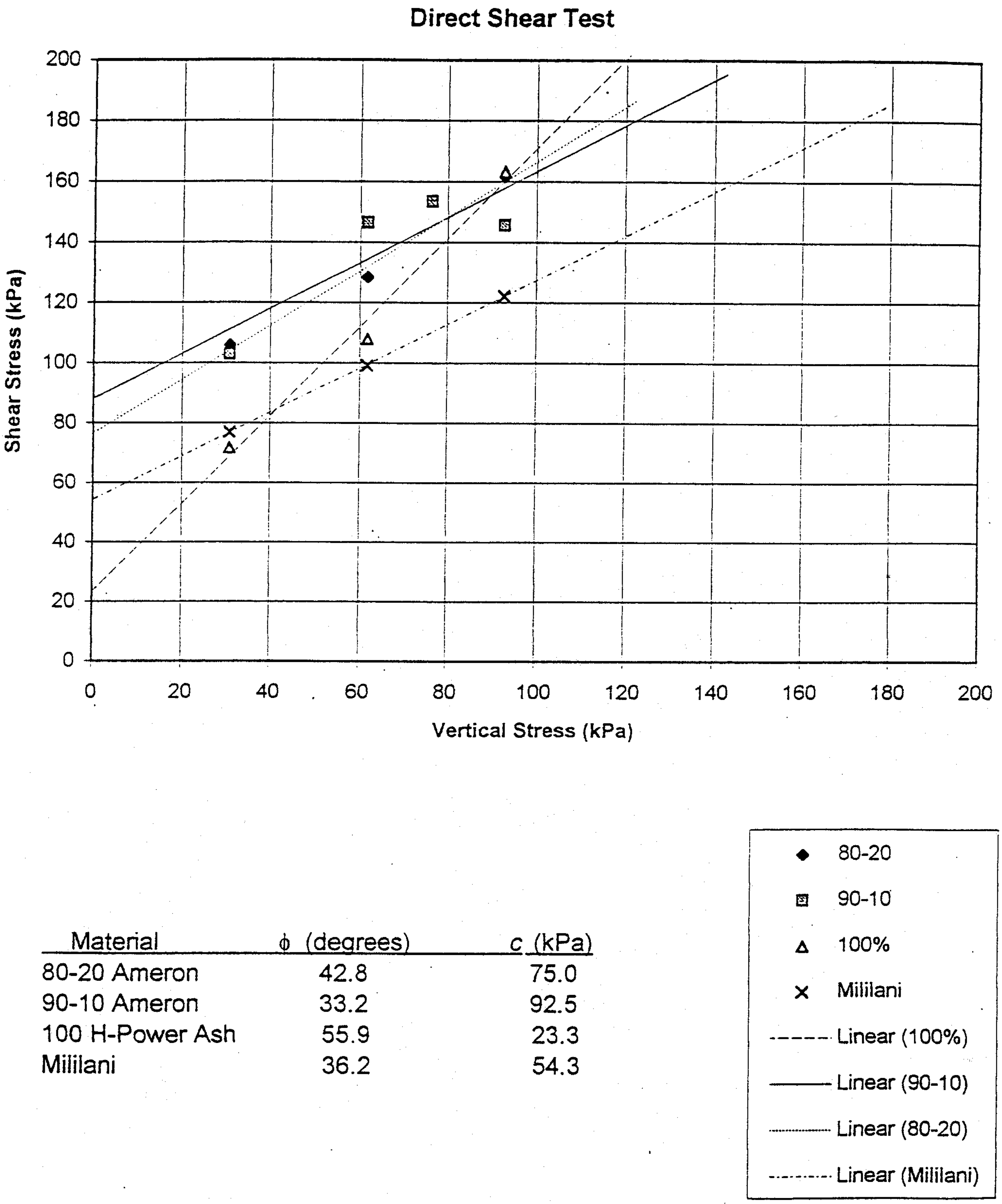
FALLING HEAD PERMEABILITY TEST						5-Jul-95	TO	10-Jul-95	
90% H-Power Ash - 10% AMERON Fines						Confining Stress = 3.25 psi			
Time	t (sec)	h1	h2	h1-h2	log(h1/h2)	V	del V	K (cm/sec)	
10:48:00	0	90.10	90.10	0.00		0			
11:22:00	2040	90.10	90.00	0.10	0.0002690	0.10	0.10	2.44E-08	6-Jul-95
11:50:00	1680	90.00	89.90	0.10	0.0002692	0.20	0.10	2.96E-08	
12:13:00	1380	89.90	89.90	0.00	0.0000000	0.20	0.00	#DIV/0!	
12:39:00	1560	89.90	89.90	0.00	0.0000000	0.30	0.10	#DIV/0!	
13:22:00	2580	89.90	89.80	0.10	0.0002693	0.40	0.10	1.93E-08	
14:27:00	3900	89.80	89.80	0.00	0.0000000	0.40	0.00	#DIV/0!	
15:01:00	2040	89.80	89.70	0.10	0.0002695	0.50	0.10	2.44E-08	
21:30:00	23340	89.70	88.70	1.00	0.0027042	1.20	0.70	1.50E-08	
9:45:00	44100	88.70	88.60	0.10	0.0002713	2.50	1.30	1.48E-08	7-Jul-95
11:02:00	4620	88.60	88.50	0.10	0.0002715	2.70	0.20	2.17E-08	
11:17:00	900	88.50	88.50	0.00	0.0000000	2.70	0.00	#DIV/0!	
11:55:00	2280	88.50	88.40	0.10	0.0002717	2.80	0.10	2.20E-08	
7:43:00	71280	88.40	87.00	1.40	0.0038216	5.40	2.60	1.84E-08	8-Jul-95
8:01:00	1080	87.00	87.00	0.00	0.0000000	5.40	0.00	#DIV/0!	
9:51:00	6600	87.00	86.90	0.10	0.0002743	5.60	0.20	1.54E-08	
15:33:00	20520	86.90	86.60	0.30	0.0008238	6.20	0.60	1.48E-08	
20:57:00	19440	86.60	86.10	0.50	0.0013765	6.90	0.70	1.83E-08	
8:26:00	41340	86.10	85.50	0.60	0.0016576	8.00	1.10	1.36E-08	9-Jul-95
14:30:00	21840	85.50	85.10	0.40	0.0011086	8.80	0.80	1.88E-08	
9:05:00	66900	85.10	84.10	1.00	0.0027839	10.70	1.90	1.46E-08	10-Jul-95
10:07:00	3720	84.10	84.00	0.10	0.0002794	10.80	0.10	1.39E-08	
								1.87E-08	AVERAGE

FALLING HEAD PERMEABILITY TEST						11-Jul-95	TO	19-Jul-95		
100% Mixed H-Power Ash						Confining Stress = 3.25 psi				
Time	t (sec)	h1	h2	h1-h2	log(h1/h2)	V	del V	K (cm/sec)		
16:10:00	0	90.00	90.00	0.00		0				
11:15:00	68700	90.00	87.40	2.60	0.0070530	4.50	4.50	3.28E-08	11-Jul-95	
11:59:00	2640	87.40	87.30	0.10	0.0002736	4.60	0.10	1.91E-08	12-Jul-95	
13:50:00	6660	87.30	87.10	0.20	0.0005477	5.00	0.40	3.04E-08		
14:24:00	2040	87.10	87.10	0.00	0.0000000	5.00	0.00	#DIV/0!		
14:57:00	1980	87.10	86.90	0.20	0.0005484	5.20	0.20	5.12E-08		
21:07:00	22200	86.90	86.30	0.60	0.0016492	6.40	1.20	2.74E-08		
8:47:00	42000	86.30	85.10	1.20	0.0033174	8.50	2.10	2.55E-08	13-Jul-95	
10:46:00	7140	85.10	84.90	0.20	0.0005554	8.90	0.40	2.87E-08	*(bubbles)*	
11:34:00	2880	84.90	84.80	0.10	0.0002779	9.00	0.10	1.78E-08		
12:57:00	4980	84.80	84.60	0.20	0.0005564	9.40	0.40	4.13E-08		
14:34:00	5820	84.60	84.30	0.30	0.0008360	9.90	0.50	4.42E-08		
16:09:00	5700	84.30	84.10	0.20	0.0005582	10.20	0.30	2.71E-08		
22:12:00	21780	84.10	83.60	0.50	0.0013987	11.20	1.00	2.37E-08		
10:14:00	43320	83.60	82.40	1.20	0.0033754	13.20	2.00	2.40E-08	14-Jul-95	
13:31:00	11820	82.40	82.00	0.40	0.0011310	13.90	0.70	3.09E-08		
21:45:00	29640	82.00	81.10	0.90	0.0025555	15.40	1.50	2.65E-08	3.01E-08	Average

FALLING HEAD PERMEABILITY TEST						11-Jul-95	TO	18-Jul-95	
Mililani Soil						Confining Stress = 3.25 psi			
Time	t (sec)	h1	h2	h1-h2	log(h1/h2)	V	del V	K (cm/sec)	
15:18:00	0	90.00	90.00	0.00		0			11-Jul-95
16:10:00	3120	90.00	89.80	0.20	0.0005385	0.40	0.40	6.38E-08	
11:14:00	68640	89.80	88.90	0.90	0.0024315	1.90	1.50	1.09E-08	12-Jul-95
11:58:00	2640	88.90	88.80	0.10	0.0002710	2.00	0.10	1.90E-08	
13:50:00	6720	88.80	88.70	0.10	0.0002712	2.20	0.20	1.49E-08	
14:23:00	1980	88.70	88.70	0.00	0.0000000	2.20	0.00	#DIV/0!	
15:56:00	5580	88.70	88.60	0.10	0.0002713	2.40	0.20	1.80E-08	
21:06:00	18600	88.60	88.30	0.30	0.0008151	2.90	0.50	1.35E-08	
8:48:00	42120	88.30	87.80	0.50	0.0013619	4.00	1.10	1.31E-08	13-Jul-95
10:44:00	6960	87.80	87.70	0.10	0.0002729	4.10	0.10	7.24E-09	
11:58:00	4440	87.70	87.60	0.10	0.0002731	4.20	0.10	1.14E-08	
12:54:00	3360	87.60	87.60	0.00	0.0000000	4.30	0.10	#DIV/0!	
14:34:00	6000	87.60	87.40	0.20	0.0005466	4.50	0.20	1.68E-08	
16:10:00	5760	87.40	87.20	0.20	0.0005473	4.80	0.30	2.63E-08	
22:13:00	21780	87.20	87.00	0.20	0.0005480	5.00	0.20	4.65E-09	
10:13:00	43100	87.00	86.30	0.70	0.0019235	6.50	1.50	1.77E-08	14-Jul-95
13:30:00	11820	86.30	86.10	0.20	0.0005511	6.80	0.30	1.29E-08	
21:44:00	29640	86.10	85.60	0.50	0.0013809	7.70	0.90	1.55E-08	
13:47:00	144180	85.60	83.30	2.30	0.0064093	11.90	4.20	1.50E-08	16-Jul-95
10:54:00	76020	83.30	82.00	1.30	0.0036650	14.20	2.30	1.58E-08	17-Jul-95
12:40:00	92760	82.00	80.50	1.50	0.0042676	17.00	2.80	1.59E-08	18-Jul-95
								1.73E-08	AVERAGE

APPENDIX C:

DIRECT SHEAR TEST RESULTS



Material	ϕ (degrees)	c (kPa)
80-20 Ameron	42.8	75.0
90-10 Ameron	33.2	92.5
100 H-Power Ash	55.9	23.3
Mililani	36.2	54.3

APPENDIX D:

FREE SWELL TEST RESULTS

SWELL TEST				8-Aug-95
80% H-Power Ash - 20% AMERON Fines				
			Confining Stress = 0.04 psi	
	Actual		Dial Guage	Percent
Date	Time	Minutes	Reading	Swell (%)
8-Aug-95	10:50:00	0.1	0.3600	0
	10:50:06	0.1	0.3600	0
	10:50:12	0.2	0.3600	0
	10:50:30	0.5	0.3600	0
	10:51:00	1.0	0.3600	0
	10:52:00	2.0	0.3600	0
	10:54:00	4.0	0.3600	0
	10:58:00	8.0	0.3600	0
	11:05:00	15.0	0.3598	0.02
	11:20:00	30.0	0.3566	0.34
	11:50:00	60.0	0.3561	0.39
	12:56:00	126.0	0.3550	0.50
	14:52:00	242.0	0.3538	0.62
	18:45:00	475.0	0.3523	0.77
9-Aug-95	11:04:00	1454.0	0.3467	1.33
10-Aug-95	9:58:30	2828.5	0.3413	1.87
11-Aug-95	11:25:00	4355.0	0.3380	2.20

SWELL TEST				30-Aug-95
90% H-Power Ash - 10% AMERON Fines				
			Confining Stress = 0.04 psi	
	Actual		Dial Guage	Percent
Date	Time	Minutes	Reading	Swell (%)
30-Aug-95	13:33:00	0.0	0.2600	0
	13:33:06	0.1	0.2598	0.02
	13:33:12	0.2	0.2598	0.02
	13:33:30	0.5	0.2598	0.02
	13:34:00	1.0	0.2597	0.03
	13:35:00	2.0	0.2596	0.04
	13:37:00	4.0	0.2587	0.13
	13:41:00	8.0	0.2575	0.25
	13:48:00	15.0	0.2561	0.39
	14:00:00	27.0	0.2542	0.58
	14:33:00	60.0	0.2503	0.97
	15:33:00	120.0	0.2463	1.37
	17:33:00	240.0	0.2401	1.99
	21:34:00	481.0	0.2342	2.58
31-Aug-95	13:13:00	1420.0	0.2267	3.33
1-Sep-95	13:38:00	2885.0	0.2187	4.13
2-Sep-95	13:33:00	4320.0	0.2111	4.89

SWELL TEST				8-Aug-95
100% H-Power Ash				
			Confining Stress = 0.04 psi	
	Actual		Dial Guage	Percent
Date	Time	Minutes	Reading	Swell (%)
8-Aug-95	10:53:00	0.1	0.4000	0.00
	10:53:06	0.1	0.4000	0.00
	10:53:12	0.2	0.4000	0.00
	10:53:30	0.5	0.4000	0.00
	10:54:00	1.0	0.4000	0.00
	10:55:00	2.0	0.4000	0.00
	10:57:00	4.0	0.4000	0.00
	11:01:00	8.0	0.4000	0.00
	11:08:00	15.0	0.3967	0.33
	11:23:00	30.0	0.3967	0.33
	11:53:00	60.0	0.3965	0.35
	12:56:30	123.5	0.3960	0.40
	14:53:00	240.0	0.3955	0.45
	18:46:00	473.0	0.3949	0.51
9-Aug-95	11:04:00	1451.0	0.3922	0.78
10-Aug-95	9:59:00	2826.0	0.3897	1.03
11-Aug-95	11:25:00	4352.0	0.3861	1.39

SWELL TEST				8-Aug-95
Mililani Soil				
			Confining Stress = 0.04 psi	
	Actual		Dial Guage	Percent
Date	Time	Minutes	Reading	Swell (%)
8-Aug-95	11:15:00	0.1	0.3000	0.03
	11:15:06	0.1	0.3000	0.03
	11:15:12	0.2	0.3000	0.03
	11:15:30	0.5	0.3000	0.03
	11:16:00	1.0	0.3000	0.03
	11:17:00	2.0	0.3000	0.03
	11:19:00	4.0	0.3002	0.01
	11:23:00	8.0	0.3002	0.01
	11:30:00	15.0	0.3002	0.01
	11:45:00	30.0	0.3003	0.00
	12:17:00	62.0	0.3003	0.00
	13:13:00	118.0	0.3001	0.02
	15:08:00	233.0	0.3001	0.02
	18:46:00	451.0	0.3000	0.03
9-Aug-95	11:05:00	1430.0	0.2992	0.11
10-Aug-95	10:00:00	2805.0	0.2988	0.15
11-Aug-95	11:25:00	4330.0	0.2959	0.44

Appendix D

Waimanalo Gulch Sanitary Landfill Alternative Daily Cover Demonstration Project

Appendix D

Waimanalo Gulch Sanitary Landfill Alternative Daily Cover Demonstration Project

D1 Schedule and Protocol

D2 WGSL Operation Plan

D3 HDOH Approval

D4 Waste Management, Inc. Concerns

D5 Drawings

Project Location
Working Face Layout
ADC Cross Section
Ash Mine Layout

D6 Photos
Station Ambient Upwind
Station Ambient Downwind 1 (Sta D1) and Station Ambient Downwind 1A (Sta D1A)
Station Ambient Downwind 2 (Sta D2) and Station Ambient Downwind 2A (Sta D2A)
Station Ash Dump
Station OSHA Upwind
Station OSHA Spotter/Spotter Area and Station OSHA Downwind
Station OSHA Compactor and Station OSHA Pusher D9N
Station OSHA Spotter/Spotter Area
Meteorological Station
Typical Station Setup
Ash Mine
HRRV Truck Unloading Ash
Construction of ADC
Compaction of MSW on ADC
Construction of ADC on MSW
D9N Compacting Sheet Rock
Dust Cloud From Truck Tires
Dust From Tires and Bed of D30D CAT Truck Hauling Rocks and Gravel
Quarry Not in Use – Minimal Dust
Heavy Dust From Quarry

D7 Waimanalo Gulch Landfill Air Sample Data

D8 Summary – Ambient Air Monitoring of Beneficial Use of Municipal Waste Combustor (MWC) Ash as Daily Landfill Cover

Appendix D1

Waimanalo Gulch Sanitary Landfill Alternative Daily Cover Demonstration Project Schedule and Protocol

The testing is planned for the period of July 8, 1996 – July 16, 1996. The schedule is as follows:

July 6 - 7	Planning meeting at H-POWER office.
July 8	Waste Management, Inc. demonstration of use of H-POWER ash as Alternative Daily Cover (ADC). Test all monitoring equipment at Waimanalo Gulch.
July 9 – 15	Sample collection in accordance with protocol.
July 16 – 17	Ash mining demonstration and sample collection. Ash dumping sample collection. Equipment demobilization and sample submission to laboratory.

PROTOCOL FOR TESTING PROGRAM: USE OF H-POWER COMBINED ASH AS ALTERNATE DAILY COVER (ADC), WAIMANALO GULCH LANDFILL

SUMMARY: A one-week testing demonstration program is proposed that would collect data on dust concentrations and specific metal and crystalline silica concentrations during specific activities when H-POWER combined ash is used as ADC for municipal solid waste (MSW). Specifically, total and respirable dust, total and respirable metals (As, Ba, Cr, Cd, Ni, Pb, Se, and Ag), respirable crystalline silica, total hexavalent chromium, and total mercury (particulate and elemental vapor) will be measured. Ambient air samples will be collected during dumping of ash into daily stockpiles, pushing and compacting of MSW on the previous day's ADC, pushing and compacting of MSW on fresh MSW, creating of the daily cover at day's end, and during the overnight period when the ADC is exposed to the elements. In addition, air samples will be taken during ash mining and loading operations. A concurrent combined ash sample will also be collected every day and analyzed for As, Ba, Cr, CrVI, Cd, Hg, Ni, Pb, Se, and Ag.

The risk assessment is concerned about chemical constituents present in respiratory dust, rather than in total dust. Because of the small sample sizes required in this testing program, it is expected that many metals will not be detected in total and respiratory dust samples. For risk assessment purposes, surrogate metal concentrations will be calculated in one of several ways, as appropriate. Either it will conservatively be assumed that all respiratory dust is ash-derived, and chemical concentrations will be estimated by multiplying respiratory dust concentrations by the chemical concentrations of specific constituents in combined ash, or, if the metal is detected in total dust samples, respiratory metal concentrations will be estimated by multiplying the total metal concentration by the ratio of respiratory dust to total dust in the sample. Both methods are more realistic than using detection limits as surrogates for measured concentrations when chemicals are not detected. For several samples both total metal and respiratory metal concentrations will be measured as a validation of the above methods.

Key to abbreviations:

TD	Total Dust (2.0 L/min, PVC filter)
RD	Respirable Dust (1.7 L/min, PVC filter with cyclone)
Metals	Total As, Ba, Cr, Cd, Ni, Pb, Se, and Ag (2.0 L/min, MCE filter)
Cr VI	Hexavalent Chromium (2.0 L/min, PVC filter)
Hg	Total Hg- elemental vapor plus particulate (tube plus MCE filter)
R Silica	Respirable Crystalline Silica (1.7 L/min, PVC filter with cyclone)
R Metals	Respirable As, Ba, Cr, Cd, Ni, Pb, Se, and Ag (1.7 L/min, MCE filter with cyclone)

I. ALL-DAY SAMPLES

The following samples will be taken over the entire workday (8 hours) for every day during the one-week test period:

Caterpillar Operator	
On operator:	RD, Metals
In Cab:	TD
Compactor Operator	
On operator:	RD, Metals
In Cab:	TD
Spotter:	
On spotter:	RD, Metals
In Area:	TD
Upwind Area:	RD, TD, Metals
Downwind Area:	RD, TD, Metals

The following samples will be taken over the entire workday (8 hours) periodically during the one-week test period. Hexavalent chromium and mercury vapor will be taken alternately every other day for a 6 day period.

Caterpillar Operator In Cab:	Cr VI (3 days), Hg (3 days), R-Silica (2 days)
Compactor Operator In Cab:	Cr VI (3 days), Hg (3 days), R-Silica (2 days)
Spotter: In Area:	Cr VI (3 days), Hg (3 days), R-Metals (4 days), R-Silica (2 days)
Upwind Area:	Cr VI (3 days), Hg (3 days), R-Metals (4 days)
Downwind Area:	Cr VI (3 days), Hg (3 days), R-Metals (4 days)

II. ACTIVITY-SPECIFIC SAMPLES:

The following samples will be taken over the limited time periods when specific activities are taking place for the specified number of days during the test period. Either three area samples will be taken during each activity in downwind locations, or two downwind area samples will be taken and one sample will be placed on the spotter. Hexavalent chromium and mercury vapor will be taken alternately every other day for a 4 day period.

Pushing/Compacting MSW on ADC 0700-0900	TD, RD, Metals (7 days) Cr VI, Hg, R-Silica (2 days)
Pushing/Compacting MSW on MSW 0900-1500	TD, RD, Metals (7 days) Cr VI, Hg, R-Silica (2 days)
Constructing ADC 1500-1700	TD, RD, Metals (7 days) Cr VI, Hg, R-Silica (2 days)
Exposed Ash from ADC 1700-0700	TD, RD, Metals (7 days) Cr VI, Hg, R-Silica (2 days)

III. ASH DUMPING SAMPLES:

The following samples will be taken for three days during the one-week test period. One area sample will be taken over an 8 hour period in the ash dumping area on each of three days.

Ash Dumping	TD, RD, Metals

The following samples will be taken during an ash dumping event.

Ash Dumping	TD, RD, Metals, Cr VI, Hg

IV. ASH MINING SAMPLES:

The following samples will be taken during an ash mining demonstration for approximately three hours on one day during the one-week test period.

Spotter	
On Spotter:	RD, Metals, R-Silica
In Area:	TD, Cr VI
Dozer Operator	
On Operator:	RD, Metals, R-Silica
In Cab:	TD, Cr VI
Four Area Samples	
3-Downwind	TD, RD, Metals, Cr VI, Hg, R-Silica
1-Upwind	TD, RD, Metals

V. BULK ASH SAMPLES:

One bulk combined ash sample will be taken from an ash truck every day during the test period.

Bulk Ash	Metals, Cr VI, Hg

Appendix D2

WGSL Operation Plan

WASTE MANAGEMENT OF HAWAII, INC.

Landfill Divisions

Waimanalo Gulch Municipal Solid Waste Landfill
West Hawaii Municipal Solid Waste Landfill

H-POWER ASH RE-USE PROJECT

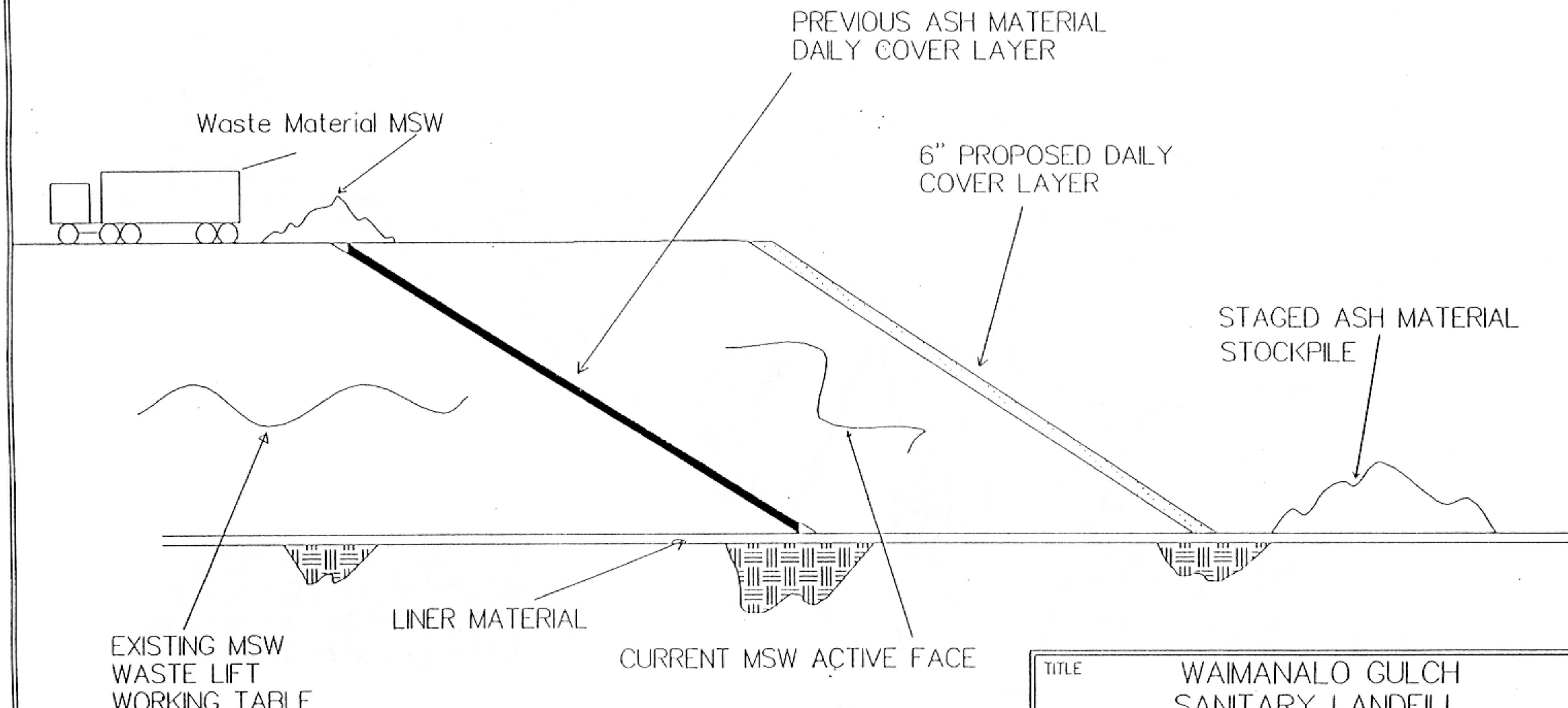
Daily Cover Operation Plan

The following is the **Operational Plan** for placing municipal solid waste in MSW Cell 4C and providing daily cover with the use of H-Power Ash material for a special demonstration proposed on July 8, 1996 at the Waimanalo Gulch Municipal Solid Waste Landfill.

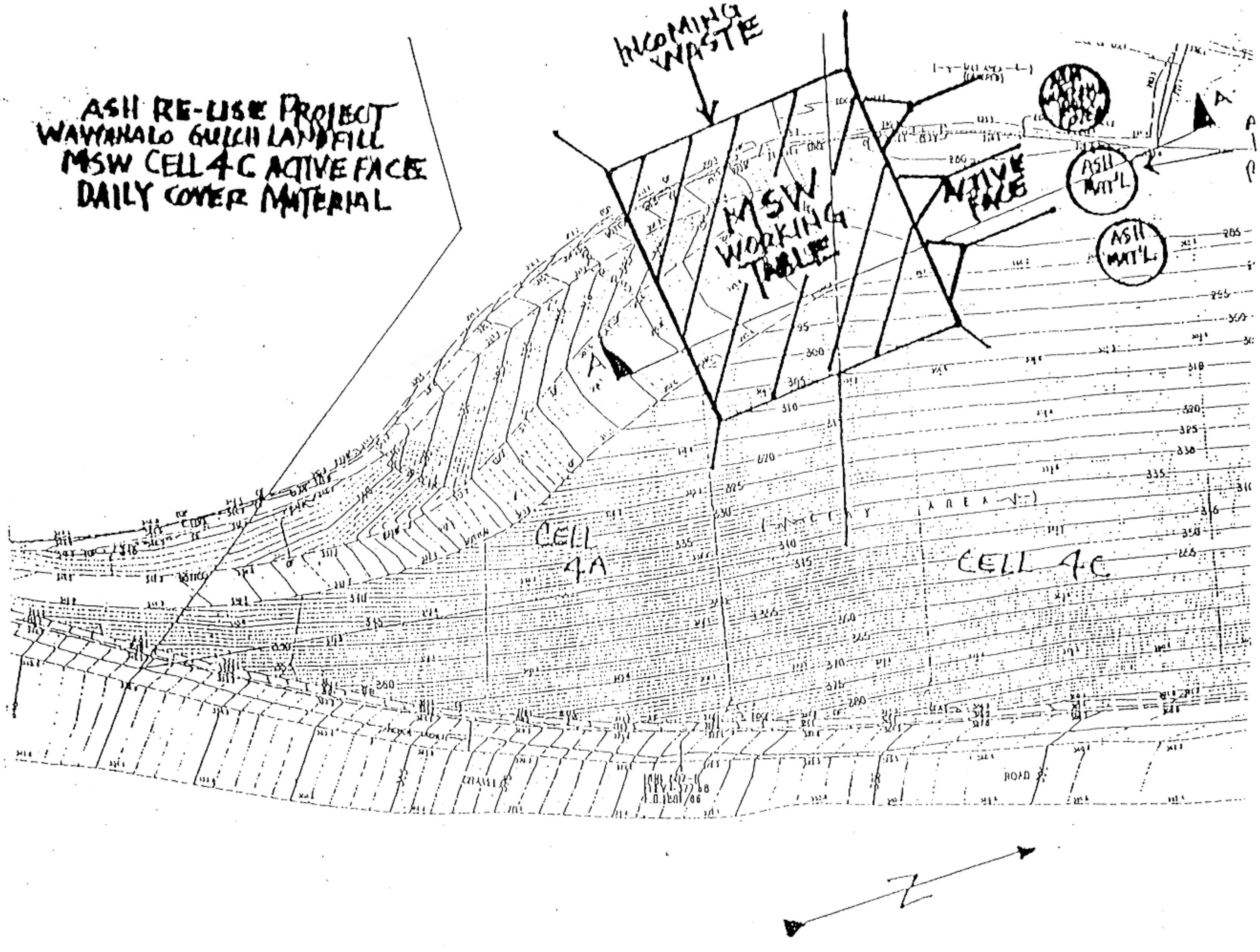
- Facility operations personnel were oriented on the special demonstration re-use of the H-Power Ash material for daily cover at the active face.
- Waste loads are directed to the newly completed MSW Cell 4C for placement and build-up of a working table.
- Current, normal disposal operations will be conducted in the placement of waste and compaction of the waste lift.
- H-Power trucks will be directed to the north-west end of MSW Cell 4C to off-load ash material for stockpiling in preparation of spreading of a minimum of 6-inches of daily cover layer at the end of the day.
- A water truck will be available and on hand at acceptable frequencies to address any possible dust issues. This is in accordance with current operations procedures.
- The following day's operations will continue as above with a new layer of waste placed over the previous day's layer of daily cover.

The above plan is subject to on-site conditions as they present themselves.

MSW CELLS 4A & 4C
CROSS-SECTION A



TITLE	WAIMANALO GULCH SANITARY LANDFILL DAILY COVER PROJECT
DATE 7/5/96	SCALE NOT TO SCALE


ASH RE-USE PROJECT
WAIMANALO GULCH LANDFILL
MSW CELL 4C ACTIVE FACE
DAILY COVER MATERIAL
INCOMING WASTE
MSW WORKING TABLE
ACTIVE FACE
ASH MAT'L
ASH MAT'L
CELL 4A
CELL 4C
A
A
N

MEMORANDUM

TO: Gary Siu, P.E. (Fax:586-7509)
FROM: Brian Magee, Ph.D. (Fax: 682:0715)
DATE: July 12, 1996

This memorandum describes a proposed change in the protocol for the ambient air monitoring study being executed at the Waimanalo Gulch Landfill during the period of July 9-July 15. Our original plan was to gather samples from Tuesday, July 9 through Monday, July 15. This would cover a full week of landfill activity using H-Power combined ash as daily cover. The monitoring covers day and night during a period when predominately commercial vehicles use the landfill (Tuesday-Friday, Monday) and a period when predominately private vehicles use the landfill (Saturday, Sunday). Because of the large number of samples collected in this effort and because Waste Management of Hawai'i has requested that we stop the sampling program a day early to allow landfill activities to return to normal operations, I am requesting that you approve a modification to the protocol. If sampling stops at 7:00 Monday morning, we will have gathered the following number of samples:

Total Dust	103
Respirable Dust	104
Total metals (8)	104
Chromium 6+	27
Particulate Hg	25
Hg vapor	25
Respirable Crystalline silica	30
Respirable total metals (8)	12
Total Samples	430

If you concur with this protocol modification, please initial this memorandum below and fax it to me at 682-0715.

[signature] OSWM
Approved

7/12/96
Date

Appendix D3

HDOH Approval

BENJAMIN J. CAYETANO
GOVERNOR OF HAWAII

STATE OF HAWAII
DEPARTMENT OF HEALTH
P.O. BOX 3378
HONOLULU, HAWAII 96801

LAWRENCE MIIKE
DIRECTOR OF HEALTH

RECEIVED
REFUSE DIVISION
H-POWER OFFICE
JUN 21 11 59 AM '96

In reply, please refer to:
EMD/SHW

June 7, 1996

S0609GS

Mr. Colin Jones
Refuse Collection and Disposal Division
Department of Public Works
City and County of Honolulu
650 South King Street, 6th Floor
Honolulu, Hawaii 96813

File: Waimanalo Gulch MSWLF

Dear Mr. Jones:

SUBJECT: Waimanalo Gulch Municipal Solid Waste Landfill (MSWLF) H-Power Ash Re-use Demonstration Project as Daily Cover

We received your fax of June 5, 1996 which included the June 5, 1996 letter from Mr. Ray A. Rossetti of Waste Management of Hawaii to you, approving the pilot testing of MSW ash as daily cover at the Waimanalo Gulch Sanitary Landfill. Based on the review by your technical staff, the Department of Health, Office of Solid Waste Management hereby **approves** of a one time, limited term, demonstration daily cover project with the following conditions:

1. A written daily cover operation plan with dust control measures must be provided for the record, before the start of the pilot program.

2. Records of the demonstration project with photo documentation must be made. Any modifications or operational difficulties should be recorded. And,

3. A post-demonstration evaluation be prepared for future use.

We note that Waste Management's approval is made with comments. Those comments must be addressed prior to the start of the demonstration.

Should there be any questions, please call Mr. Gary Siu of the Office of Solid Waste Management at 586-4240.

Very truly yours,

STEVEN Y.K. CHANG, Manager
Solid and Hazardous Waste Branch

JH:GS:ma

c: Mr. Ray A. Rossetti, Waste Management of Hawaii, Inc.
Mr. Frank Doyle, City & County of Honolulu, DPW

WASTE MANAGEMENT OF HAWAII, INC.
92-460 Farrington Highway
Ewa Beach, Hawaii 96707
808/668-2985 • FAX: 808/668-1366

RECEIVED
JUN 6 4 18 PM '96
DIVISION OF REFUSE
COLLECTION & DISPOSAL

June 5, 1996

Mr. Colin Jones
Refuse Collection and Disposal Division
Department of Public Works
City and County of Honolulu
650 South King Street, 6th Floor
Honolulu, Hawaii 96813

Re: Waimanalo Gulch Sanitary Landfill - H-Power Ash Re-use Demonstration Project

Dear Mr. Jones:

The proposed testing protocol and Health Risk Assessment of the Beneficial Re-Use of H-Power Combined Ash has been reviewed by both our corporate industrial hygienist, Dr. Dave Dolan, and our West Group Environmental Vice-President, Mr. Bob Barber. As noted by both individuals, the health risks associated with the short term pilot /demonstration project are minimal. Waste Management of Hawaii, Inc. hereby approves the pilot testing of the H-Power combined ash at the Waimanalo Gulch Sanitary Landfill.

It has been noted by Dr. Dolan that additional testing parameters would be beneficial in ensuring that there are minimal health risks associated with long term use of H-Power ash as daily cover or other landfill uses.

Please let us know if you require any additional information to obtain approval from the State Department of Health. I may be contacted at 668-2985.

Sincerely,

Ray A. Rossetti

Ray A. Rossetti
Waste Management of Hawaii, Inc.
Division President and General Manager

cc: J. Harder - State Dept. of Health
F. Doyle - C & Co. Dept. of Public Works

Appendix D4

Waste Management, Inc. Concerns

WASTE MANAGEMENT INC.
WEST GROUP OFFICE
Memorandum

Date: June 3, 1996

To: Ray Rossetti

From: Bob Barber

Subject: Proposed Air Sampling for Pilot Scale Use of H-Power Combined Ash and Daily Cover at Waimanalo Gulch Landfill

---

Attached is a memo from Dave Dolan concerning the use of H-Power Ash in the daily cover demonstration project. We don't anticipate any problems from conducting the pilot study but recommend that some additional parameters be tested to make sure that all bases are covered.

If you have any questions, please give me a call.

RDB:jf

cc: Dave Dolan
Garry Mosier

DATE: May 31, 1996

TO: Bob Barber
Ray Rossetti

FROM: David Dolan, Ph.D.

RE: **Final Comments on the Proposed Air Sampling during the Pilot-Scale Use of H-Power Combined Ash in the Daily Cover of the Waimanalo Gulch Sanitary Landfill**

I have reviewed the Ogden Environmental and Energy Services risk assessment for the use of the H-Power combined ash as daily cover. Overall, the conclusions of the report that the use of the H-Power combined ash as daily cover at the Waimanalo Gulch Landfill poses no significant human health risk may be correct, but we won't know until additional details and calculations are provided. I believe that the short-term risks from the one-week pilot study are low, but that the only definitive way of knowing whether there could be long-term on-site or off-site risks associated with the proposed change in ash management is to actually perform the operation and to monitor the ambient air quality.

The ambient air monitoring protocol proposed by Ogden Environmental and Energy Services appears to be insufficient to generate the data needed to properly conclude whether the ash can be safely handled in the proposed manner. The list of analytes should be expanded to include more than just lead and respirable dust. At the very least, a bulk sample of H-Power MWC ash should be collected and analyzed for crystalline silica, and ambient air samples should be analyzed for total and respirable dust and the NIOSH welding panel (or the eight other metals and inorganics -- arsenic, barium, cadmium, chromium, mercury, nickel, selenium, and silver -- reported in the risk assessment to be present in H-Power ash). It should be noted that while only arsenic is carcinogenic via ingestion, arsenic, cadmium, hexavalent chromium, and certain nickel species can also be carcinogenic via inhalation.

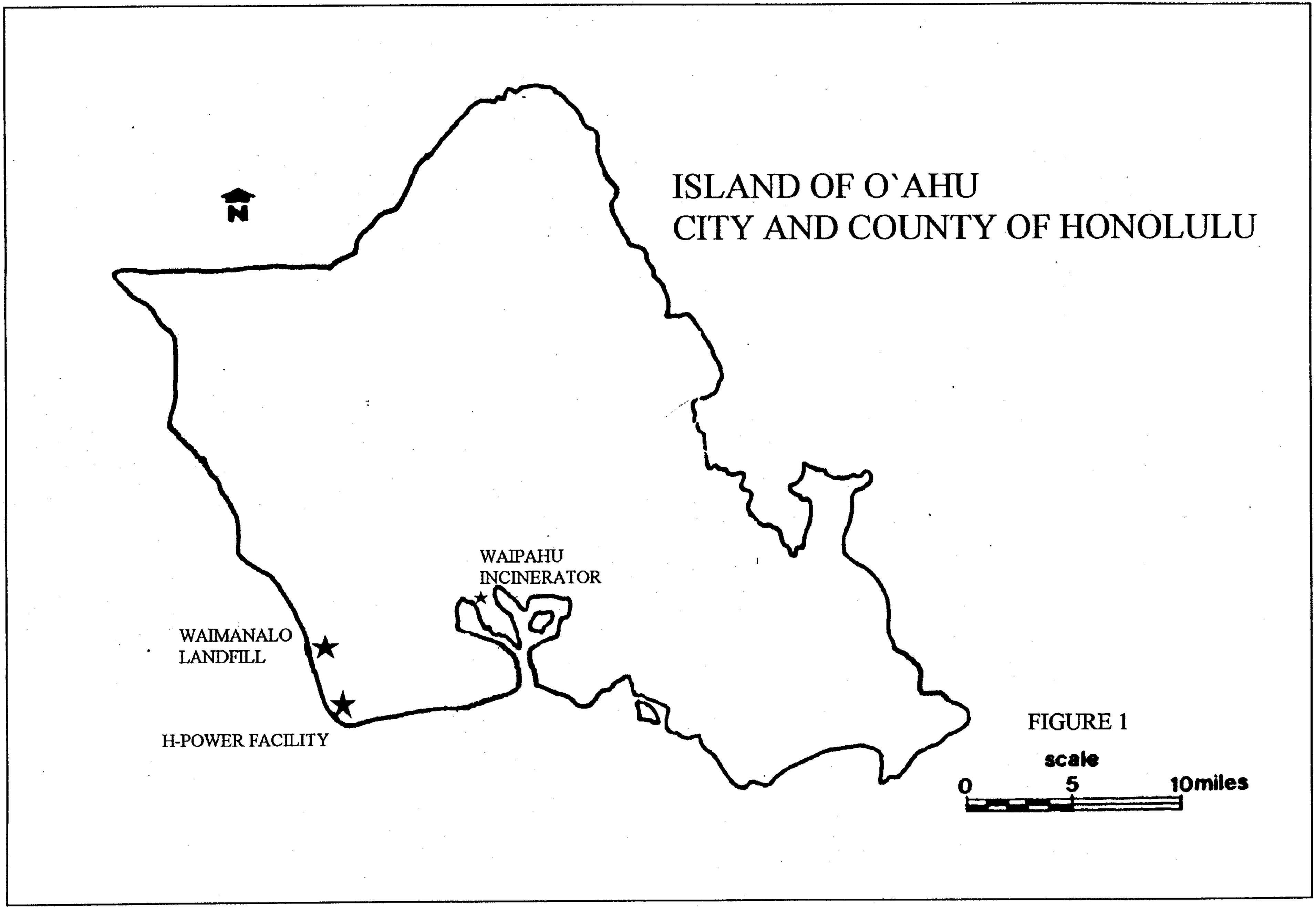
If you have any questions, please feel free to call me at (708) 218-1537.

cc: Tom Frank
Jim McHenry

0603A.DOC

Appendix D5

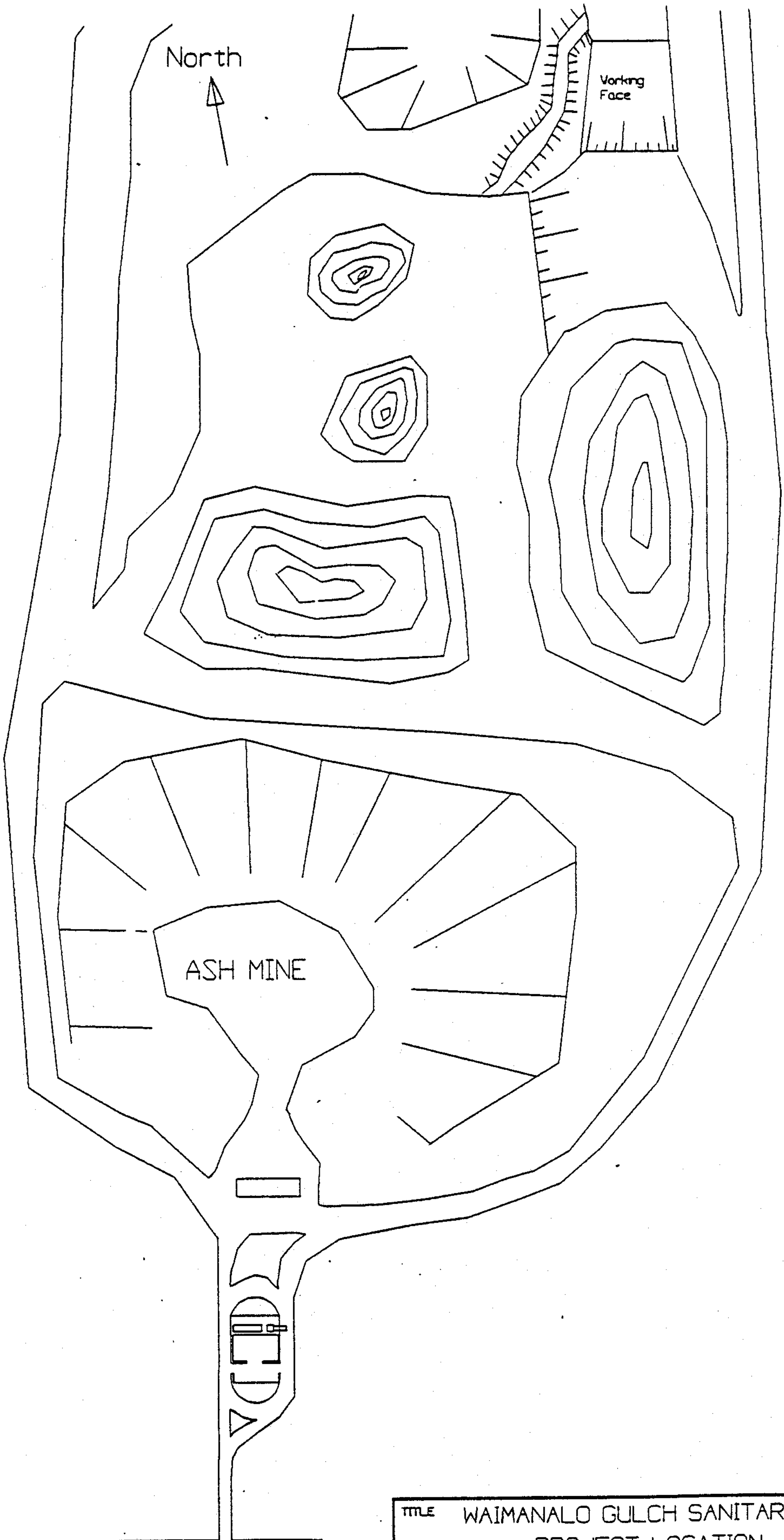
Drawings



ISLAND OF O`AHU
CITY AND COUNTY OF HONOLULU
N
WAIPAHU
INCINERATOR
WAIMANALO
LANDFILL
H-POWER FACILITY
scale
0
5
10miles

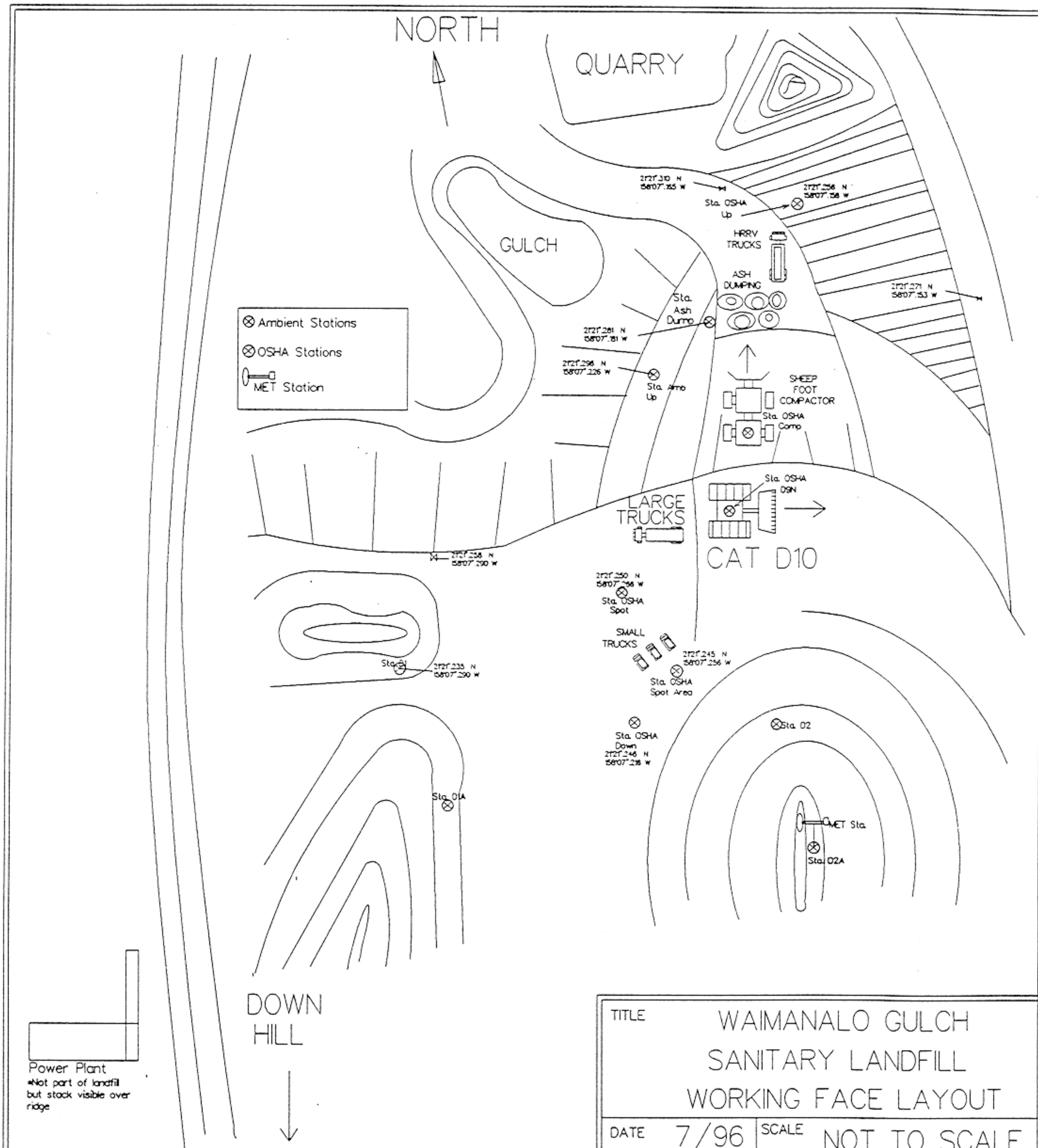
FIGURE 1

Waimanalo Gulch Sanitary Landfill

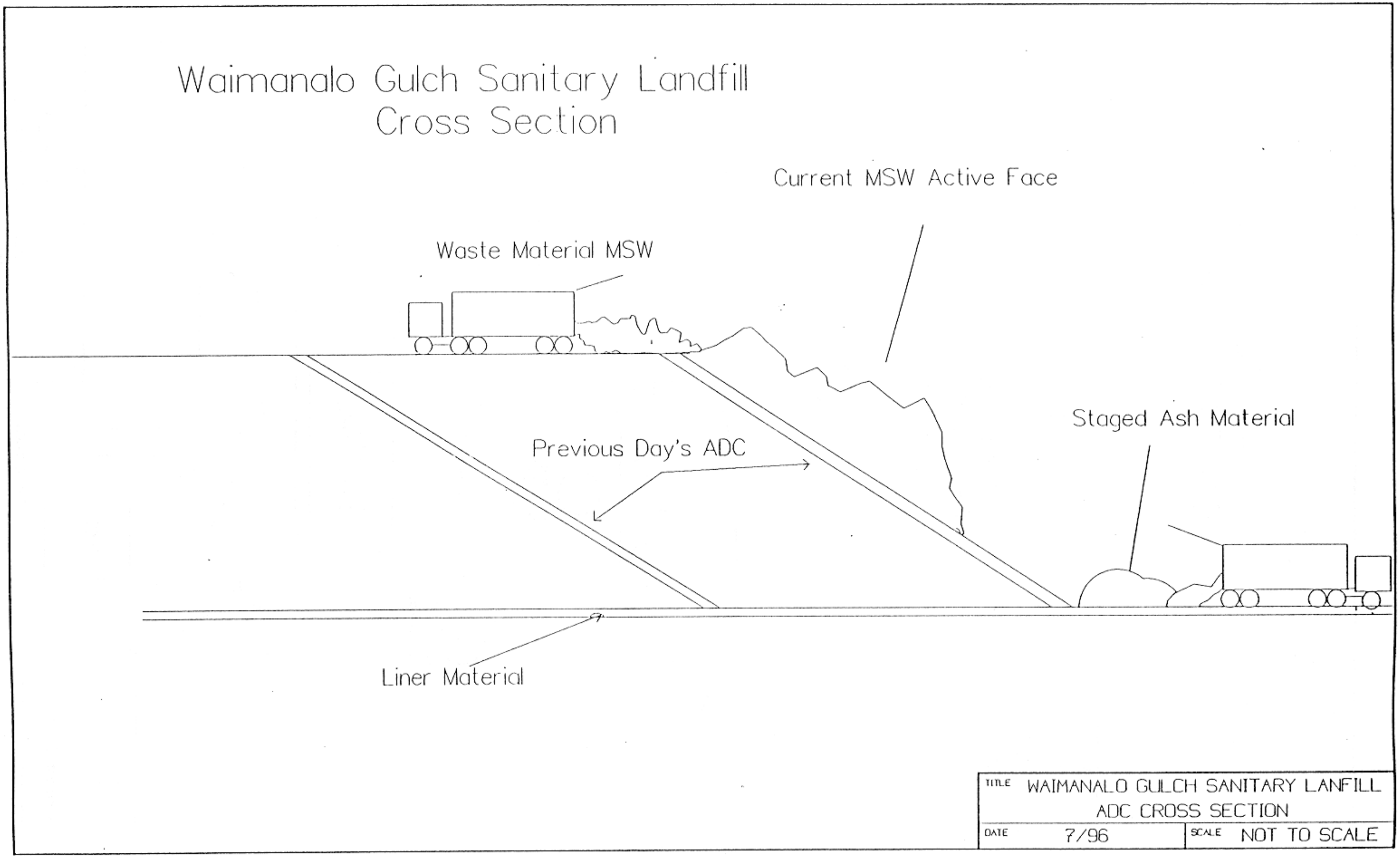


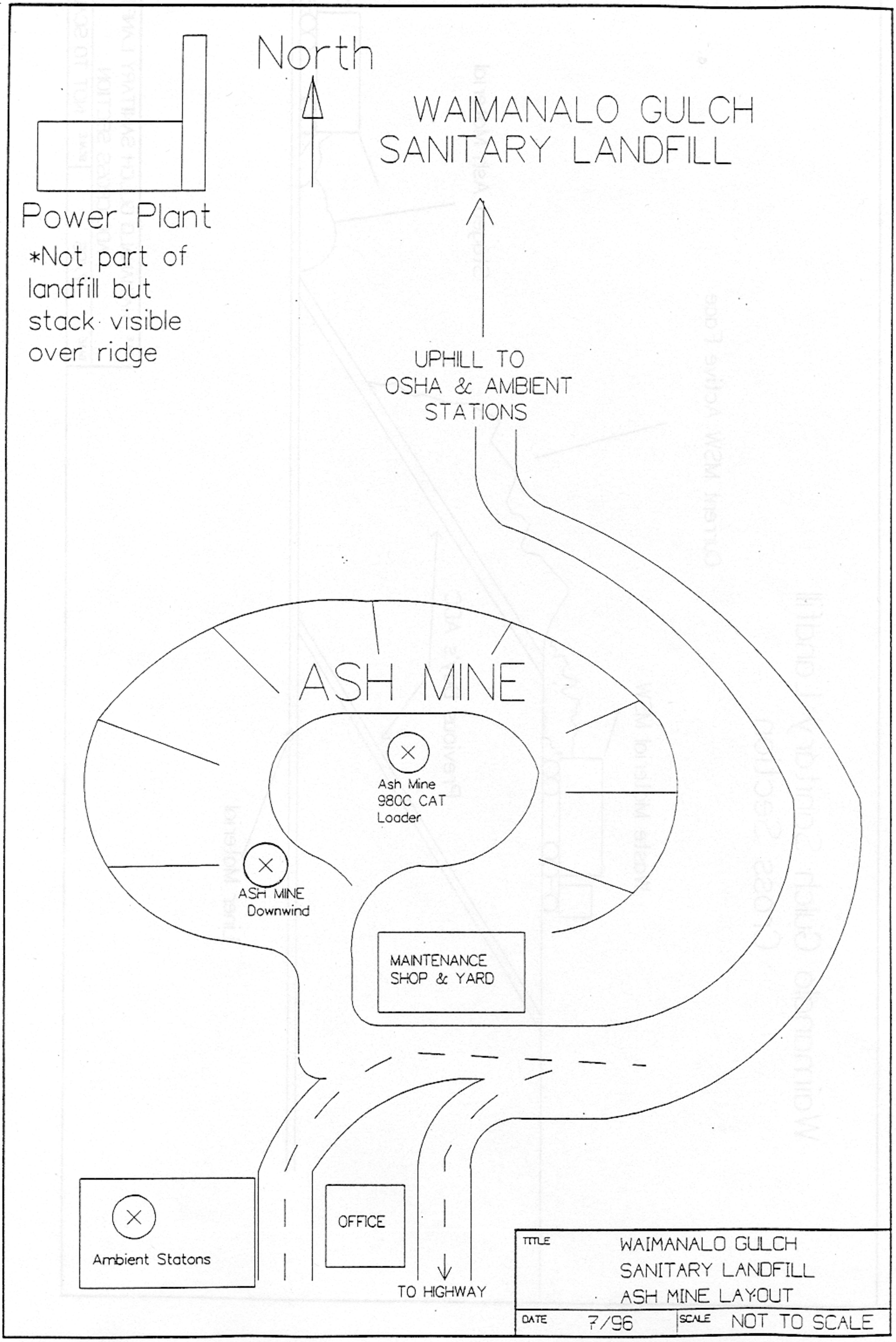
TITLE WAIMANALO GULCH SANITARY LANDFILL
PROJECT LOCATION

DATE 7/96 SCALE NOT TO SCALE



NORTH
QUARRY
GULCH
Ambient Stations
OSHA Stations
MET Station
Sta. OSHA Up
HRRV TRUCKS
ASH DUMPING
Sta. Ash Dump
Sta. Amb Up
SHEEP FOOT COMPACTOR
Sta. OSHA Comp
Sta. OSHA OSN
LARGE TRUCKS
CAT D10
Sta. OSHA Spot
SMALL TRUCKS
Sta. OSHA Spot Area
Sta. OSHA Down
Sta. D2
Sta. D1A
MET Sta.
Sta. D2A
DOWN HILL
Power Plant
*Not part of landfill but stack visible over ridge
TITLE
WAIMANALO GULCH
SANITARY LANDFILL
WORKING FACE LAYOUT
DATE 7/96
SCALE NOT TO SCALE


Waimanalo Gulch Sanitary Landfill
Cross Section
Current MSW Active Face
Waste Material MSW
Staged Ash Material
Previous Day's ADC
Liner Material
TITLE WAIMANALO GULCH SANITARY LANFILL
ADC CROSS SECTION
DATE 7/96
SCALE NOT TO SCALE


North
WAIMANALO GULCH
SANITARY LANDFILL
Power Plant
*Not part of landfill but stack visible over ridge
UPHILL TO OSHA & AMBIENT STATIONS
ASH MINE
Ash Mine 980C CAT Loader
ASH MINE Downwind
MAINTENANCE SHOP & YARD
Ambient Statons
OFFICE
TO HIGHWAY
TITLE
WAIMANALO GULCH
SANITARY LANDFILL
ASH MINE LAYOUT
DATE
7/96
SCALE
NOT TO SCALE

Appendix D6

Photos

Station Ambient Upwind (Sta. Amb Up)

Station Ambient Downwind 1 (Sta. D1) & Station Ambient Downwind 1A (Sta. D1A)
Sta. D1 Front of Gravel Pile Upper Right
Sta. D1A Left of Dirt Pile Lower Left

Station Ambient Downwind 2 (Sta. D2) & Station Ambient Downwind 2A (Sta. D2A)
Sta. D2 Front Face of Hill
Sta. D2A Top Left Side of Hill

Station Ash Dump (Sta. Ash Dump)
Station Ash Dump Center Right Above Ash Piles

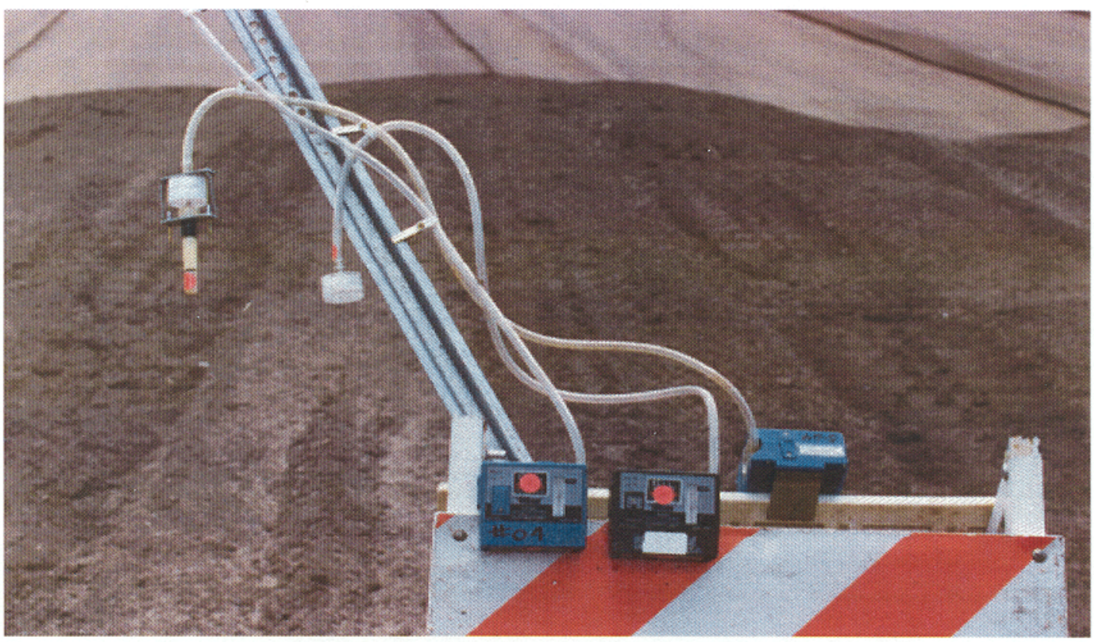
Station OSHA Upwind (Sta. OSHA Up)

Station OSHA Spotter/Spotter Area (Sta. OSHA Spot/Area) &
Station OSHA Downwind (Sta. OSHA Down)
Station OSHA Spot/Area - Center
Station OSHA Spot/Area - Left
Station OSHA Down - Right

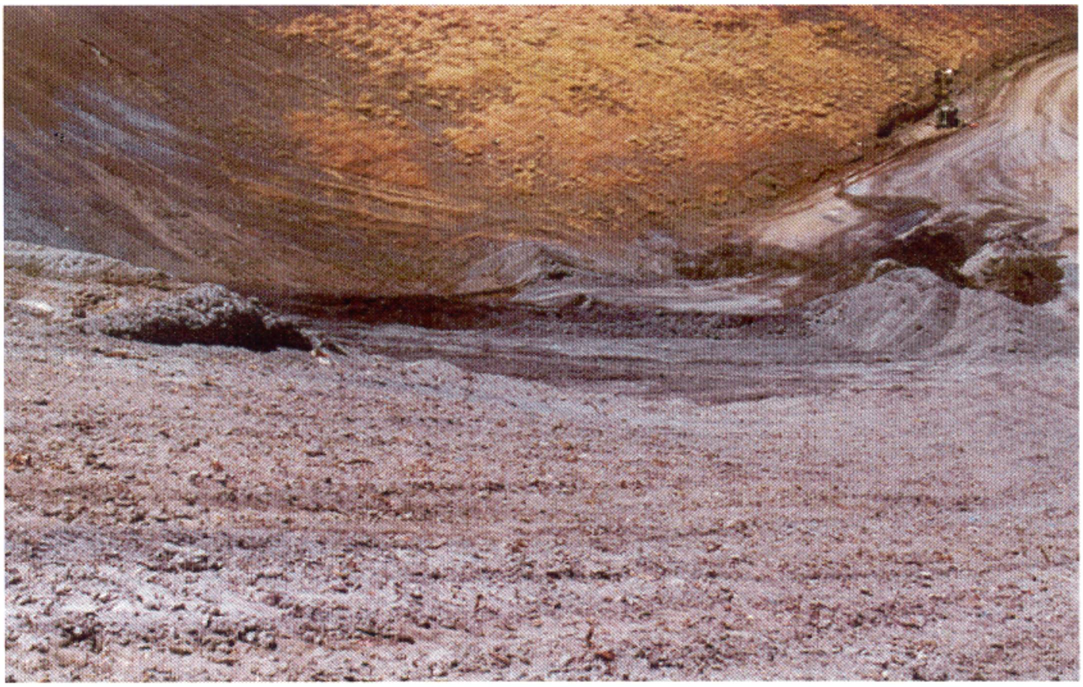
Station OSHA Compactor (Sta. OSHA Comp) &
Station OSHA Pusher D9N (Sta. OSHA D9N)

Station OSHA Spotter/Spotter
Area (Sta. OSHA Spot/Area)

Meteorological Station ("Met" Sta.)



Typical Station Setup



Ash Mine -- Dark Gray Areas Show Wet Ash
Light Gray Areas Show Layer of Dry Ash Cover

HRRV Truck Unloading Ash 30 - 35% Moisture

Construction of ADC

Compaction of MSW on ADC

Construction of ADC on MSW

D9N Compacting Sheet Rock

Dust Cloud From Truck Tires

Dust From Tires and Bed of D30D CAT Truck Hauling Rocks and Gravel

Quarry Not in Use Minimal Dust

Heavy Dust From Quarry

Appendix D7

Waimanalo Gulch Landfill Air Sample Data

Table 1
TOTAL DUST

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA U	0.73	1.0	0.43	1.3	0.36	0.21
OSHA D	0.31	0.54	0.32	0.45	0.94	0.20
CAT	0.11	0.22	0.19	0.17	0.25	0.60
COMP	<0.02	0.41	0.27	0.62	0.20	0.28
SPOT	0.48	0.59*	0.07	1.4	0.63	0.21
AMBIENT STATIONS						
U S1	0.2	0.42	0.36	0.1	<0.08	<0.1
U S2	0.65	0.44	0.76	0.27	0.05	0.09
U S3	-a	0.4	<0.2	<0.1	-a	-a
U S4	<0.02	<0.02	0.06	<0.02	<0.02	<0.02
D1 S1	<0.09		0.3		<0.07	
D1 S2	0.62		0.3		0.12	
D1 S3	-a		- b		-a	
D1 S4	- b		<0.02		<0.02	
D1A S1		0.34		0.33		0.2
D1A S2		0.22		0.39		- c
D1A S3		<0.2		<0.2		-a
D1A S4		<0.02		<0.02		0.03
D2 S1	<0.09		<0.07		<0.07	
D2 S2	0.23		0.30		0.17	
D2 S3	-a		<0.2		- a	
D2 S4	<0.02		- b		<0.02	
D2A S1		0.42		<0.02		<0.1
D2A S2		<0.03		0.16		<0.03
D2A S3		<0.2		<0.2		-a
D2A S4		<0.02		<0.02		<0.02
ASH DUMP		0.83		0.44		0.05
ASH MONITORING						
ASH MINE DUMP			<0.08			
ASH MINE LOADER						

Notes:

a: Sample aborted due to landfill schedule change.

b: Sample not collected due to pump fault.

c: Sample aborted. Cassette dislodged from sampling tube/pump and was found on the ground.

*: Cassette found on the ground and reconnected to sampling apparatus.

Table 2
RESPIRABLE DUST

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA U	0.19	0.23	0.09	0.25	0.03	0.08
OSHA D	0.05	0.27 *	0.11	0.09	0.08	0.09
CAT	0.03	0.07	<0.02	0.09	0.05 *	0.24
COMP	0.04	0.14	0.13	0.25	0.13	0.07
SPOT	0.09	0.18	0.17 *	0.15	0.18	0.06
AMBIENT STATIONS						
U S1	0.4	<0.08	<0.09	<0.09	-b	<0.2
U S2	0.03	0.03	0.05	0.1	<0.04	-a
U S3	-a	<0.2	<0.3	0.3	-a	-a
U S4	<0.02	<0.02	<0.02	0.6	<0.02	<0.02
D1 S1	<0.1		<0.08		<0.08	
D1 S2	0.1		0.04		0.05	
D1 S3	-a		<0.2		-a	
D1 S4	<0.02		<0.02		<0.02	
D1A S1		<0.08		0.84		<0.2
D1A S2		0.05		0.07		-a
D1A S3		<0.2		<0.2		-a
D1A S4		<0.02		<0.02		<0.02
D2 S1	<0.1		0.2		<0.08	
D2 S2	<0.03		<0.04		0.09	
D2 S3	-a		<0.2		-a	
D2 S4	<0.02		<0.02		<0.02	
D2A S1		<0.07		<0.08		-c
D2A S2		<0.04		0.1		-c
D2A S3		<0.2		<0.2		-a
D2A S4		<0.02		<0.02		<0.02
ASH DUMPING		0.04		0.02		<0.03
ASH MONITORING						
ASH MINE DUMP			<0.09			
ASH MINE LOADER			0.3			

Notes:
*: Laboratory report indicated sample was contaminated with tap water; results may be biased high.
a: Sample aborted due to landfill schedule change.
b: Sample not collected due to pump fault.
c: Sample not collected due to battery failure.

Table 3
TOTAL METALS

ARSENIC

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-D	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
OSHA-U	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CAT	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
COMP	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SPOT	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
AMBIENT STATIONS						
U-S1	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.005
U-S2	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
U-S3	- a	< 0.008	< 0.009	< 0.005	- a	- a
U-S4	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
D1-S1	< 0.004		< 0.004		< 0.004	
D1-S2	< 0.002		< 0.002		< 0.002	
D1-S3	- a		< 0.008		- a	
D1-S4	< 0.001		< 0.001		< 0.001	
D2-S1	< 0.004		< 0.004		< 0.004	
D2-S2	< 0.002		< 0.002		< 0.002	
D2-S3	- a		< 0.006		- a	
D2-S4	< 0.001		< 0.001		< 0.001	
D1A-S1		< 0.004		< 0.004		< 0.005
D1A-S2		< 0.002		< 0.002		< 0.002
D1A-S3		< 0.008		< 0.006		- a
D1A-S4		< 0.001		< 0.001		< 0.001
D2A-S1		< 0.004		< 0.004		< 0.006
D2A-S2		< 0.002		< 0.002		< 0.002
D2A-S3		< 0.008		< 0.006		- a
D2A-S4		< 0.001		< 0.001		< 0.001
ASH DUMPING		< 0.001		< 0.001		< 0.002
ASH MONITORING						
ASH MINE DUMP			< 0.004			
ASH MINE LOADER			< 0.004			

Notes:
a: Sample aborted due to landfill schedule change.

Table 4

TOTAL METALS

BARIUM

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
OSHA-D	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
CAT	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	**0.0002**
COMP	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
SPOT	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
AMBIENT STATIONS						
U-S1	< 0.0008	< 0.0007	< 0.0008	< 0.0007	< 0.0007	< 0.0009
U-S2	< 0.0003	< 0.0003	< 0.0003	< 0.0004	< 0.0003	< 0.0003
U-S3	- a	< 0.002	< 0.002	< 0.001	- a	- a
U-S4	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
D1-S1	< 0.0008		< 0.0007		< 0.0007	
D1-S2	< 0.0003		< 0.0003		< 0.0003	
D1-S3	- a		< 0.002		- a	
D1-S4	< 0.0002		< 0.0002		< 0.0002	
D2-S1	< 0.0008		< 0.0007		< 0.0007	
D2-S2	< 0.0003		< 0.0003		< 0.0003	
D2-S3	- a		< 0.002		- a	
D2-S4	< 0.0002		< 0.0002		< 0.0002	
D1A-S1		< 0.0007		< 0.0007		< 0.0009
D1A-S2		< 0.0003		< 0.0003		< 0.0003
D1A-S3		< 0.002		< 0.002		- a
D1A-S4		< 0.0002		< 0.0002		< 0.0002
D2A-S1		< 0.0007		< 0.0007		< 0.002
D2A-S2		< 0.0003		< 0.0003		< 0.0003
D2A-S3		< 0.002		< 0.002		- a
D2A-S4		< 0.0002		< 0.0002		< 0.0002
ASH DUMPING		< 0.0002		< 0.0002		< 0.0003
ASH MONITORING						
ASH MINE DUMP			< 0.0008			
ASH MINE LOADER			< 0.0008			

Notes:

a: Sample aborted due to landfill schedule change.

Table 5
TOTAL METALS

CADMIUM

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
OSHA-D	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
CAT	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
COMP	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SPOT	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
AMBIENT STATIONS						
U-S1	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0005
U-S2	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
U-S3	- a	< 0.0008	< 0.0009	< 0.0005	- a	- a
U-S4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
D1-S1	< 0.0004		< 0.0004		< 0.0004	
D1-S2	< 0.0002		< 0.0002		< 0.0002	
D1-S3	- a		< 0.0008		- a	
D1-S4	< 0.0001		< 0.0001		< 0.0001	
D2-S1	< 0.0004		< 0.0004		< 0.0004	
D2-S2	< 0.0002		< 0.0002		< 0.0002	
D2-S3	- a		< 0.0006		- a	
D2-S4	< 0.0001		< 0.0001		< 0.0001	
D1A-S1		< 0.0004		< 0.0004		< 0.0005
D1A-S2		< 0.0002		< 0.0002		< 0.0002
D1A-S3		< 0.0008		< 0.0006		- a
D1A-S4		< 0.0001		< 0.0001		< 0.0001
D2A-S1		< 0.0004		< 0.0004		< 0.0006
D2A-S2		< 0.0002		< 0.0002		< 0.0002
D2A-S3		< 0.0008		< 0.0006		- a
D2A-S4		< 0.0001		< 0.0001		< 0.0001
ASH DUMPING		< 0.0001		< 0.0001		< 0.0002
ASH MONITORING						
ASH MINE DUMP		< 0.0001		< 0.0001		< 0.0002
ASH MINE LOADER			< 0.0004			

Notes:
a: Sample aborted due to landfill schedule change.

Table 6
TOTAL METALS

TOTAL CHROMIUM

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-D	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
OSHA-U	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CAT	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
COMP	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SPOT	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
AMBIENT STATIONS						
U-S1	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.005
U-S2	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
U-S3	- a	< 0.008	< 0.009	< 0.005	- a	- a
U-S4	< 0.001		< 0.001	< 0.001	< 0.001	< 0.001
D1-S1	< 0.004		< 0.004		< 0.004	
D1-S2	< 0.002		< 0.002		< 0.002	
D1-S3	- a		< 0.008		- a	
D1-S4	< 0.001		< 0.001		< 0.001	
D2-S1	< 0.004		< 0.004		< 0.004	
D2-S2	< 0.002		< 0.002		< 0.002	
D2-S3	- a		< 0.006		- a	
D2-S4	< 0.001		< 0.001		< 0.001	
D1A-S1		< 0.004		< 0.004		< 0.005
D1A-S2		< 0.002		< 0.002		< 0.002
D1A-S3		< 0.008		< 0.006		- a
D1A-S4		< 0.001		< 0.001		< 0.001
D2A-S1		< 0.004		< 0.004		< 0.006
D2A-S2		< 0.002		< 0.002		< 0.002
D2A-S3		< 0.008		< 0.006		- a
D2A-S4		< 0.001		< 0.001		< 0.001
ASH DUMPING		< 0.001		< 0.001		< 0.002
ASH MONITORING						
ASH MINE DUMP			< 0.004			
ASH MINE LOADER			< 0.004			

Notes:
a: Sample aborted due to landfill schedule change.

Table 7
TOTAL METALS

CHROMIUM VI

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U		< 0.0001		<0.0002		<0.0007
OSHA-D		<0.0002		<0.0002		<0.0002
CAT		<0.0002		<0.0002		<0.0002
COMP		<0.0002		<0.0002		<0.0002
SPOT		<0.0002		<0.0002		<0.0002
AMBIENT STATIONS						
U-S1		< 0.0006				< 0.002
U-S2		< 0.0003				< 0.0004
U-S3		< 0.002				- a
U-S4		< 0.0001				< 0.0001
D1-S1						
D1-S2						
D1-S3						
D1-S4						
D2-S1						
D2-S2						
D2-S3						
D2-S4						
D1A-S1		< 0.0006				< 0.002
D1A-S2		< 0.0003				< 0.0004
D1A-S3		< 0.002				- a
D1A-S4		< 0.0001				< 0.0001
D2A-S1		< 0.0006				< 0.002
D2A-S2		< 0.0003				< 0.0004
D2A-S3		< 0.002				- a
D2A-S4		- a				< 0.0001
ASH DUMPING		< 0.0002		< 0.0002		< 0.0002

Notes:
a: Sample aborted due to landfill schedule change.

Table 8
TOTAL METALS

LEAD

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
OSHA-D	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
CAT	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
COMP	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
SPOT	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
AMBIENT STATIONS						
U-S1	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.003
U-S2	< 0.0006	< 0.0007	< 0.0008	< 0.0008	< 0.0008	< 0.0008
U-S3	- a	< 0.004	< 0.005	< 0.003	- a	- a
U-S4	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
D1-S1	< 0.002		< 0.002		< 0.002	
D1-S2	< 0.0006		< 0.0008		< 0.0008	
D1-S3	- a		< 0.004		- a	
D1-S4	< 0.0005		< 0.0005		< 0.0005	
D2-S1	< 0.002		< 0.002		< 0.002	
D2-S2	< 0.0006		< 0.0008		< 0.0008	
D2-S3	- a		< 0.003		- a	
D2-S4	< 0.0005		< 0.0005		< 0.0005	
D1A-S1		< 0.002		< 0.002		< 0.003
D1A-S2		< 0.0007		< 0.0008		< 0.0008
D1A-S3		< 0.004		< 0.003		- a
D1A-S4		< 0.0005		< 0.0005		< 0.0005
D2A-S1		< 0.002		< 0.002		< 0.003
D2A-S2		< 0.0007		< 0.0008		< 0.0008
D2A-S3		< 0.004		< 0.003		- a
D2A-S4		< 0.0005		< 0.0005		< 0.0005
ASH DUMPING		< 0.0005		< 0.0005		< 0.0006
ASH MONITORING						
ASH MINE DUMP		< 0.0005		< 0.0005		< 0.0006
ASH MINE LOADER			< 0.002			

Notes:
a: Sample aborted due to landfill schedule change.

Table 9
TOTAL METALS

NICKEL

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
OSHA-D	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
CAT	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
COMP	**0.0002**	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
SPOT	**0.0002**	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
AMBIENT STATIONS						
U-S1	< 0.0008	< 0.0007	< 0.0008	< 0.0007	< 0.0007	< 0.0009
U-S2	< 0.0003	< 0.0003	< 0.0003	< 0.0004	< 0.0003	< 0.0003
U-S3	- a	< 0.002	< 0.002	< 0.001	- a	- a
U-S4	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
D1-S1	< 0.0008		< 0.0007		< 0.0007	
D1-S2	< 0.0003		< 0.0003		< 0.0003	
D1-S3	- a		< 0.002		- a	
D1-S4	< 0.0002		< 0.0002		< 0.0002	
D2-S1	< 0.0008		< 0.0007		< 0.0007	
D2-S2	< 0.0003		< 0.0003		< 0.0003	
D2-S3	- a		< 0.002		- a	
D2-S4	< 0.0002		< 0.0002		< 0.0002	
D1A-S1		< 0.0007		< 0.0007		< 0.0009
D1A-S2		< 0.0003		< 0.0003		< 0.0003
D1A-S3		< 0.002		< 0.002		- a
D1A-S4		< 0.0002		< 0.0002		< 0.0002
D2A-S1		< 0.0007		< 0.0007		< 0.002
D2A-S2		< 0.0003		< 0.0003		< 0.0003
D2A-S3		< 0.002		< 0.002		- a
D2A-S4		< 0.0002		< 0.0002		< 0.0002
ASH DUMPING		< 0.0002		< 0.0002		< 0.0003
ASH MONITORING						
ASH MINE DUMP			< 0.0008			
ASH MINE LOADER			< 0.0008			

Notes:
a: Sample aborted due to landfill schedule change.

Table 10
TOTAL METALS

SELENIUM

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-D	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
OSHA-U	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
CAT	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
COMP	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SPOT	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
AMBIENT STATIONS						
U-S1	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.005
U-S2	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
U-S3	- a	< 0.008	< 0.009	< 0.005	- a	- a
U-S4	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
D1-S1	< 0.004		< 0.004		< 0.004	
D1-S2	< 0.002		< 0.002		< 0.002	
D1-S3	- a		< 0.008		- a	
D1-S4	< 0.001		< 0.001		< 0.001	
D2-S1	< 0.004		< 0.004		< 0.004	
D2-S2	< 0.002		< 0.002		< 0.002	
D2-S3	- a		< 0.006		- a	
D2-S4	< 0.001		< 0.001		< 0.001	
D1A-S1		< 0.004		< 0.004		< 0.005
D1A-S2		< 0.002		< 0.002		< 0.002
D1A-S3		< 0.008		< 0.006		- a
D1A-S4		< 0.001		< 0.001		< 0.001
D2A-S1		< 0.004		< 0.004		< 0.006
D2A-S2		< 0.002		< 0.002		< 0.002
D2A-S3		< 0.008		< 0.006		- a
D2A-S4		< 0.001		< 0.001		< 0.001
ASH DUMPING		< 0.001		< 0.001		< 0.002
ASH MONITORING						
ASH MINE DUMP			< 0.004			
ASH MINE LOADER			< 0.004			

Notes:
a: Sample aborted due to landfill schedule change.

Table 11
TOTAL METALS

SILVER

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
OSHA-D	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
CAT	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
COMP	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SPOT	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
AMBIENT STATIONS						
U-S1	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0005
U-S2	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
U-S3	- a	< 0.0008	< 0.0009	< 0.0005	- a	- a
U-S4	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
D1-S1	< 0.0004		< 0.0004		< 0.0004	
D1-S2	< 0.0002		< 0.0002		< 0.0002	
D1-S3	- a		< 0.0008		- a	
D1-S4	< 0.0001		< 0.0001		< 0.0001	
D2-S1	< 0.0004		< 0.0004		< 0.0004	
D2-S2	< 0.0002		< 0.0002		< 0.0002	
D2-S3	- a		< 0.0006		- a	
D2-S4	< 0.0001		< 0.0001		< 0.0001	
D1A-S1		< 0.0004		< 0.0004		< 0.0005
D1A-S2		< 0.0002		< 0.0002		< 0.0002
D1A-S3		< 0.0008		< 0.0006		- a
D1A-S4		< 0.0001		< 0.0001		< 0.0001
D2A-S1		< 0.0004		< 0.0004		< 0.0006
D2A-S2		< 0.0002		< 0.0002		< 0.0002
D2A-S3		< 0.0008		< 0.0006		- a
D2A-S4		< 0.0001		< 0.0001		< 0.0001
ASH DUMPING		< 0.0001		< 0.0001		< 0.0002
ASH MONITORING						
ASH MINE DUMP		< 0.0001		< 0.0001		< 0.0002
ASH MINE LOADER			< 0.0004			

Notes:
a: Sample aborted due to landfill schedule change.

Table 12
RESPIRABLE METALS

ARSENIC

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U		< 0.001	< 0.002		< 0.002	< 0.002
OSHA-D		< 0.001	< 0.002		< 0.002	< 0.002
CAT						
COMP						
SPOT		< 0.002	< 0.002		< 0.002	< 0.002

BARIUM

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U		< 0.0002	< 0.0003		< 0.0003	< 0.0003
OSHA-D		< 0.0002	< 0.0003		< 0.0003	< 0.0003
CAT						
COMP						
SPOT		< 0.0003	< 0.0003		< 0.0003	< 0.0003

CADMIUM

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U		< 0.0001	< 0.0002		< 0.0002	< 0.0002
OSHA-D		< 0.0001	< 0.0002		< 0.0002	< 0.0002
CAT						
COMP						
SPOT		< 0.0002	< 0.0002		< 0.0002	< 0.0002

CHROMIUM

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U		< 0.001	< 0.002		< 0.002	< 0.002
OSHA-D		< 0.001	< 0.002		< 0.002	< 0.002
CAT						
COMP						
SPOT		< 0.002	< 0.002		< 0.002	< 0.002

LEAD

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U		< 0.0005	< 0.0006		< 0.0006	< 0.0006
OSHA-D		< 0.0005	< 0.0006		< 0.0006	< 0.0006
CAT						
COMP						
SPOT		< 0.0006	< 0.0006		< 0.0006	< 0.0006

Table 12 cont'd
RESPIRABLE METALS

NICKEL

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U		< 0.0002	< 0.0003		< 0.0003	< 0.0003
OSHA-D		**0.0002**	< 0.0003		< 0.0003	< 0.0003
CAT						
COMP						
SPOT		< 0.0003	< 0.0003		< 0.0003	< 0.0003

SELENIUM

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U		< 0.001	< 0.002		< 0.002	< 0.002
OSHA-D		< 0.001	< 0.002		< 0.002	< 0.002
CAT						
COMP						
SPOT		< 0.002	< 0.002		< 0.002	< 0.002

SILVER

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA-U		< 0.0001	< 0.0002		< 0.0002	< 0.0002
OSHA-D		< 0.0001	< 0.0002		< 0.0002	< 0.0002
CAT						
COMP						
SPOT		< 0.0002	< 0.0002		< 0.0002	< 0.0002

Table 13
RESPIRABLE CRYSTALLINE SILICA

OSHA STATIONS	Day 1 07/09 (mg/m3)	Day 2 07/10 (mg/m3)	Day 3 07/11 (mg/m3)	Day 4 07/12 (mg/m3)	Day 5 07/13 (mg/m3)	Day 6 07/14 (mg/m3)
OSHA U				< 0.010		<0.012
OSHA D				< 0.010		<0.011
CAT						<0.010
COMP						<0.010
SPOT				< 0.011		<0.012
AMBIENT STATIONS						
U S1				<0.042	- b	
U S2				<0.018	<0.018	
U S3				<0.059	- a	
U S4				<0.071	<0.006	
D1 S1					<0.040	
D1 S2					0.030	
D1 S3					- a	
D1 S4					<0.006	
D1A S1				<0.040		
D1A S2				<0.018		
D1A S3				<0.069		
D1A S4				<0.0072		
D2 S1					<0.039	
D2 S2					<0.018	
D2 S3					- a	
D2 S4					<0.006	
D2A S1				<0.040		
D2A S2				<0.018		
D2A S3				<0.064		
D2A S4				<0.0070		
ASH DUMPING						
ASH MONITORING						
ASH MINE DUMP			<0.042			
ASH MINE LOADER			<0.043			

Notes:
a: Sample aborted due to landfill schedule change.
b: Sample not collected due to pump fault.

Table 14
MERCURY

	Particulate Concentrations (mg/m3)						Vapor Concentrations (mg/m3)					
OSHA STATIONS	Day 1 07/09/96 (mg/m3)	Day 2 07/10/96 (mg/m3)	Day 3 07/11/96 (mg/m3)	Day 4 07/12/96 (mg/m3)	Day 5 07/13/96 (mg/m3)	Day 6 07/14/96 (mg/m3)	Day 1 07/09/96 (mg/m3)	Day 2 07/10/96 (mg/m3)	Day 3 07/11/96 (mg/m3)	Day 4 07/12/96 (mg/m3)	Day 5 07/13/96 (mg/m3)	Day 6 07/14/96 (mg/m3)
OSHA U			< 0.0005		< 0.0006				**0.0008**		**0.0009**	
OSHA D			< 0.0005		**0.0014**				**0.001**		**0.0013**	
CAT			**0.0008**		< 0.0005				**0.0007**		**0.0005**	
COMP			**0.0019**		< 0.0004				**0.0007**		< 0.0004	
SPOT			< 0.0005		< 0.0006				**0.0013**		< 0.0006	
AMBIENT STATIONS												
U S1			< 0.002		< 0.002				< 0.002		**0.006**	
U S2			< 0.0009		< 0.0008				< 0.0009		**0.001**	
U S3			< 0.005		- a				**0.009**		- a	
U S4			< 0.0004		**0.0015**				< 0.0004		**0.0016**	
D1 S1			**0.016**		< 0.002				**0.006**		**0.008**	
D1 S2			< 0.0009		< 0.0008				< 0.0009		< 0.0008	
D1 S3			**0.02**		- a				**0.012**		- a	
D1 S4			**0.0004**		< 0.0003				**0.0007**		**0.0005**	
D2 S1			< 0.002		< 0.002				< 0.002		< 0.002	
D2 S2			< 0.0008		< 0.0008				< 0.0008		**0.0026**	
D2 S3			< 0.004		- a				< 0.004		- a	
D2 S4			**0.0005**		< 0.0003				< 0.0003		**0.0003**	
ASH DUMPING		< 0.0006		0.0023		< 0.0006		**0.0022**		**0.0009**		**0.0009**

Notes:
1. <0.008: Indicates mercury was not detected in the sample. Value represents the detection limit.
2. Values in boldface type represent detected concentrations.
a: Sample aborted due to landfill schedule change.

TABLE 15
ANALYTICAL RESULTS FOR ASH AND QUARRY-FINE SAMPLES

CONSTITUENT	Ash 7/9/96 (mg/kg)	Ash 7/10/96 (mg/kg)	Ash 7/11/96 (mg/kg)	Ash 7/12/96 (mg/kg)	Ash 7/13/96 (mg/kg)	Ash 7/14/96 (mg/kg)	Quarry Fines 7/9/96 (mg/kg)	Quarry Fines 7/13/96 (mg/kg)
Arsenic	35	40	35	70	54	33	9	7
Barium	800	880	400	450	630	600	125	95
Cadmium	28	39	21	60	38	40	ND (0.5)	ND (0.5)
Chromium	65	80	55	80	80	60	100	40
Lead	2200	16000	1800	7500	6200	1900	10	ND (5.0)
Mercury	3.8	5.3	3.5	5.3	4.4	1.4	ND (0.05)	ND (0.05)
Nickel	85	80	75	80	200	90	185	115
Selenium	ND (0.5)	ND (0.5)	ND (0.5)	ND (0.5)	ND (0.5)	ND (0.5)	ND (0.5)	ND (0.5)
Silver	4	4	4	5	4	4	ND (0.5)	ND (0.5)

TABLE 16
MERCURY DATA FROM OCTOBER 1996 SAMPLING
WAIMANALO GULCH SANITARY LANDFILL

	Particulate Concentrations (1, 2)			Vapor Concentrations (1, 2)		
	Day 1 10/01/96 (mg/m3)	Day 2 10/02/96 (mg/m3)	Day 3 10/03/96 (mg/m3)	Day 1 10/01/96 (mg/m3)	Day 2 10/02/96 (mg/m3)	Day 3 10/03/96 (mg/m3)
AMBIENT STATIONS - DAY						
ASH MONOFILL	<0.0007	<0.0005	<0.0005	<0.0007 (<0.0008)	<0.0005 (<0.0005)	<0.0005
D1 (3)	<0.0006		<0.0005	<0.0006 (<0.0007)		<0.0005 (<0.0005)
D2 (4)		<0.0005			<0.0005	
KAHE POINT (5)	<0.001			<0.001 (<0.0009)		
H-POWER / AES FENCE		<0.0005			<0.0005	
QUARRY			<0.0005			<0.0005
WESTERN EDGE (6)	<0.0006	<0.0005	<0.0005	<0.0006	<0.0005	<0.0005
SPOTTER AREA	<0.0007		<0.0005	<0.0007		<0.0005
ASH TRUCK (7)		<0.002			<0.002	
AMBIENT STATIONS - NIGHT						
ASH MONOFILL	<0.0004	<0.0003	<0.0003	<0.0004 (<0.0004)	<0.0003 (<0.0003)	<0.0003
D1 (3)	<0.0003		<0.0003	<0.0003 (<0.0003)		<0.0003 (<0.0003)
D2 (4)		<0.0003			<0.0003	
H-POWER PARKING LOT	<0.0003			<0.0003 (<0.0003)		
WMX PARKING LOT		<0.0003			<0.0003	
QUARRY			<0.0003			<0.0003
WESTERN EDGE (6)	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
SPOTTER AREA	<0.0003		<0.0003	<0.0003		<0.0003
ASH TRUCK (7)		<0.0003			<0.0003	

Notes:

1. <0.008: Indicates mercury was not detected in the sample, value shown is the detection limit. Values in parentheses are results for duplicate samples.
2. Blanks indicate that samples were not collected from that location on that day.
3. This sampling station was in the same location as station D1 during the July 1996 sampling.
4. This sampling station was in the same location as station D2A during the July 1996 sampling.
5. Sampling station located in the parking lot at Kahe Point.
6. Sampling station located at the western edge of Waimanalo Gulch Landfill, near the microwave tower.
7. Ash truck sampling occurred at H-Power. Daytime samples were collected from beneath the cover of an ash truck. Nighttime samples were collected inside the ash loading tower.

Appendix D8

Summary – Ambient Air Monitoring of Beneficial Use of Municipal Waste Combustor (MWC) Ash as Daily Landfill Cover

Ambient Air Monitoring of the Beneficial Use of Municipal Waste Combustor (MWC) Ash as Daily Landfill Cover

Brian H. Magee
Ogden Environmental and Energy Services, Inc.
239 Littleton Rd., Suite 1B
Westford, MA 01886

Amy C. Miller
Ogden Environmental and Energy Services, Inc.
239 Littleton Rd., Suite 1B
Westford, MA 01886

Jeffrey L. Hahn
Ogden Projects, Inc.
40 Lane Road
Fairfield, NJ 07007

Colin M. Jones
City and County of Honolulu
91-174 Hanua Street
Kapolei, HI 96707

INTRODUCTION

This paper summarizes Human Health Risk Assessments of the proposed use of combined ash from the H-POWER municipal waste combustor (MWC) in two beneficial uses: (1) Landfill Daily Cover for the Waimanalo Gulch Sanitary Landfill in Ewa, Oahu, Hawaii, which is operated by Waste Management of Hawaii, Inc. for the City and County of Honolulu and (2) Landfill Final Cover, a component in the final cover of the Waipahu landfill, in Waipahu, Oahu, Hawaii.

The human health risk assessment represents one phase of a larger project involving the investigation of several potential uses of H-POWER MWC ash as alternatives to the current practice of disposal in a lined monofill located at the Waimanalo Gulch Sanitary Landfill. The ash consists of approximately 70% bottom ash and 30% fly ash from the MWC, hereafter referred to as H-POWER combined ash.

At this time, three alternative uses of H-POWER combined ash have been identified: The first option consists of using H-POWER combined ash as a component in the final cover in the closure of the Waipahu Landfill; the second option consists of using H-POWER combined ash as daily cover at the Waimanalo Gulch Sanitary Landfill; and, the third option consists of mixing H-POWER combined ash into aggregate to be used in roadway paving material.

Investigations into these proposed ash uses are detailed in a September 1994 report which presents the rationale for and results of tests conducted to support alternative ash use as landfill cover (daily cover and final cover) and as roadway aggregate.[1] The tests conducted for this Phase I investigation included biological, chemical, and engineering tests (*e.g.*, botanical growth potential, metals content, sieve analyses, strength analyses, permeability, and others). The results of the Phase I investigation indicate that H-POWER combined ash is suitable for these alternative beneficial uses.

During June 1995, subsequent to completion of the Phase I investigation, ambient total suspended particulate (dust) concentrations were measured at Waimanalo Gulch Sanitary Landfill during disposal of municipal solid waste (MSW) as well as disposal of H-POWER combined ash into the lined monofill. The purpose of collecting these preliminary data was to estimate an emission factor for the combined ash. These data, together with the chemical data collected during Phase I, were used as the basis of human health risk assessments conducted for both landfill cover options (final cover and daily cover).

The human health risk assessment of the use of H-POWER combined ash in the closure of the Waipahu Landfill was conducted by Ogden, and a report was submitted to the State of Hawaii Department of Health (DOH).[2] Preliminary review by the DOH indicated that they approve of the methodology and procedures used therein.

Following this, Ogden prepared a preliminary human health risk assessment of the use of H-POWER combined ash as alternate daily cover at the Waimanalo Gulch Sanitary Landfill. Based on chemical analytical data for ash samples collected during the Phase I investigation and other testing, noncarcinogenic and carcinogenic health effects were evaluated for ten constituents. Potential exposures to ash, ash-derived dust, and ash leachate were evaluated for key potential receptors, including landfill workers, adults and children who may visit the landfill (to dispose of household waste), and adults and children who live in nearby residential neighborhoods.

Several activities associated with the proposed use of H-POWER combined ash as daily cover theoretically have the potential to create fugitive dust and, therefore, were evaluated in the risk assessment. They include:

- pushing and compacting fresh MSW on the previous day's ash cover;
- pushing and compacting fresh MSW on MSW;
- pushing and compacting fresh combined ash on MSW to create the daily cover; and,
- mining of combined ash.

The ambient air data collected in June 1995 (downwind of combined ash disposal in a lined monofill and MSW disposal in the lined landfill) were used as surrogate data for the dust concentrations associated with these specific activities. However, each of these activities has a different potential for dust generation and, at the time of the preliminary risk assessment, each was expected to produce different downwind dust concentrations. The 1995 dust data were used because activity-specific dust concentrations had not yet been measured. Analytical data generated from ash samples collected during the Phase I investigation and other testing were used to evaluate potential direct exposures to H-POWER combined ash (ingestion and dermal contact), to predict leachate concentrations, and as mentioned, to estimate metals concentrations in dust. The results of this preliminary risk assessment were presented in a report to the Hawaii and indicated that the proposed use of H-POWER combined ash for daily cover would pose no significant noncarcinogenic or carcinogenic human health risk.[3]

The preliminary risk assessment for ash use as daily cover identified the lack of available air data associated with specific landfill activities. To address this data gap, approval was sought and obtained from the DOH to conduct a one-week demonstration program involving use of H-POWER combined ash as alternate daily cover at the Waimanalo Gulch Sanitary Landfill. This demonstration program was conducted with the cooperation of the City and County of Honolulu, Waste Management of Hawaii, Inc., and the DOH.

These results were incorporated into the final human health risk assessment of the use of H-POWER combined ash as alternate daily cover for the Waimanalo Gulch Sanitary Landfill. The revised risk estimates for the daily cover risk assessment are reported in this paper.

AMBIENT AIR MONITORING PROGRAM

During the one-week demonstration program, conducted during July 1996, concentrations of dust, metals, and crystalline silica were measured. Specifically, total and respirable dust, total and respirable metals (including arsenic, barium, chromium, cadmium, lead, nickel, selenium, and silver), respirable crystalline silica, hexavalent chromium, and total mercury (particulate and elemental vapor) were measured. Personal sampling was conducted in equipment cabs and on outdoor employees, and ambient sampling was conducted in numerous locations upwind and downwind of specific landfill activities. Overall, more than 100 personal and area samples were collected using personal sampling pumps, and more than 400 analyses were performed.

Ambient air samples were collected during dumping of ash into stockpiles (for use as daily cover), pushing and compacting of MSW on the previous day's ash cover, pushing and compacting of MSW on fresh MSW (current day's waste), and creating the daily cover at day's end. Data collected during the overnight period when the ash cover was exposed to the elements was evaluated separately. In addition to these daily activities, air samples were also collected during the excavation of H-POWER combined ash previously disposed in the landfill's ash monofill and subsequent loading onto dump trucks (referred to as ash mining).

At certain stations, all-day samples were collected. Locations included: OSHA U (upwind), OSHA D (downwind), CAT (in cab of caterpillar tractor), COMP (in cab of compactor), and SPOT (either on spotter or in spotter area). At other stations, designated ambient stations, samples were collected during four specific time periods defined as shifts 1-4 (S1-S4). These shifts corresponded to early morning, mid-day, late afternoon, and overnight. Ambient locations included: Ambient U (upwind), Ambient D1, Ambient D1A, Ambient D2, and Ambient D2A. In addition, a station designated ASH DUMP was established near to and directly downwind of the daily piles of H-POWER combined ash that were dumped during the day for use as daily cover at day's end. Finally, on one day, a demonstration of ash mining in the ash monofill area was monitored. Station ASH MINE DUMP was established directly downwind of the operation, and station ASH MINE LOADER was on the window of the front end loader which loaded ash into dump trucks.

The analytical results from the demonstration program indicate total dust concentrations ranged from 50 to 1,400 mg/m^3, and respirable dust ranged from 30 to 840 mg/m^3 (see Tables 1 and 2). The ratio of respirable dust to total dust was calculated for each sample location where both were detected. The average ratio of respirable to total dust was 0.38 from 10 samples collected inside equipment cabs, and 0.24 from 30 outdoor ambient samples.

Arsenic, cadmium, chromium (total and hexavalent), mercury, lead, selenium, and silver were not detected in any of the total or respirable dust samples tested. Barium was detected in one total dust sample (at the detection limit of 0.0002 mg/m^3) but was not detected in any respirable dust samples. Similarly, nickel was detected in two total dust samples (at the detection limit of 0.0002 mg/m^3) but was not detected in any respirable dust samples.

Meteorological Observations

An on-site meteorological station was installed on the top of the hill at monitoring station D2A. Wind direction and wind speed data were collected for 15 minute average time periods. Windroses were developed for each monitoring period of interest so that it could be determined if a station was up-, down-, or cross-wind from a potential source during each specific time period.

The wind roses indicate that regional wind direction was generally from the north, northeast, and east directions during the monitoring period. Thus, the OSHA Upwind and Ambient Upwind stations were generally upwind of the working face at all times. The OSHA Upwind station was generally upwind of the ash piles at all times. The OSHA Compactor, Caterpillar operator, Spotter, and Downwind stations were generally downwind of the ash piles and the working face at all times. The Ambient D1/D1A stations were generally downwind of the ash piles and the working face at all times. Lastly, the Ambient D2/D2A stations were generally down- to cross-wind of the ash piles and the working face.

A simple evaluation of the OSHA eight hour samples indicates that a source other than the working face of the landfill or the ash piles is the likely source of the dust. For instance, on July 10, the total dust was highest in the upwind location and lowest directly on the working face. Respirable dust was also higher in upwind than downwind locations.

Similarly, on July 11, total dust was highest in the upwind location and lowest on the spotter. Respirable dust was similar in upwind and downwind locations. Also, on July 12, total dust was similar in the upwind location and the spotter location. Respirable dust was greater in the upwind location than in downwind and spotter locations.

A similar evaluation of the ambient monitoring results also strongly suggests that the H-POWER combined ash was not the source of the dust. Stations D1/D1A are clearly downwind of the ambient upwind location, and the latter is generally upwind of the ash piles and the working face. There is a trend of the upwind location having higher dust measurements. Out of 8 respirable dust values, 5 were higher in ambient upwind samples than in D1/D1A samples, with the average ratio being 9-fold. Out of 13 total dust measurements, 8 were higher in ambient upwind samples compared to D1/D1A samples with the average ratio being 2-fold. This again suggests that the source of the dust is not the ash piles or the working face.

Comparison of Results During Different Activities

If the ash were a source of dust, the time when most ash-derived fugitive dust would be created would have been during the S1 period when the compactor was operating atop ash and the S3 period when the compactor was creating the day's cover with ash. Measured dust during the S3 period was not elevated. In all samples from ambient downwind locations, no respirable dust or total dust was detected with detection limits of ~0.2 mg/m3. This data indicates that the spreading and compacting of H-POWER combined ash to construct a daily cover does not create a significant amount of dust.

In addition, measured dust during the S1 period when the compactor was running over ash was not elevated compared to the S2 period when the compactor was generally running on fresh MSW. (On some days, the ash was not completely covered by the start of the S2 period, but it is still true that the compactor was on ash a greater fraction of the period during S1 than during S2.) Out of 28 samples (respirable dust and total dust) that had a detected value in at least one of the time periods (S1 and S2), only 7 were higher in S1 than in S2. For most of the samples (21/28), the values during S2 were higher than during S1. For this analysis, 1/2 the detection limit was used as a surrogate value for nondetects. In fact, in 17 of the 28 data pairs, dust was not even detected during the S1 period. These data indicate that the running of a heavy compactor over a landfill face covered with H-POWER combined ash does not create a significant amount of dust.

The Ashdump sampling station was downwind of the OSHA Upwind station and downwind of the ash piles. The OSHA Upwind station was upwind of the ash piles. In every case (7/10, 7/12, and 7/14), the 8-hour OSHA Upwind sample was higher in respirable dust and total dust than the ashdump sample (by a factor of ~ 5 fold). This suggests that the ash pile itself was not the source of the dust monitored in the Ashdump samples.

Ashmining was also shown not to produce significant dust. No dust was detected at the ambient station placed downwind of the operation. Respirable dust was detected in the cab of the loader as would be expected. Small dust clouds were also visually observed when the loader dumped ash into the trucks.

A comparison of sampling locations where dust was detected with meteorological data concurrently collected during the demonstration program strongly suggests that the H-POWER combined ash is not the source of dust concentrations observed. Lastly, it was observed during the demonstration project that running heavy equipment in and atop H-POWER combined ash did not generate elevated dust levels, and therefore, typical landfill activities were grouped together and collectively evaluated as “daily activities”.

HAZARD IDENTIFICATION

H-POWER combined ash samples have been analyzed for several inorganic parameters as well as dioxin/furan congeners. TCLP metals data are available for combined ash samples from approximately 1989 and to 1998. In addition, total metals analyses have included aluminum, arsenic, barium, cadmium, calcium, chromium, copper, iron, lead, mercury, nickel, potassium, selenium, silver, and zinc. From this list of constituents, aluminum, calcium, copper, iron, potassium, and zinc were eliminated from evaluation in the risk assessment because they have very low toxicity and/or are essential human nutrients. The remaining constituents were evaluated in the risk assessment.

The final list of chemicals of potential concern (CPC) includes the following metals: arsenic, barium, cadmium, chromium, lead, mercury, nickel, selenium, and silver (see Table 3). Furthermore, with the exception of nickel, these are the metals required to be tested by the Resource Conservation and Recovery Act (RCRA). Nickel was included because it is often defined as a chemical of concern for risk assessments of combustors. In addition to these metals, dioxin/furan congeners were also included in this risk assessment because they have historically been the focus of risk assessments of MWC facilities.

TOXICITY ASSESSMENT

Cancer slope factors, Reference Doses, and Reference Concentrations for all CPCs were obtained from standard EPA sources.[4,5] However, there is currently no EPA-verified Reference Dose for lead. Risk assessments for lead commonly use models of varying complexity that predict blood lead levels, which are then compared to benchmark levels of blood lead. The benchmarks have been determined by regulatory agencies to present no significant risk of harm. Because the U.S. EPA model can only predict blood lead levels in children, the Hawaii Department of Health requested that the California DTSC model be used for this risk assessment.

The major components of the DTSC model were used as presented in DTSC guidance.[6] Specifically, the intake-blood lead slope factors (termed "constants" in the DTSC model) were not modified. However, several of the soil-specific default exposure parameters were modified as allowed by DTSC guidance, so that they were applicable to the assessment of human health risks posed by lead in *ash* versus residential soil. In addition, site-specific information on background lead exposures from air, water, and food was incorporated.

A review of the recent literature revealed that the lowest current regulatory blood lead limit for adults was 25 mg/dL.[7-13] This value was used as the benchmark for risk assessment of adult worker exposures in this analysis. The benchmark for young children and adult females of childbearing age was defined as 10 ug/dL.

EXPOSURE ASSESSMENT

The exposure assessment is presented separately for the Landfill Daily Cover Project (Waimanalo Gulch Sanitary Landfill) and the Landfill Final Cover Project (Waipahu Landfill).

Landfill Daily Cover (Waimanalo Gulch Sanitary Landfill)
It is proposed that H-POWER combined ash be used for daily cover of the working face at the Waimanalo Gulch Sanitary Landfill. It is assumed that the daily cover would involve the placement and compacting of H-POWER combined ash to a depth of approximately 6 inches over the working face of the landfill. This is assumed to require an 18 inch thickness of uncompacted ash. The risk assessment assumes that the dimensions of working face are approximately 55.5 m by 20.7 m, or 1,149 square meters (12,350 square feet). This was based on actual measurement of the working face during the July 1996 demonstration project.

The risk assessment assumes the amount of H-POWER combined ash required for daily cover at the landfill is 686 cubic yards per day. H-POWER currently produces approximately 300 cubic yards of combined ash per day. Since H-POWER ash has been landfilled at the Waimanalo Gulch Sanitary Landfill for many years, the remaining amount needed for daily cover during the demonstration project, 354 cubic yards, was mined from the previously landfilled H-POWER ash. For conservative purposes, it is assumed that the daily cover is 100% H-POWER combined ash, supplied by current H-POWER operations as well as by mining of the previously landfilled ash.

Ash was mined during the demonstration project from July 9 - July 13. Mined amounts ranged from 360 tons/day to 900 tons/day, with the average amount mined per day being 504 tons. No ash was mined on July 14. Deliveries of unprocessed combined ash during the demonstration project averaged 332 tons/day, which corresponds to approximately 332 cubic yards per day.

It is proposed that the ash will be processed before using it for daily cover of the working face at the Waimanalo Gulch Sanitary Landfill. Ferrous and nonferrous metals will be removed and the water content of the ash will be adjusted to a moisture content of approximately 25%. The estimated volume of processed ash produced per day is 176 cubic yards (214 tons/day /1.215 tons/cubic yard). Thus, the daily requirement for processed combined ash exceeds the production rate for a working face of 12,350 square feet. In the future, it is proposed that the remaining need for daily cover be mined from the previously landfilled ash. Also, the working face is often as small as 6,000 square feet. Daily production of H-POWER combined ash would be sufficient to provide daily cover for this size working face, and no ash mining would be required.

The use of H-POWER ash as daily cover assumes the following activities: In the morning (0700-1000 hours), workers push and compact municipal solid waste (MSW) over the previous day's ash cover. This ash has been exposed to the air for 14 hours and may have a lower moisture content than fresh H-POWER ash. During the mid-day (1000-1500 hours), workers push and compact MSW over MSW deposited earlier the same day (*i.e.*, by this time, the previous day's ash cover has been covered with the current day's MSW, on top of which additional MSW is placed). During this time period, the workers are not running equipment atop of H-POWER ash. During the late afternoon (1500-1700 hours), the workers are pushing and compacting ash over the fresh MSW to create the day's cover. This ash is fresh ash, which has a high moisture content. Then, this cover is exposed to the elements during the evening and night (1700-0700 hours). In addition to the daily operations described above, mining of H-POWER ash previously disposed at the Waimanalo Gulch Sanitary Landfill is conservatively assumed to take place throughout every workday (0700 - 1700 hours).

Landfill Final Cover (Waipahu Landfill)
It is proposed that H-POWER combined ash be used as the bottom layer of the final cover in the closure of the Waipahu Landfill. This risk assessment assumes that the landfill area to be covered is 43 acres. It is assumed that the closure as proposed would involve the placement and compacting of 24 inches of H-POWER combined ash and then 18 inches of local soil. The total amount of H-POWER combined ash required to cover 43 acres to a depth of 24 inches is 138,746 cubic yards.

It is proposed that the H-POWER combined ash be used as it is produced and processed. Each day's production of ash would be transported to the Waipahu Landfill, placed, compacted, and covered with local soil. The risk assessment addresses potential exposures that might occur during the period when the ash is proposed to be placed, compacted and covered at Waipahu Landfill and during the post-closure period.

The Waipahu Landfill is located adjacent to West Loch of Pearl Harbor with a small residential area to the northwest of the landfill. Accordingly, the risk assessment evaluates potential exposures that might occur in these areas. In addition, there is another residential area towards the southwest of the facility. Exposures in this area are also evaluated. In addition, risks posed by contact with surface water, sediment, and fish in West Loch are quantitated.

The risk assessment evaluated three potential scenarios regarding the manner in which the H-POWER ash would be used as part of the landfill closure. In the first, it is assumed that the H-POWER ash is delivered to Waipahu Landfill during the week and diverted to Waimanalo Gulch over the weekend. Deliveries only occur during the daylight hours. During the week, ash is stored at the H-POWER Plant in covered trailers overnight and delivered to the landfill each morning. At the end of each day, it is assumed that the ash is spread, compacted, and covered with soil. This scenario is referred to as "Closure-No Stockpile" throughout the risk assessment.

In the second scenario, it is assumed that all of the combined ash is delivered to the Waipahu Landfill. Again, however, deliveries only occur during daylight hours (10 hours/day). Overnight during the week, it is assumed that ash is stored in covered trailers at the H-POWER plant. During the weekend, the ash is continued to be delivered throughout the day on Saturday and Sunday, thus creating a temporary stockpile at the site that is spread, compacted, and covered with Mililani soil on Monday of each week. At the end of each day, it is assumed that the ash is spread, compacted, and covered with soil. This scenario is referred to as "Closure-Stockpile" throughout the risk assessment.

In the third scenario, it is assumed that the amount of ash delivered daily is spread and compacted, but it is not covered with Mililani soil at the end of the day. It is assumed that the day's ash delivery dries somewhat and can become entrained into the air as fugitive dust overnight before it is covered with soil on the next day. This scenario is referred to as "Closure-Uncovered" throughout the risk assessment.

After closure, it is possible that the Waipahu Landfill will be converted to a soccer field, a softball field, or a picnic area. There is no possibility that the ash can cause airborne dust or surface water run-off, however, because the ash will be covered with 18 inches of native soils. The landfill will also be vegetated.

Accordingly, a Post-Closure scenario was defined in which the ash was disrupted so that there was a mechanism by which ash-derived dust and surface water run-off could be created.

For this scenario, it is assumed that dirt bikers have disrupted the integrity of the vegetated cover. It is assumed that this disruption has resulted in 10% of the landfill area (17,402 square meters) becoming unvegetated and thus subject to surface run off. It is also assumed that 2% of the landfill area (3,480 square meters) has been compromised to the extent that H-POWER combined ash is exposed at the surface and subject to dust generation in addition to surface run off. This scenario is referred to as "Post Closure" throughout the risk assessment.

Identification of Receptors

Potential human receptors were identified for on-site and offsite scenarios on the basis of land use information (see Table 5). For the landfill daily cover risk assessment, receptors were identified on-site and offsite at the nearest inhabited location to the south of the site. For the landfill final cover risk assessment, potential human receptors were identified for each closure and post closure scenario. Receptors were identified on-site, off-site at the nearest inhabited locations to the north and south of the site (in the direction of both Trade and Kona Winds), and at locations where relevant activities such as fishing or swimming could occur.

Exposure Point Concentrations

Total metal concentrations in H-POWER combined ash are used as exposure point concentrations for the ash, itself (see Table 3). Data from TCLP analyses are used as estimates of chemical concentrations in ash leachate (see Table 3).

On-site and off site receptors may be exposed to chemicals of potential concern in ash via inhalation of fugitive dust generated by placement, grading, and compacting of ash, as well as fugitive dust generated by wind erosion of uncovered ash placed in piles or placed in a layer over a portion of the area of either landfill. The on-site concentrations of fugitive dust generated by various ash use activities were directly measured during the two monitoring events in 1995 and 1996.

To estimate the off-site concentrations of dust generated by these activities, measured on-site concentrations were used to estimate respirable dust emission rates. These emission rates and local meteorological data were used as input parameters for EPA-recommended air dispersion models to estimate off-site dust concentrations. The modeled concentrations of dust in ambient air offsite were combined with chemical concentrations detected in ash to evaluate potential human exposures via inhalation.

This approach is health-protective in that it assumes that all dust is ash-derived and that all of the chemicals detected in ash are transported to dust. As noted above, the dust measured during the daily cover demonstration project was not correlated with ash handling and use. Instead, the dust observed during the project was correlated with truck traffic on dusty roads and rock crushing activities at the adjacent quarry. However, the measured dust concentrations can be used as worst case estimates of the dust generated by ash handling and use.

On-Site Dust Concentrations. During the six day demonstration project during which air monitoring was performed, twelve day-long total suspended particulate samples were taken inside of the caterpillar tractor and the MSW compactor. The average TSP value was 0.278 mg/m^3. The average ratio of TSP to PM_{10} for samples taken inside of equipment was 0.38. Accordingly, the PM_{10} concentration for the landfill workers working inside the cabs of heavy equipment was derived as 0.105 mg/m^3.

One landfill worker, the spotter, worked outdoors throughout the entire work day. Five day-long samples of total suspended particulates were taken. The average TSP value was 0.558 mg/m^3. The average ratio of TSP to PM_{10} for samples outside was 0.24. Accordingly, the PM_{10} concentration for the landfill workers working outside was derived as 0.134 mg/m^3.

To be health-protective, the respirable particulate (PM_{10}) concentration for the spotter was used for all on-site workers during daily operations. This concentration overestimates the exposures for workers who are working inside of earth moving equipment.

During the ash mining operation, one sample was taken for respirable dust on the window of the front end loader, but no samples were taken for total suspended particulates. Accordingly, the respirable dust value of 0.300 mg/m^3 was used for this potential receptor.

Samples collected during the 1996 demonstration project were used to derive the average outdoor TSP concentration. The average TSP concentration for all outdoor samples was higher than the average TSP concentration for all outdoor *downwind* samples. Of the total dataset of outdoor samples, those samples collected in upwind locations (e.g. at or near the adjacent quarry's rock crushing operations) were excluded. Thirty nine samples were taken outdoors in downwind areas where visitors might be exposed to on-site dust. The average TSP value was 0.268 mg/m^3. The average ratio of TSP to PM_{10} for samples outside was 0.24. Accordingly, the PM_{10} concentration for the on-site landfill visitors (landfill daily cover) or trespassers (landfill final cover) was derived as 0.064 mg/m^3.

Off-Site Dust Concentrations. PM_{10} emission rates were estimated from measured concentration data using a simple Box Model[14] and site-specific data for source length and mean wind speed (5.14 m/sec). The PM_{10} concentration in the box was assumed to be uniformly mixed by human activities on the landfill. Mixing height was assumed to be 2 m.

The SCREEN3 model (Version 95181)[15] was used to estimate offsite ambient PM10 concentrations for the various scenarios. SCREEN3 is a USEPA-preferred model and is recommended by USEPA for a screening-level air dispersion modeling. The SCREEN3 model determines 1-hour chemical concentrations. Eight-hour and annual average PM10 concentrations are calculated by multiplying factors of 0.7 and 0.08, respectively.

Wind data are site-specific with the stability of D and wind speed of 5.14 m/s. Source areas were modeled as ground-level area sources with site-specific areas. A receptor height of 1.0 m was assumed. Site locations were considered as rural areas, and they were modeled using the simple terrain approach because the terrain heights of nearby human receptors are lower than the emission sources.

RISK CHARACTERIZATION

Table 4 presents the results of the lead risk assessment for all receptors and scenarios for both the Landfill Daily Cover risk assessment (Waimanalo Gulch Sanitary Landfill) and the Landfill Final Cover risk assessment (Waipahu Landfill). In all cases, the 99th percentile blood lead concentration is less than the applicable blood lead health benchmark. In all cases, the majority of blood lead was associated with the assumed ingestion and dermal contact with ash. Only a small fraction was associated with inhalation of dust. For instance, for the Landfill Daily Cover risk assessment, inhalation of lead from ash-derived dust in air by on-site workers contributes 0.49 mg/dL, 7% of the total blood lead concentration. Inhalation of lead from ash-derived dust in air by ash mining workers contributes 1.1 mg/dL, 15% of the total blood lead concentration. Inhalation of lead in ash-derived dust contributes less than 1% of the total blood lead concentration for the on-site adult visitor receptor. Inhalation of lead in ash-derived dust contributes less than 0.1% of the total blood lead concentration for the on-site child visitor receptor.

The same is true for the Landfill Final Cover risk assessment. Inhalation of lead from ash-derived dust in air contributes 0.20 mg/dL, 4% of the total blood lead concentration for construction workers. For the trespasser closure scenarios (assuming no stockpile, stockpile present, and uncovered ash), inhalation of lead in ash-derived dust contributes less than 1% of the total blood lead concentration for each receptor.

For other receptors and scenarios, such as the West Loch recreator (Closure-Stockpile, Closure-Uncovered, and Post-Closure scenarios), exposures to lead in background air, food, and water contribute essentially all of the 99th percentile blood lead concentrations. Surface water, sediment, and fish consumption exposures are associated with less than 1% of the total blood lead concentration for each receptor.

Table 5 presents the results of the noncarcinogenic risk assessment for all receptors and scenarios for both the Landfill Daily Cover risk assessment (Waimanalo Gulch Sanitary Landfill) and the Landfill Final Cover risk assessment (Waipahu Landfill). In all cases, the hazard indices are less than 1.0. These results indicate that proposed use of ash for daily cover at the landfill poses no unacceptable incremental increase in noncarcinogenic health risks.

Estimated Lifetime Cancer Risks (ELCRs) are also shown in Table 5. For all receptors and scenarios, the estimated cancer risk is within or below U.S. EPA's acceptable risk range of 10^{-4} to 10^{-6} and OSHA's criteria of 1×10^{-3} for setting occupational standards. Note that inhalation risks for all receptors were calculated based on the assumption that 100% of dust is ash-derived (*i.e.*, 100% of metals concentrations detected in ash were assumed to be present in dust), and that worker risks were estimated assuming that exposure occurs without regard to personal protective equipment and personal hygiene practices required under the applicable OSHA standards for arsenic, cadmium, and lead.

SUMMARY AND CONCLUSIONS

Human health risk assessments were performed for two proposed beneficial uses of H-POWER combined ash: Landfill Daily Cover (Waimanalo Gulch Sanitary Landfill) and Landfill Final Cover (Waipahu Landfill). In all cases, with all receptors and ash use scenarios, estimated blood lead concentrations were less than 25 mg/dL for adult male workers and 10 mg/dL for nonworkers assumed to be young children or female adults of child-bearing age. Estimated hazard indices were all less than 1.0, and estimated excess lifetime cancer risks were within or below U.S. EPA's acceptable risk range of 10^{-4} to 10^{-6} and OSHA's criteria of 1×10^{-3} for setting occupational standards.

Ambient and personal monitoring was performed during a demonstration project of landfill daily cover. Although no metals were detected in total or respirable dust and total dust was not found to be correlated with ash handling and use, measured dust concentrations were assumed to represent worst case estimates of ash-generated dust levels. The risk assessment assumed that dust was totally ash-derived, and ash-derived metal concentrations were derived from the total metals content of H-POWER combined ash. Even with this very health-protective assumption, the risk assessment results were found to be dominated by the assumptions that potential receptors would directly ingest and dermally contact H-POWER combined ash.

While such assumptions are commonly made by risk assessors, it should be noted that construction workers or landfill workers must adhere to strict requirements concerning personal hygiene practices and the use of personal protective equipment required under the applicable OSHA standards for arsenic, cadmium, and lead. Thus, assuming that workers will violate Federal law is a very health-protective approach to human health risk assessment.

REFERENCES

1. Utilization of Ash from Municipal Solid Waste Combustion. Final Report. Phase I, NREL/TP-430-7382, National Renewable Energy Laboratory, Golden, CO, September, 1994.

2. Risk Assessment of the Beneficial Use of H-POWER Combined Ash in the Final Cover for the Waipahu Landfill Closure, Ogden Environmental and Energy Services, Inc., Westford, MA, March, 1996.

3. Risk Assessment of the Beneficial Use of H-POWER Combined Ash in the Daily Cover of the Waimanalo Gulch Sanitary Landfill, Ogden Environmental and Energy Services, Inc., Westford, MA, April, 1996.

4. Health Effects Assessment Summary Tables, FY-1995 Annual, EPA/540/R-95/036, U.S. EPA, Office of Solid Waste and Emergency Response, Washington, D.C. May, 1995.

5. Integrated Risk Information System, U.S. EPA, On-Line Database, 1996.

6. Assessment of Health Risks from Inorganic Lead in Soil, California Department of Toxic Substance Control, 1993.

7. Case Studies in Environmental Medicine, Lead Toxicity, Agency for Toxic Substances and Disease Registry, 1992.

8. Toxicological Profile for Lead, PB93-182475, Agency for Toxic Substances and Disease Registry, National Technical Information Service, Atlanta, GA. April, 1993.

9. Preventing Lead Poisoning in Young Children, A Statement by the Centers for Disease Control, Centers for Disease Control, October, 1991.

10. Healthy People 2000: National Health Promotion and Disease Prevention Objectives, PHS 91-50212, Department of Health and Human Services, Centers for Disease Control, 1991.

11. H.W. Henxe, B. Filipak and U. Keil, "The association of blood lead and blood pressure in population surveys," Epidemiology, 4: 173-179 (1993).

12. J.L. Pirkle, J. Schwartz, J.R. Landis, et al., "The relationship between blood lead levels and blood pressure and its cardiovascular risk implications," Am. J. Epidemiology, 121: 246-258 (1985).

13. W. Victery, H.A. Tyroler, R. Volpe, et al., "Summary of discussion sessions: symposium on lead-blood pressure relationships," Env. Health Perspectives, 78: 139-155 (1988).

14. A.C. Stern, Fundamentals of Air Pollution, Academic Press, Inc., 1987.

15. Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, Revised, EPA/454/R-92-019, U.S. EPA, October, 1992.

TABLE 1
TOTAL DUST CONCENTRATIONS

OSHA STATIONS	Day 1 7/10/96 (mg/m3)	Day 2 7/11/96 (mg/m3)	Day 3 7/12/96 (mg/m3)	Day 4 7/13/96 (mg/m3)	Day 5 7/14/96 (mg/m3)	Day 6 7/15/96 (mg/m3)
OSHA U	0.73	1.0	0.43	1.3	0.36	0.21
OSHA D	0.31	0.54	0.32	0.45	0.94	0.20
CAT	0.11	0.22	0.19	0.17	0.25	0.60
COMP	<0.02	0.41	0.27	0.62	0.20	0.28
SPOT	0.48	0.59*	0.07	1.4	0.63	0.21
AMBIENT STATIONS						
U S1	0.2	0.42	0.36	0.1	<0.08	<0.1
U S2	0.65	0.44	0.76	0.27	0.05	0.09
U S3		0.4	<0.2	<0.1		
U S4	<0.02	<0.02	0.06	<0.02	<0.02	<0.02
D1 S1	<0.09		0.3		<0.07	
D1 S2	0.62		0.3		0.12	
D1 S3						
D1 S4			<0.02		<0.02	
D1A S1		0.34		0.33		0.2
DIA S2		0.22		0.39		
DIA S3		<0.2		<0.2		
DIA S4		<0.02		<0.02		0.03
D2 S1	<0.09		<0.07		<0.07	
D2 S2	0.23		0.30		0.17	
D2 S3			<0.2			
D2 S4	<0.02				<0.02	
D2A S1		0.42		<0.02		<0.1
D2A S2		<0.03		0.16		<0.03
D2A S3		<0.2		<0.2		
D2A S4		<0.02		<0.02		<0.02
ASH DUMP		0.83		0.44		0.05
ASH MINING						
ASH MINE DUMP			<0.08			
ASH MINE LOADER						

NOTES:

*Cassette found on the ground and reconnected to sampling apparatus.

TABLE 2
RESPIRABLE DUST CONCENTRATIONS

OSHA STATIONS	Day 1 7/10/96 (mg/m3)	Day 2 7/11/96 (mg/m3)	Day 3 7/12/96 (mg/m3)	Day 4 7/13/96 (mg/m3)	Day 5 7/14/96 (mg/m3)	Day 6 7/15/96 (mg/m3)
OSHA U	0.19	0.23	0.09	0.25	0.03	0.08
OSHA D	0.05	0.27*	0.11	0.09	0.08	0.09
CAT	0.03	0.07	<0.02	0.09	0.05*	0.24
COMP	0.04	0.14	0.13	0.25	0.13	0.07
SPOT	0.09	0.18	0.17*	0.15	0.18	0.06
AMBIENT STATIONS						
U S1	0.4	<0.08	<0.09	<0.09		<0.2
U S2	0.03	0.03	0.05	0.1	<0.04	
U S3		<0.2	<0.3	0.3		
U S4	<0.02	<0.02	<0.02	0.6	<0.02	<0.02
D1 S1	<0.1		<0.08		<0.08	
D1 S2	0.1		0.04		0.05	
D1 S3			<0.2			
D1 S4	<0.02		<0.02		<0.02	
D1A S1		<0.08		0.84		<0.2
DIA S2		0.05		0.07		
DIA S3		<0.2		<0.2		
DIA S4		<0.02		<0.02		<0.02
D2 S1	<0.1		0.2		<0.08	
D2 S2	<0.03		<0.04		0.09	
D2 S3			<0.2			
D2 S4	<0.02		<0.02		<0.02	
D2A S1		<0.07		<0.08		
D2A S2		<0.04		0.1		
D2A S3		<0.2		<0.2		
D2A S4		<0.02		<0.02		<0.02
ASH DUMPING		0.04		0.02		<0.03
ASH MINING						
ASH MINE DUMP			<0.09			
ASH MINE LOADER			0.3			

NOTES:

*Laboratory report indicated sample was contaminated with tap water; results may be biased high.

TABLE 3
DATA SUMMARY FOR H-POWER COMBINED ASH

Chemical	Concentration in Ash (Dry Weight, mg/kg)[1,2]	Concentration in TCLP Leachate (mg/L)[2,3]
Arsenic	49	0.67
Barium	410	1.6
Cadmium	29	0.31
Chromium	69	0.064
Lead	2500	1.0
Mercury	11	0.0045
Nickel	75	not analyzed
Selenium	0.91	0.19
Silver	7.1	0.088
TCDD-Toxic Equivalents[4]	0.00043	not analyzed

[1] Combined ash samples with metal pieces removed, samples collected during 3/20/95-12/18/95.
[2]Upper 95% confidence interval of the mean concentration using H statistic per U.S. EPA guidance assuming lognormal distribution.
[3]Combined ash samples with metal pieces removed, samples collected from 12/89-8/95.
[4]Mean of two samples in which total congener profile was measured.

TABLE 4
ESTIMATED BLOOD LEAD CONCENTRATIONS

LANDFILL DAILY COVER

Receptor	95th %ile (ug/dl)	99th %ile (ug/dl)
On-Site Worker pushing/compacting MSW/Daily Cover	5.3	6.7
On-Site Worker - ash mining	5.8	7.3
On-Site Visitor - young child	2.7	3.4
On-Site Visitor - female of childbearing age	1.4	1.8
Off-Site Resident - young child	1.5	1.9

LANDFILL FINAL COVER

Receptor	95th %ile (ug/dl)	99th %ile (ug/dl)
On-Site Construction Worker	4.0	5.0
On-Site Trespasser (young child)		
Closure No Stockpile	2.1	2.7
Closure with Stockpile	2.7	3.4
Closure Uncovered	2.7	3.4
Off-Site Resident (young child)		
Closure No Stockpile	1.5	1.9
Closure with Stockpile	1.5	1.9
Closure Uncovered	1.5	1.9
Post Closure	1.5	1.9
Recreator (fishing/swimming)		
Closure with Stockpile	1.5	1.9
Closure Uncovered	1.5	1.9
Post Closure	1.5	1.9
Recreator (child dirt biking)		3.4
Post Closure	2.7	

TABLE 5
ESTIMATED NONCARCINOGENIC AND CARCINOGENIC HEALTH RISKS

LANDFILL DAILY COVER

Receptor	Hazard Index	Cancer Risk
On-Site Worker pushing/compacting MSW/Daily Cover	0.4	3×10^{-5}
On-Site Worker - ash mining	0.6	5×10^{-5}
On-Site Visitor - young child	0.2	4×10^{-6}
On-Site Visitor - female of childbearing age	0.05	4×10^{-6}
Off-Site Resident - young child	0.001	2×10^{-8}

LANDFILL FINAL COVER

Receptor	Hazard Index	Cancer Risk
On-Site Construction Worker		
Closure No Stockpile	0.2	2×10^{-6}
Closure with Stockpile	0.2	2×10^{-6}
Closure Uncovered	0.2	2×10^{-6}
On-Site Trespasser (young child)		
Closure No Stockpile	0.08	9×10^{-7}
Closure with Stockpile	0.3	1×10^{-6}
Closure Uncovered	0.3	2×10^{-6}
Off-Site Resident (young child)		
Closure No Stockpile	0.001	2×10^{-8}
Closure with Stockpile	0.008	2×10^{-8}
Closure Uncovered	0.001	2×10^{-8}
Post Closure	0.0008	2×10^{-8}
Recreator (fishing/swimming)		
Closure with Stockpile	0.001	7×10^{-8}
Closure Uncovered	0.004	2×10^{-7}
Post Closure	0.07	9×10^{-7}

Recreator (child dirt biking)	Post Closure	0.2	1×10^{-6}

Appendix E

Operation Plan – Use of H-POWER Municipal Solid Waste Ash for Pilot Study Roadbed at H-POWER Facility

Appendix E-1

Operation Plan – Use of H-POWER Municipal Solid Waste Ash for Pilot Study Roadbed at H-POWER Facility

OPERATION PLAN
USE OF H-POWER MUNICIPAL SOLID WASTE ASH
FOR PILOT STUDY ROADBED AT H-POWER FACILITY

I. COLLECTION OF H-POWER COMBINED ASH

The H-POWER combined ash historically exhibits a range of concentrations in total metals as well as in the concentrations of metals in aqueous extracts. In designing a pilot study, it is desirable to examine a combined ash that is typical of that which will be used in future applications. Examination of a combined ash that is relatively poor in metals has the potential to render the experimental results inappropriate (i.e., under protective) for a risk assessment. Similarly, to facilitate comparisons between different experimental conditions (e.g., extraction of roadway materials with and without physical deterioration), it is necessary to control the quality of the combined ash in the trials. For these reasons, combined ash of known, consistent quality will be used for execution of the studies discussed in this Operation Plan.

First, an assumption must be made regarding the amount of ash needed for the test pavement. The project involves paving the up ramp to the municipal solid waste packer truck tipping floor at the H-POWER facility with 2 inches of wearing (topcoat) coat using screened H-POWER Combined ash-amended asphalt. Damage to the down ramp will be repaired with unamended asphalt. Then, the down ramp from the municipal solid waste packer truck tipping floor at the H-POWER facility will be paved with 2 inches of wearing (top) coat using unamended asphalt. Figure 1 shows the general view of the facility, with the up and down ramp areas that will be paved shaded.

Initial assumptions regarding the paving of ash amended asphalt involve an asphalt mix with 15% ash. However that assumption will be reduced to approximately 3% ash. The high moisture content of H-POWER combined ash, 30-35% moisture, poses a technical problem due to the energy lost in heating up the asphalt to the required temperature of 320° F or higher. H-POWER is informed by Grace Pacific that an ash aggregate of less than 10% moisture is necessary, to keep energy loss to a minimum, for a 15% ash asphalt mix. With too high of a moisture content in the ash aggregate the asphalt will be too cold to be a workable mix. The amount of ash collected and screened was done with the initial focus on a 15% ash mix.

The volume of the up ramp is roughly 20' by 300' by 2". This volume would require approximately 80 tons of asphalt. Sieve analyses reported in the NREL Phase I report indicate that 96.9% of H-POWER Combined Ash passes a 3/8 inch screen. Roughly 5 tons of combined ash, as typically disposed, will be collected every day for a total of five days. A separate, dedicated ash trailer will replace the usual ash collection trailer for a single period on each of the five days to allow ash to be collected for the pilot study. The combined ash will be collected on a daily basis by starting at the rear of the trailer and allowing the ash to build a mound in one spot. When approximately 5 tons has been collected, a normal ash trailer will replace the dedicated ash trailer, which will then be scaled to obtain the cumulative weight. The mesh tarps in the ash trailer will be closed. The trailer will be appropriately marked and parked at the west end of the ash trailer parking lot for storage until the next day's ash collection period. Figure 2 shows the area where the trailer will be parked. After approximately 25 tons has been collected, the dedicated ash trailer will be parked at the same location for ash aging and storage for several weeks until the ash is screened.

II. COMBINED ASH SAMPLING

Two samples will be taken each day within two hours of ash collection. Each of these ten (10) samples will be submitted for total metals analysis and TCLP analysis. Thus, there will be ten (10) total metal samples and ten (10) TCLP samples. It is important that TCLP data on the collected combined ash be directly comparable to the historical TCLP data. Accordingly, fly ash and bottom ash samples will be separately collected and mixed, with metal pieces removed using the established H-POWER protocol for TCLP testing, which is described in Section 5.1.2 of the 7/31/90 revised ash sampling protocol. (However, the eighteen separate samples required for compliance testing will *not* be collected.) If the collected ash is representative of historical combined ash *viz a viz* TCLP metals, it will be screened, tested by HRRV and Grace Pacific, transported to Grace Pacific, and used to prepare the test asphalt.

III. REPRESENTATIVENESS TEST CRITERIA

Representativeness will be determined by comparing the mean TCLP sample results for each TCLP element to the criteria in Table 1, which were determined from the historical data. If the mean sample results all fall within the ranges defined in Table 1 for each element, they will be considered representative. Data from total metal analyses will be evaluated, but because of the limited historical total metal data, specific criteria cannot be defined for sample representativeness.

TABLE 1
TCLP CRITERIA FOR ASH REPRESENTATIVENESS

ELEMENT	CRITERIA
Lead	0.04 to 0.50 mg/L
Cadmium	0.02 to 0.30 mg/L
Mercury	0.0003 to 0.01 mg/L
Selenium	0.01 to 0.10 mg/L
Silver	0.001 to 0.50 mg/L
Barium	0.10 to 8.0 mg/L
Arsenic	0.01 to 0.50 mg/L
Chromium	0.001 to 0.10 mg/L

IV. COMBINED ASH SCREENING

After all combined ash has been collected and sampled, a 3/8 inch screen will be delivered to the H-POWER plant. The screening process will be conducted at the ash tower cul-de-sac to ensure that there are no runoff problems in the event of rain. Any runoff would be collected in the ash sump and then used as boiler quench water as is all ash washing water from current operations.

The ash will be dumped from the dedicated ash trailer onto the asphalt pad. The ash trailer will be washed, and all wash water will be collected in the ash sump. Then, an appropriately sized piece of equipment, such as a front end loader or a Bobcat, will feed the ash through the screening machine onto the asphalt pad. The ash will then be loaded back into the ash trailer. Any residual ash present on the pavement will be promptly swept up with the street sweeper. The screening machine will then be washed with water at the H-POWER facility before being returned.

H-POWER Combined Ash contains roughly 30-35% moisture and was shown in the *Risk Assessment of the Beneficial Use of H-POWER Combined Ash as Daily Cover for the Waimanalo Gulch Sanitary Landfill* not be a source of fugitive dust whether present as a stockpile or present as a thin layer covering a large area of the ground cover. Thus, minimal, if any, dust would be anticipated from the screening and moving of recently collected ash. Nonetheless, the screening operation will be done during a period of low wind as a precaution against the generation of fugitive dust.

Screened H-POWER combined ash will be stored in the same dedicated ash trailer, which is appropriately marked, until it is transported to Grace Pacific. The mesh tarps in the ash trailer will be closed. The trailer will be weighed and then parked at the west end of the ash trailer parking lot for storage for a period of approximately a month. To ensure that the ash does not get too hard to handle, the combined ash will be cycled periodically. A front end loader bucket full will be removed periodically and placed in the back of the trailer. During this period, screened ash and ash extracts will be chemically analyzed, screened ash will be tested for engineering performance at Grace Pacific, and final plans will be made for the paving project.

V. COLLECTION OF SAMPLES OF SCREENED H-POWER COMBINED ASH

As discussed above, the H-POWER combined ash samples collected over five days will be analyzed for TCLP and total metals to ensure that the ash collected is representative of typical H-POWER combined ash. Then the screened H-POWER Combined Ash (the aggregate substitute) will be tested, because the risk assessment planned for execution at a later date will evaluate the risks posed by transportation to, storage at, and processing of this material by an asphalt plant. Ten (10), ten kg samples of the screened ash will be collected. The ten samples will then be split into two sets of ten 5 kg samples. One set will be sent to the laboratory for chemical analysis and one set will be sent to Grace Pacific for performance testing.

VI. ANALYTICAL REQUIREMENTS FOR SCREENED H-POWER COMBINED ASH

Ten (10) samples of the screened H-POWER Combined Ash will be subjected to laboratory analyses for total metals in the solid as well as metals that are extractable into aqueous extracts. In the later case, artificial rainwater will be prepared according to the Synthetic Precipitation Leaching Procedure (EPA Method 1312) Extraction Fluid #1 (pH 4.2) and used in a column leaching test. This will allow for evaluation of availability of metals to the most relevant extractant: rainwater. The pH of the extracting fluid is acidic to mimic the pH of the rainwater on the Big Island during periods of volcanic disturbance. In most cases, however, Hawaiian rainwater will be far less acidic.

pH and hardness will be evaluated in the extract to help evaluate the potential bioavailability of certain metals in solution. pH of the solid will be measured to evaluate potential controls on metal solubility as well as to provide a means of comparing screened H-POWER Combined Ash sub-samples. The metals selected for analysis are those that are a potential concern in human health and environmental risk assessments. The specific analytes are listed in Table 2. Note that aluminum, copper, and zinc are analytes, because these metals can pose ecological concerns in aquatic environments. These metals are not TCLP metals and are not normally tested, so no historical data exist.

In addition, five (5) samples of the screened H-POWER Combined Ash will be subjected to a biologically relevant extraction by extracting the ash for four hours at body temperature with a pH 2 buffered solution to mimic stomach contents. Similar tests have been very useful in showing that lead from some other sources is not highly bioavailable. The samples will be randomly chosen by the laboratory.

TABLE 2

ANALYTES FOR ASH SAMPLES

Aluminum (Not normally tested, therefore no historical data)
Arsenic
Barium
Cadmium
Chromium
Copper (Not normally tested, therefore no historical data)
Lead
Mercury
Selenium
Silver
Nickel (Not normally tested, therefore no historical data)
Zinc (Not normally tested, therefore no historical data)
pH (Limited historical data)
Hardness (Limited historical data)

TABLE 3

PROPOSED NUMBER AND TYPES OF CHEMICAL ANALYSES OF H-POWER COMBINED ASH AND H-POWER TEST ASH

TEST MATERIAL	PROPOSED ANALYSES
H-POWER Combined Ash	10 TCLP
	10 Total metals
Screened H-POWER Combined Ash	10 Total metals
	10 pH
	10 moisture
Screened H-POWER Combined Ash Synthetic Rainwater Extracts	10 Total metals
	10 pH
	10 hardness
Screened H-POWER Combined Ash Biologically Relevant Extracts	5 Total metals
	5 pH

VII. DISPOSAL OF COMBINED ASH NOT PASSING SCREEN

The residual combined ash that does not pass the 3/8 inch screen will be promptly loaded into a front end loader and taken to an empty or partially empty ash trailer at the H-POWER facility. The trailer will then be used for routine combined ash collection. When full, the trailer containing a mixture of combined ash and combined ash that did not pass the 3/8 inch screen will be transported to the Waimanalo Gulch Sanitary Landfill for disposal in the ash monofill.

VIII. PERFORMANCE TESTING OF SCREENED H-POWER COMBINED ASH

After the H-POWER combined ash is screened and samples have been taken and submitted for chemical analysis, Grace Pacific will need to test the screened H-POWER combined ash for its engineering properties as an aggregate substitute. Ten 5 kg samples of the screened ash will be placed in sealed plastic buckets and transported to Grace Pacific.

The screened H-POWER combined ash will be used as delivered. Thus, the mix testing will be done with the actual screened ash that will be used to prepare the asphalt. During this laboratory testing, Grace Pacific will determine how much of other types of aggregate must be added to the screened H-POWER combined ash to create an asphalt mix that meets City and State specifications. Because the screened combined ash will only comprise a small fraction (approximately 3%) of the total aggregate required, additional aggregate of different sizes, including fines, will be added to the combined ash. To achieve the required maximum amount of fines in the asphalt mix, Grace Pacific will restrict the *additional* amount of fines added from their standard stockpiles.

The following describes the analyses that will be performed on the screened H-POWER Combined ash and the ash-amended asphalt at Grace Pacific to ensure that the ash-amended asphalt meets the City and County of Honolulu Mix 3 (City and County of Honolulu, 1996) and State of Hawaii Mix 4 (State DOT, 1994) standards:

Requirements of Marshall Method of Mix Design
Asphalt Content test
Gradation Analysis
Specific Gravity Test
Test to Determine Compaction Done in Accordance with ASTM D 2041 (Rice Method)
Core/Cut Samples for the Determination of the Thickness and Density of the Completed Pavement Using Nuclear Gauge for Determination of Density

Grace Pacific will place residues from aggregate tests and tests on bench-scale quantities of asphalt back into the bucket for disposal. The residue will be transported back to the H-POWER plant in sealed buckets and placed in an ash trailer for disposal at the Waimanalo Gulch Sanitary Landfill in the ash monofill.

IX . TRANSPORTATION OF SCREENED H-POWER COMBINED ASH TO GRACE PACIFIC AND STORAGE AT GRACE PACIFIC

The trailer containing the screened H-POWER combined ash will be transported to Grace Pacific within several hours of their planned preparation of test asphalt containing the screened H-POWER combined ash. 3.08 tons of screened ash will be transported to Grace Pacific. Until its addition to the asphalt mix, the ash will remain in the ash trailer with the mesh tarp in place. Thus, there is no possibility that the screened ash can create fugitive dust during storage at Grace Pacific.

Any excess screened ash not transported to Grace Pacific will be taken to an empty or partially empty ash trailer at the H-POWER facility. The trailer will then be used for routine combined ash collection. When full, the trailer containing a mixture of combined ash and screened combined ash that was not transported to Grace Pacific will be transported to the Waimanalo Gulch Sanitary Landfill for disposal in the ash monofill.

X. MANUFACTURE OF ASH-AMENDED ASPHALT

When needed, the screened ash will be off-loaded directly from the ash trailer into a front end loader at the Grace Pacific property. The front end loader will then unload the H-POWER combined ash into the metering bin located near the heated mixing chamber. The mixing bin is a large metal bin that Grace Pacific uses to feed recycled asphalt into the production line. Grace Pacific is equipped with bag filters for the mixing chamber to control any dusting problems that occur as the ash is mixed with the other natural aggregates.

Grace Pacific is a large scale asphalt production plant. Their minimum production speed is 200 tons per hour of asphalt. The entire process of ash addition and asphalt manufacture will take approximately fifteen minutes to produce the required amount of ash-amended asphalt for the proposed project. The metering bin is about 10 feet deep and the ash should experience no fugitive dusting from wind as the ash will sit deep in the bin. The total ash handling activities will all take place in less than one hour. Thus, the potential for dust generation outdoors is minimal. Any dust that is formed within the process line of the asphalt plant will be controlled with the normal air cleaning devices. The Clean Air Branch of the Department of Health will be consulted about the project, and any necessary variations to Grace Pacific's air permit will be obtained. If there is any residual ash-amended asphalt left at the Grace Pacific plant, it will be transported to the Waimanalo Gulch Sanitary Landfill and disposed as municipal solid waste.

Grace Pacific will take standard test cores (4 inch diameter by 2-2.5 inch thickness). Two cores taken from the ash-amended up ramp and two cores from the non-ash down ramp for use in the bench-scale testing program. Grace Pacific will also prepare a total of 30 core samples (4 inch diameter by 2-2.5 inch thickness) to be used for leachate testing. There will be 15 samples of ash-amended asphalt and 15 samples of non-ash asphalt to be used for leachate testing purposes.

XI. DISPOSAL OF RESIDUAL H-POWER SCREENED COMBINED ASH

If there is any excess screened H-POWER combined ash not used by Grace Pacific, it will remain in the ash trailer covered with a mesh tarp and be disposed at the Waimanalo Gulch Sanitary Landfill in the ash monofill. The screened ash will be wetted if necessary to ensure that it is not too dry for shipment. The material will be transported to the H-POWER plant or the landfill within 24 hours with the mesh tarp top closed.

XII. TRANSPORTATION OF ASH-AMENDED ASPHALT TO H-POWER FACILITY

The ash-amended asphalt will be loaded at the Grace Pacific plant into asphalt trucks and transported to the H-POWER facility by Grace Pacific in the normal fashion on the day that road construction is planned.

XIII. CONSTRUCTION OF PILOT ROADWAY

The up ramp will be paved with the ash-amended asphalt test pavement. The down ramp will be re-paved with a top course of normal fresh pavement to create a valid test/control comparison.

Specifically, the down ramp will be constructed with 2 inches of asphalt containing natural aggregate, and the up ramp will be constructed with 1.5 inches of asphalt containing screened - combined ash as substitute for a fraction of the required aggregate. At the time of construction, the dimensions of the roadway and the slope will be recorded. Photographs will be taken to document the construction. The weight and volume of traffic felt by both the up and down ramps will be monitored for the period of the pavement study. Reasonable estimates of traffic will be made from scale house data for all trucks dumping municipal solid waste. It will be assumed that all transfer trailer loads are dumped directly on the floor and that all other loads are dumped from the elevated floor.

If there is any residual ash-amended asphalt not used in the paving operation, it will be transported to the Waimanalo Gulch Sanitary Landfill and disposed as municipal solid waste.

XIV. SCHEDULE

The following schedule (see Table 4) outlines the tentative plan for activities associated with the preparation of ash-amended asphalt and construction of the test pavement. We anticipate that at the conclusion of this field study and the subsequent risk assessment study, we will have either determined that this ash-based asphalt material is satisfactory for pavement purposes, with no adverse impacts to public health or the environment; or we will have determined that the material is unsatisfactory. In the former case, the material will be left in place until it needs replacement, and in the latter case, it will be removed and placed in the landfill with other H-POWER combined ash in the ash monofill.

XV. REFERENCES

City and County of Honolulu. 1996. Standard Specifications for Public Works Construction, September 1986. Section SP- Asphalt Concrete Pavement 144B-1, July 23, 1996.

State DOT. 1994. Hawaii Standard Specifications for Road, Bridge, and Public Works Construction.

TABLE 4
TENTATIVE SCHEDULE

ACTIVITY	SCHEDULED DATE
Meeting with HRRV, City & County of Honolulu, Hawaii DOH, and Ogden Environmental & Energy Services	January 21
HDOH Review of Operation Plan	January 21 - January 23
Anticipated HDOH Approval of Operation Plan	January 23
Ash Collection and Sampling	January 26 - January 30
Submission of Samples to Laboratory	January 31
Receipt of Laboratory Results	February 9
Summarization and Analysis of Laboratory Data	February 9 - February 18
Go/No Go Decision Based on Representativeness of Ash	February 18
Screening Machine Delivered	April 13
Ash Screening and Sampling	April 14-15
Transportation of Screened Ash to Grace Pacific	October 11
Manufacture of Ash-Amended Asphalt; Preparation of Test Monoliths; Transportation of Asphalt to HRRV; Pave Upramp with Ash-Amended Asphalt	October 11
Initiation of Testing Program	October 12

Appendix E 2

Asphaltic Concrete Mix Design

CONSTRUCTION ENGINEERING LABS, INC.
96-1173 Waihona St. • Suite #B7 • Pearl City, HI 96782
Phone (808) 455-1522 FAX (808) 455-1384

ASPHALTIC CONCRETE MIX DESIGN
Transmittal Form

Project: H-Power Ash Mix Design
Contract No.:
Prime Contractor: Grace Pacific
Subcontractor:
Asphaltic Concrete Mix Type: State 4
Source of Aggregate: Basalt-Grace Pacific, Ash-H-Power
Work Order No.: 98126

AGGREGATE SIZE	MIX PERCENTAGE
3-COARSE	%
3-FINE	25 %
CHIPS	25 %
4-FINE	47 %
SAND (SP)	%
ASH	3 %

ASPHALT CEMENT: AR 8000
ASPHALT SOURCE: Chevron

ASPHALT CEMENT CONTENT.: 5.2 TOTAL WEIGHT OF MIX
5.5 DRY WEIGHT OF AGGREGATE

Attachments:

(X) Mix formula (Screen Combination Sheet - A.C.)
(X) Test Property Curves
(X) Computation of Mix Properties
( ) Aggregate Qualification Test Results
(X) Gradation Chart

TO BE VALID
MUST BE SEALED IN
ORIGINAL HERE

September 30, 1998
DATE

CONSTRUCTION ENGINEERING LABS, INC.

BY: Ronald A. Pickering II
ITS: Vice President Operations

CONSTRUCTION ENGINEERING LABS, INC.
96-1173 Waihona St. • Suite #B7 • Pearl City, HI 96782
Phone (808) 455-1522 FAX (808) 455-1384

AGGREGATE GRADATION & BLENDING SHEET

Project: H-Power Ash Mix Design

Plant: Grace Pacific Makakilo

Date: 9/30/98

W.O. No.: 98126

Mix Type: State 4

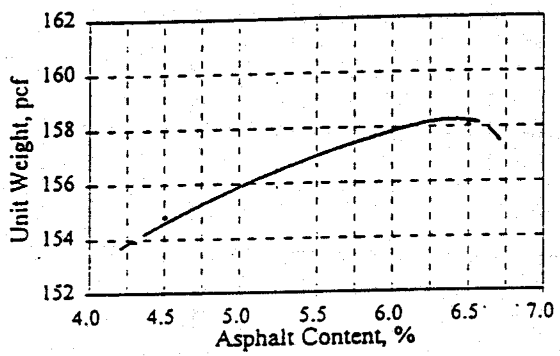
Notes: Ash moisture Approx. 25%

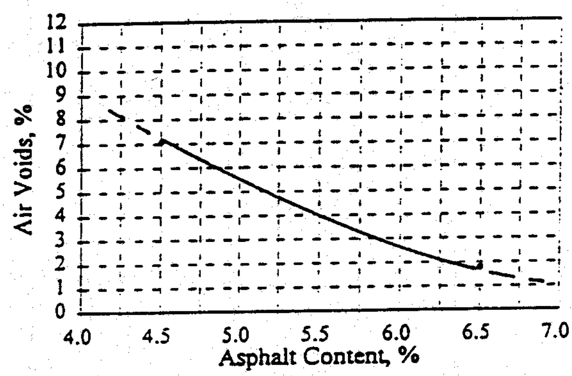
Sieve Size		1 1/4"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Material	Percent Used	Percent Passing											
ASH	3	100	100	100	100	100	93	77	63	52	41	32	24
3 Fine	25	100	100	100	49	25	6	2	2				
Chips	25	100	100	100	100	89	26	8	5	4	4		
4 Fine	47	100	100	100	100	100	100	74	46	30	22	17	14
Combined Gradation		100	100	100	87	79	58	40	25	17	13	9	7
Specifications (Low)		100	100	100	85	72	48	32	21	15	9	6	4
Specifications (High)		100	100	100	100	88	66	48	37	27	21	16	10
Tolerance		+/- 7	+/- 7	+/- 7	+/- 7	+/- 7	+/- 7	+/- 4	+/- 4	+/- 4	+/- 4	+/- 4	+/- 2

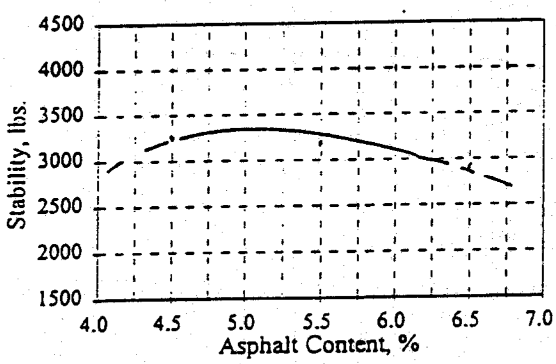
CONSTRUCTION ENGINEERING LABS, INC.
Test Property Curves

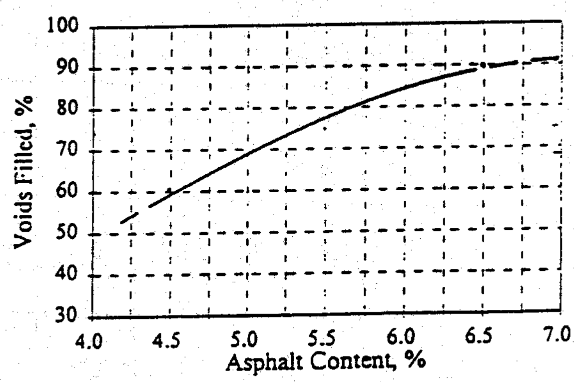
Asphalt Content (T.W.M.)	4.5	5.5	6.5	
Unit Weight , pcf	154.8	156.6	158.1	
Air Voids (T.W.M.), %	7.0	4.3	1.8	
V.M.A., %	17.9	17.8	17.9	
Voids Filled, %	61	76	90	
Stability, lbs.	3259	3212	2976	
Flow, 1/100in.	9	11	14	

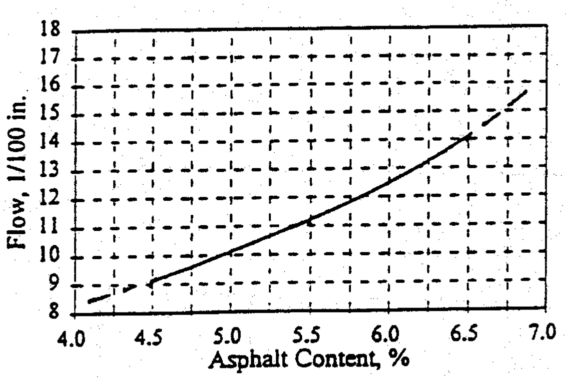
Optimum Asphalt Content = 5.2% T.W.M.
= 5.5% D.W.A.

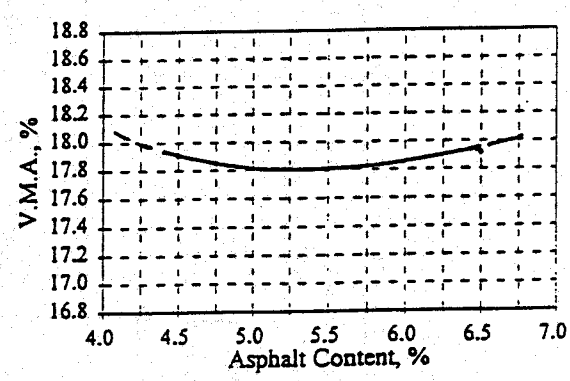










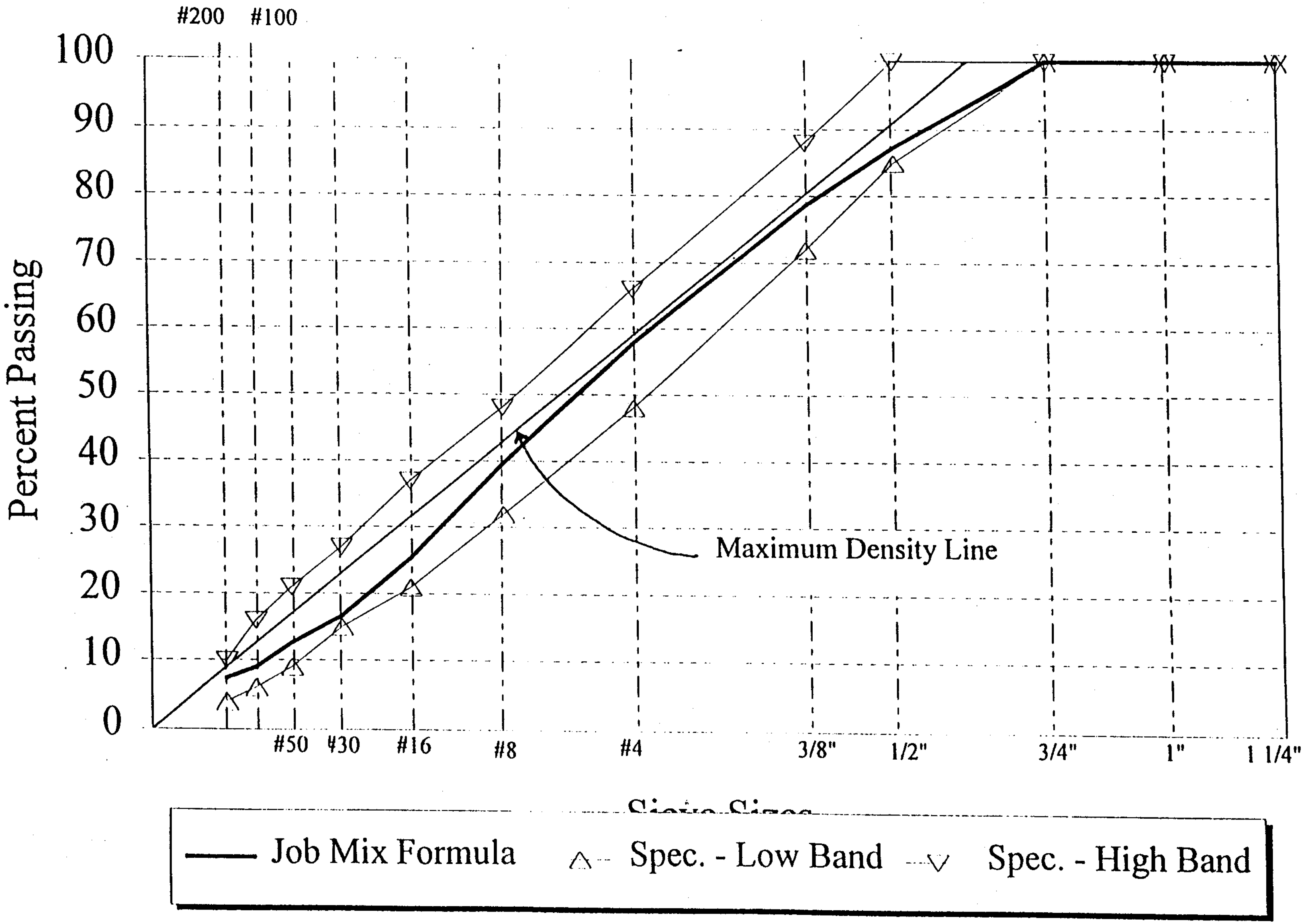


CONSTRUCTION ENGINEERING LABS, INC.
Marshall Mix Design Properties

Project: H-Power Ash Mix Design							W.O. No.: 98126							Date: 9/30/98		
Description of Blend: 3 Fine=25%, Chips=25%, 4 Fine=47%, Ash=3%							Plant: Grace Pacific Makakilo							Mix Type: State 4		
Sample I.D.	Asphalt Content	Wt. in Air (g)	Wt. in Water (g)	Wt. SSD (g)	Volume (cc)	BSG	Unit Wt. (pcf)	Maximum (Rice)	A.C. By Volume (%)	Air Voids (%)	VMA (%)	Voids Filled	Measured Stability	Corrected Stability	Flow (1/100 in.)
1	4.5	1248.4	755.2	1256.5	501.3	2.490		2.667					3534	3629	9
2		1250.6	753.3	1258.8	505.5	2.474							2918	2972	8
3		1248.2	751.9	1255.5	503.6	2.479							3107	3176	11
Avg.					503.5	2.481	154.8		10.945	7.0	17.9	61	3186	3259	9
1	5.5	1256.9	758.0	1259.3	501.3	2.507		2.623					3273	3361	10
2		1246.6	752.3	1248.3	496.0	2.513							2965	3077	12
3		1256.1	757.9	1258.3	500.4	2.510							3107	3196	11
Avg.					499.2	2.510	156.6		13.536	4.3	17.8	76	3115	3212	11
1	6.5	1264.0	767.0	1264.7	497.7	2.540		2.580					2812	2909	14
2		1270.8	769.8	1271.3	501.5	2.534							2942	3020	15
3		1256.1	760.1	1256.8	496.7	2.529							2893	2998	14
Avg.					498.6	2.534	158.1		16.149	1.8	17.9	90	2882	2976	14
Gse = 2.887		compaction temp. 290 F, 75 blows per side													

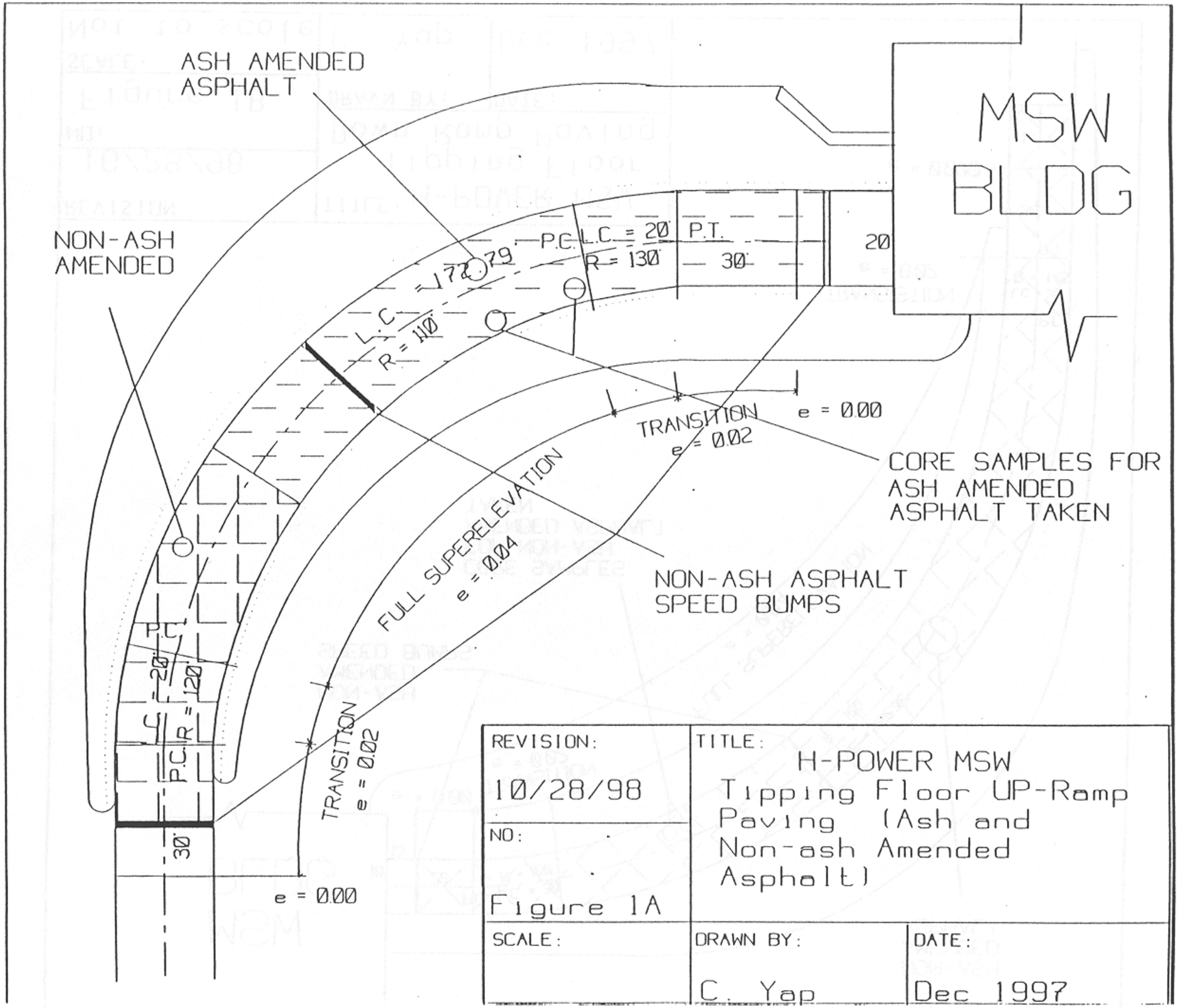
Gradation Chart -

Sieve Sizes Raised To The 0.45 Power

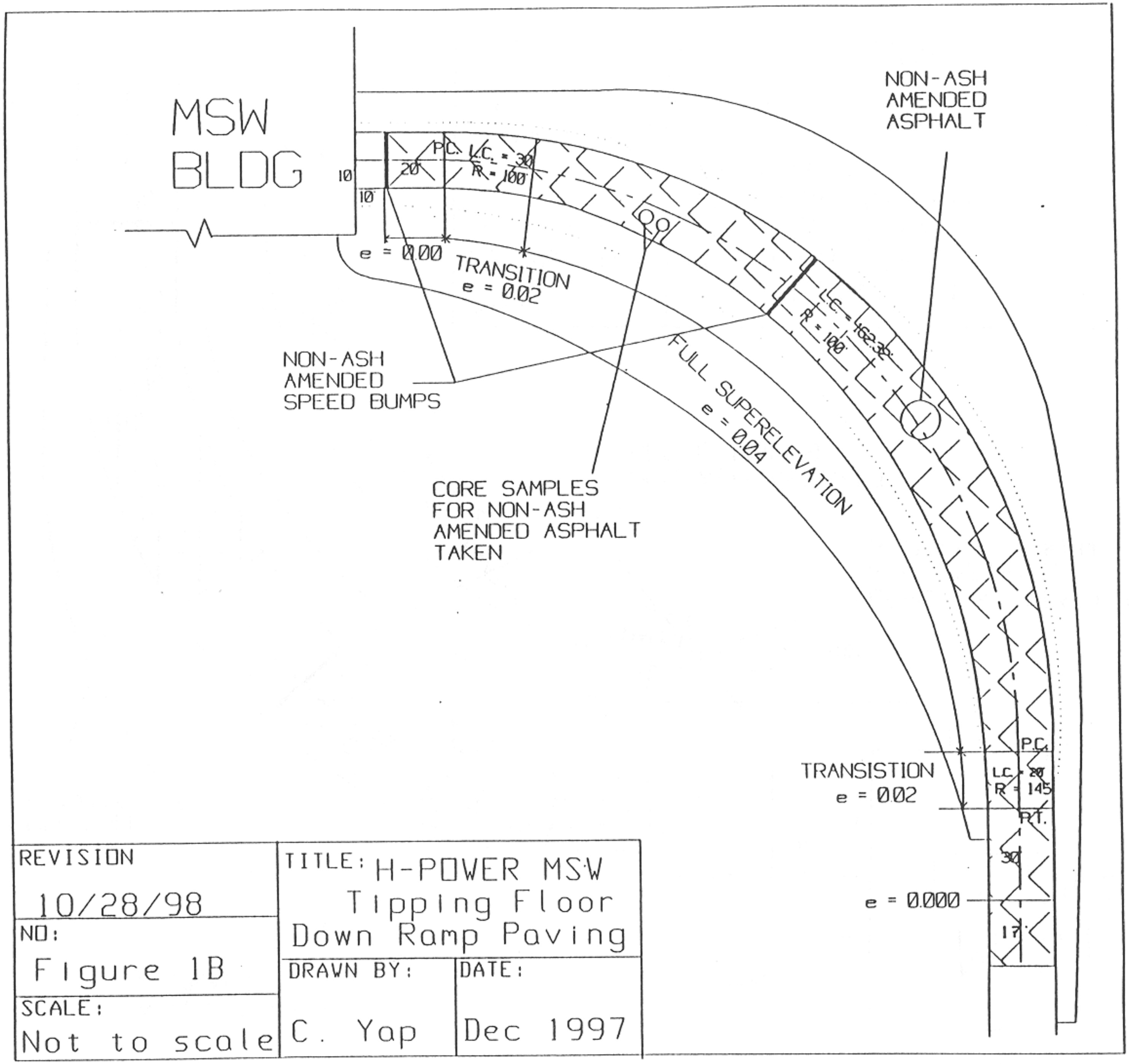


Appendix E 3

Up- and Down-Ramp Drawings and Pictures



REVISION: 10/28/98	TITLE: H-POWER MSW Tipping Floor UP-Ramp Paving (Ash and Non-ash Amended Asphalt)	
NO: Figure 1A		
SCALE:	DRAWN BY: C. Yap	DATE: Dec 1997


MSW BLDG
NON-ASH AMENDED ASPHALT
P.C.
L.C. = 30
R = 100
20
10
10
e = 0.00
TRANSITION
e = 0.02
NON-ASH AMENDED SPEED BUMPS
CORE SAMPLES FOR NON-ASH AMENDED ASPHALT TAKEN
FULL SUPERELEVATION
e = 0.04
R = 100
TRANSISTION
e = 0.02
P.C.
R = 145
P.T.
30
e = 0.000
17
REVISION
10/28/98
NO:
Figure 1B
SCALE:
Not to scale
TITLE: H-POWER MSW Tipping Floor Down Ramp Paving
DRAWN BY:
C. Yap
DATE:
Dec 1997

Up-Ramp Paved With Ash-Amended Asphalt

Down-Ramp Paved With Regular Asphalt

Appendix F

Final Work Plan for Evaluation of Leachate Quality from Roadway Materials Containing H-POWER Combined Ash
Revised January 23, 1998

FINAL WORK PLAN FOR EVALUATION OF LEACHATE QUALITY FROM ROADWAY MATERIALS CONTAINING H-POWER COMBINED ASH REVISED, JANUARY 23, 1998

I. INTRODUCTION

H-POWER has proposed the use of a combination of bottom- and fly-ash (i.e., combined ash) derived from its facility as an amendment to asphalt. This has the potential to provide a relatively low-cost source of fine materials necessary for the generation of asphalt while decreasing the disposal requirements for the byproduct of municipal waste combustion.

One of the major issues associated with this beneficial use of H-POWER combined ash is the potential leaching of the metals contained in the ash from the roadway materials (Kosson et al., 1994; Kosson et al., 1996; Eighmy and van der Sloot, 1994.). This document is a work plan to evaluate the leaching of metals from the roadway materials *in situ*.

The work plan outlines a number of investigations to evaluate the leaching of metals under likely conditions. The investigations consist of field and bench studies designed to mimic conditions of actual use, including physical deterioration of the roadway as well as chemical changes that might occur with weathering and exposure to sunlight. In addition, attention is paid to the variability of the combined ash as well as the potential that unamended asphalt is likely to be a background source of metals. Thus, procedures are outlined to obtain a representative sample of the combined ash as well as provide for controls consisting of unamended asphalt.

II. DEFINITIONS

H-POWER Combined Ash: a mixture of bottom ash (~70%) and fly ash (~30%) as currently placed into trucks for disposal at the Waimanalo Gulch landfill.

H-POWER Test Ash: a mixture of several aliquots of H-POWER combined ash that would be collected over the course of several days and then sieved through a 3/8 inch screen for use as a partial substitute for aggregate in asphalt pavement. The test ash would be shipped to an asphalt batch plant for incorporation into asphalt paving material to be used to construct a test road at the H-POWER plant.

Natural Aggregate: typical aggregate material that would normally be used to make asphalt paving material. The natural aggregate would be mixed with H-POWER test ash to make the test road aggregate mixture used in the paving material to make the test road at the H-POWER plant.

III. REQUIREMENTS FOR AGGREGATE IN ASPHALT PAVING MATERIAL

See the Operation Plan for a discussion of this topic.

IV. COLLECTION OF H-POWER COMBINED ASH

See the Operation Plan for a discussion of this topic.

V. ANALYTICAL REQUIREMENTS FOR H-POWER TEST ASH

See the Operation Plan for a discussion of this topic.

VI. CONSTRUCTION OF PILOT ROADWAY

See the Operation Plan for a discussion of this topic.

VII. GOAL OF ENVIRONMENTAL TESTING OF ASPHALT ROADWAY CONTAINING H-POWER TEST ASH

There are two goals of the testing program: (1) to determine if there is a significant increase in the release of metals from ash-amended test pavement compared to control pavement, and (2) if there is an increased release, to obtain data that can be used in a human and ecological risk assessment to determine if estimated risks are acceptably low. If the tests reveal no statistically significant increase in the release (or toxicity) of metals, it is neither possible nor appropriate to perform risk assessment calculations on the release of metals from test ash-amended material to the environment during pavement use.

VIII. HISTORICAL EXPERIENCE WITH MUNICIPAL WASTE COMBUSTOR ASH IN PAVING APPLICATIONS

Municipal Waste Combustion (MWC) ash is widely used in Europe in road construction as compacted road base; structural fill in wind barriers, sound barriers, and highway ramps; and in asphalt applications (Kosson et al., 1996). In fact, approximately ½ of the MWC bottom ash generated in Germany is used in road construction. (Stegemann and Schneider, 1991). Similarly, in the Netherlands, there are more than ten years of experience with the use of MWC fly ash as a substitute for natural aggregate in asphalt in road construction (Hudales, 1994).

The leaching behavior of asphalt containing MWC fly ash was tested by order of the Dutch Ministry of Transport, Public Works, and Water Management according to the tank diffusion Dutch leaching test NVN 5432. No differences were found in the leaching of metals between asphalt pieces containing MWC fly ash compared to natural aggregates. Ash-amended asphalt passes the requirements for aggregates dictated in the draft Dutch

Building Materials decree. Since 1988, much asphalt containing MWC bottom ash has been produced and applied in about ten pilot projects. The production of asphalt was executed without problem. There were no differences in the paving of test and control asphalts, and the pavements all performed well (Eymael et al., 1994).

There has also been considerable experience with the use and testing of ash-amended pavement in the United States. Gress et al. (1993) summarized selected paving projects in the United States in which MWC ash was used as a partial substitute for aggregate in asphalt pavement. These projects are summarized in Table 1.

TABLE 1
SELECTED COMBUSTION RESIDUE USE STUDIES

PROJECT	APPLICATION
Houston, TX	Asphalt base course
Philadelphia. PA	Asphalt wearing course
Delaware Co., PA	Asphalt wearing course
Harris, PA	Asphalt wearing course
Washington, DC	Asphalt base course
Lynn, MA	Asphalt wearing course
Harrisburg, PA	Asphalt wearing course
Tampa, FL	Asphalt wearing course

Adapted from Gress et al. (1993)

Then, Kosson et al. (1994) summarized some of the more recent MWC combustor ash utilization projects in the United States. These are listed in Table 2. Their work stems from a cooperative agreement with the U.S. EPA on identification of the issues associated with MWC residue utilization and the development of recommendations for utilization criteria. In this paper, the researchers present as an example the proposed utilization of MWC ash in the binder course for asphalt pavement. Based on tank leaching experiments of MWC ash in a variety of asphalt pavements, they conclude that the estimated release of lead from such pavement over 100 years would be less than 0.2% of the total lead present. This estimated leaching would not significantly increase soil lead concentrations over normal background levels. They conclude that the use of MWC ash in asphalt would be "environmentally protective based on conservative assumptions" (Kosson et al., 1994, 1996).

TABLE 2

SELECTED RECENT MWC ASH UTILIZATION PROJECTS

PROJECT	APPLICATION	ASH TYPE
Hennepin County, MN Pavement Demonstration	Asphalt	Combined
Hillsborough County Department of Solid Waste Municipal Combustor Ash Reuse, FL	Asphalt	Combined
McKaynite Demonstration, Acline Street, FL	Asphalt	Combined
McKaynite Demonstration, Ruskin, FL	Asphalt	Bottom
New Hampshire Bottom Ash Paving Project	Asphalt	Bottom
Ash Management Building, Montgomery County, OH	Concrete/cement	Bottom
Center for Innovative Technology, VA	Concrete/cement	Bottom, combined
Commerce Refuse-to-Energy Ash treatment and Reuse, Los Angeles County, CA	Concrete/cement	Combined
Fly Ash Stabilization Building, Long Island, NY	Concrete/cement	Combined
Islip, Blydenburgh Landfill, Long Island, NY	Concrete/cement	Combined
Pinellas County, Florida Artificial Reef	Concrete/cement	Scrubber Bottom
SUNY Artificial Reef Demonstrations	Concrete/cement	Combined
SUNY Boathouse Demonstration	Concrete/cement	Bottom, combined

Adapted from Kosson et al. (1994)

In one of the most recent paving demonstration projects in the United States, a 600 meter section of U.S. Route 3 in the City of Laconia , New Hampshire was paved with MWC bottom ash as 50% of the required aggregate in the binder course pavement (Musselman et al., 1994). Roadway runoff, surface water, and groundwater were monitored. Groundwater was collected in suction lysimeters installed 1.5 to 3 meters beneath the pavement and in groundwater monitoring wells. The asphalt and the pavement have performed well over the two year observation period, and environmental sampling showed no increases in chemical constituents compared to the control pavement which was attributable to the use of the MWC ash. An issue that arose, however, was that lead levels were elevated in upgradient groundwater and in roadside soils. Consequently, the results of the comprehensive environmental monitoring required careful evaluation. Bench scale monolith leaching tests over 64 days were also performed. According to Musselman, et al. (1994), monolith leaching tests have all indicated that release rates of chemical constituents are low and occur at levels similar to those for natural aggregates.

In Massachusetts, the Department of Environmental Protection recently issued a Beneficial Use Permit for the use of MWC ash as an amendment in asphalt paving of roads. Supporting data for this permit included bench scale leaching experiments and environmental sampling of a test road.

IX. TYPES OF TESTING PROGRAMS PREVIOUSLY EXECUTED

The release of chemical constituents to the environment has been demonstrated on numerous occasions not to be correlated with the total concentration of the constituents in the material (van der Sloot, 1991). Thus, leaching tests should be performed on the specific material. A number of leaching tests have been used to test raw MWC ash, stabilized MWC ash, and MWC ash-amended asphalt and cement products. These range from single batch extraction tests, column tests, monolith tank tests, and field lysimeters of different designs. Single batch extraction tests, such as EP-TOX, TCLP, the similar procedures developed by the Swiss, French, and German governments do not allow an extrapolation to long term effects, nor do they provide information about leaching mechanisms (van der Sloot, 1991). Column tests are useful only for granular materials. Accordingly, they would be useful if MWC ash were proposed for use as structural fill, but not for use as an amendment in pavement.

For ash-amended pavement, the most appropriate leaching tests are the monolith tank tests and the field lysimeter tests. Such tests have been performed by many investigators, with slight variations. Several examples from the literature are described below, as is a brief description of leaching mechanisms.

Leaching of chemical constituents has been shown to occur by two mechanisms, depending on the application. In diffusion controlled leaching, the pores of the products fill with water. Dissolution of metals occurs, but the dissolved constituents can reach the environment only after diffusion through the pore structure of the material. The rate limiting step is diffusion. In tank leaching tests, diffusion leaching is measured and quantified. The other leaching mechanism is percolation. This mechanism occurs when there is a flow of water through a granular material. Diffusion also occurs, but it is not the rate limiting step. The overall leaching rate is dependent on the rate of percolation. Column leaching tests measure and quantitate percolation leaching.

Release through leaching may either be percolation controlled or diffusion controlled. Percolation controlled leaching occurs when the material is granular and is used in an application having significant infiltration. Diffusion controlled leaching occurs when the material is either monolithic and durable or is compacted granular material with low permeability or with an overlying barrier preventing infiltration (Kosson et al, 1994). With MWC ash in asphalt pavement, tank leaching tests should be done, because leaching would be diffusion controlled (Kosson, et al. 1994).

Numerous researchers recommend tank leaching tests to estimate the rate of metal leaching from ash-amended pavement pieces. "The tank leaching test ... is a good characterization method for the leaching behaviour of monolithic materials as it provides knowledge on release controlling parameters and allows prediction of release at longer time scales by the leaching parameters derived from the test results" (van der Sloot et al., 1994). Such tank tests have been field validated. For instance, from tank leaching experiments over a period of up to three years, diffusion controlled release of chemical constituents from coal ash-amended asphalt was observed. A core sample of asphalt that was applied in 1966 was later analyzed to validate the assumption in a field situation that leaching was, indeed, diffusion controlled. The measured leaching depth of metals in the concrete could be explained by Fick's second law of diffusion using literature values for the effective diffusion coefficient (van der Wegen and van der Plas, 1994).

Numerous tank leaching methods have been described. For instance, Dutch method NEN 7345 (formerly NVN 5432) resembles the American Nuclear Society method ANS16.1. In the Dutch method, the liquid to solid ratio is 5, the specimen is submerged, and leachate is removed after varying time points up to 64 days. Eymael et al. (1994); Hudales (1994); Kosson et al. (1994); Eighmy et al. (1995); Gress et al. (1992); Whitehead et al. (1993); and Kosson et al. (1996) all report tests of ash-amended asphalt pieces with the Dutch method or a modification thereof.

Van der Sloot has modified the procedure and validated it with cement stabilized MWC fly ash and other materials using a shorter time (16 days). In a similar test, Bialucha et al. (1994) placed a 2 kg test specimen in 30L of deionized water in propylene or glass tank for 24 hours. The liquid to solid ratio was 10.

To evaluate the leaching of chemical constituents from cement stabilized MWC combined ash proposed for placement directly in coastal water, Hjelmar et al. (1994) performed tank leaching assays with ocean water. Monolithic 6 cm^3 specimens were suspended in a closed seawater-filled polypropylene tank by a nylon string. The water (0.9 L) was replaced by new seawater at varying time intervals from 0.7 to 47 days.

The U.S. EPA Program for Evaluation of Treatment and Utilization Technologies for Municipal Waste Combustor Residues uses a Monolith Leach Test to assess the release of chemical species from treated and untreated residues. 4 cm diameter by 4 cm high cylindrical monoliths are prepared and tested. These monoliths are extracted by contacting distilled water for up to 64 days. Contacting water is replaced at 1, 2, 4, 8, 16, 32, and 64 days and analyzed. The leach test is a modified version of the ANSI 16.1 test (Kosson et al, 1994).

Thus, monolith leaching tests are useful to evaluate the fundamental leaching behavior of ash-amended pavement. However, the total immersion of samples in water is a more aggressive test of leaching potential than will exist in the field, because pore spaces will not be saturated in the field situation (Musselman, et al, 1994). Thus, such tests should be considered conservative and health-protective.

Field test lysimeter tests have also been conducted. For instance, 12 tons of MWC ash-amended asphalt pavement was manufactured with 25% ash/75% natural aggregate. The mix was paved, compacted, and broken up after one week with a backhoe into large pieces (palm sized to 2 by 3 foot plates). These pavement pieces were placed into a 20 cubic yard double-lined roll-off container. Leachate originating from natural rainfall was collected and analyzed (Gress et al., 1995; Whitehead et al., 1993). Releases of metals from the ash-amended pavement measured in the field lysimeter were two orders of magnitude lower than the releases from the raw MWC ash in a control lysimeter. Good agreement was seen comparing the monolith tank leaching test results and the field lysimeter test results.

X. OVERALL APPROACH TO ENVIRONMENTAL TESTING

There are several options for testing ash-amended pavement for metal leaching: (1) standardized monolith leaching tests with various extractants, (2) field lysimeters with natural rainwater, and (3) direct collection and testing of water running off of pavement surfaces. Each approach has pros and cons. The benefits of using standardized monolith tank tests is that the data can be compared and related to previous studies with other materials. Also, the high liquid to solid ratio, while unnatural, is conservative. The disadvantages are that the effects of sunlight, wet/dry cycles, and cracking cannot be easily taken into account. Also, the effects of traffic wear and tear cannot be determined. Finally, tests done with any extractants other than natural rainwater are not realistic.

The benefits of the field test lysimeter method are that actual rainwater is used, and the effects of sunlight, heat, and wet/dry cycles are incorporated. In addition, the liquid to solid ratio is realistic. The disadvantages are that the effects of traffic wear and tear cannot be taken into account and that the test is cumbersome.

The benefits of the collection of water that has run off of pavement in the field is that it is totally realistic. The solid to liquid ratio is realistic, traffic wear and tear is considered, and weathering (heat, sunlight, and wet/dry cycles) effects are considered. The disadvantages are that such experiments cannot be controlled, and confounding effects may obscure the trends in the collected data. For instance, metals found in the water may originate in drippage from trucks or dust deposited on the roadway from an external source.

The strategy described here draws from the pros and cons of all of the above methods. It includes standard monolith leaching tests, collection of soil and ponded water in the areas where surface run-off collects, and performance of novel bench scale tests with simulated rainwater that focus on the factors revealed by others to influence metal leachability from ash-amended pavement.

XI. STANDARD LABORATORY TESTING

Monoliths will be prepared from test and control pavement. These monoliths will be subjected to the standard monolith tank test as executed by U.S. EPA in the MITE program using distilled water (Kosson et al., 1994).

In addition, test cores of the control and test pavement will be tested for total metals and metals in synthetic rainwater leachate (Synthetic Precipitation Leaching Procedure (Method 1312) Extraction Fluid #1 (pH 4.2)).

XII. TESTING TO EVALUATE THE EFFECTS OF SURFACE RUN-OFF

A major goal of the environmental testing is to determine if the ash-amended pavement might degrade and release metal-containing particulates or dissolved metals, affecting soil and surface water in the area adjacent to a hypothetical road paved with the material. Data on the effects of surface run-off will be gathered from the pilot roadways by periodically washing the ramps with city water and collecting and analyzing soil/sediment and water in areas where run-off collects (see Table 3). During the nine month test period, the ramps will not be cleaned with the vacuum sweeper. Instead, detritus will be hand removed from the ramps daily.

Natural patterns of surface water run-off from rainfall events have been observed for both ramps. In both cases, water flows to the inside curb because of the slopes of the ramps and the onto a specific area of the lawn in the front of the plant. In both areas, noticeable sedimentation is visible at the bottom of the ramp and on the lawn where particles deposit. All particles present on the ramps collect in these two areas, regardless of whether they are derived from pavement degradation, from material dropping off of trucks as they pass, or from dust from nearby industries that deposits on the ramps. Thus, the soil/sediment in the run-off collection areas are natural time-integrated collection devices for any metals that might be present on the pavement from any source.

Soil/sediment samples will be collected in duplicate before the ramps are paved at two locations where surface run-off collects from the upramp and at two locations where surface run-off collects from the downramp. Duplicate samples will be collected monthly for nine months. Any pavement-derived particle-bound metals that might have worn away due to pavement degradation under normal use patterns might be expected to cause a time-dependent increase in the measured levels of metals in the soils/sediments compared to the baseline levels, if the release of metals from the ash-amended pavement were significant.

In addition, after periods of high rainfall, a significant amount of run-off water from the ramps ponds in these low areas. At the present time, water is visible in these areas because of the recent rainfall. This visible water is rainwater that recently washed over the pavement on the ramps. Rainwater collects in these low areas and flows out to the ocean through a stormwater culvert only when the amount is sufficiently large that the water level in the ponded areas reaches the height of the stormwater culvert. Thus, no run-off from the up and down ramps currently exits the facility boundaries until rather large ponds have formed on the H-POWER lawn.

In theory, actual stormwater run-off could be collected from the facility on the facility lawn using the site typography as a natural collection device. However, because natural rainfall will be unpredictable during the test period, the ramps will be washed with city water twice a month, and samples will be collected within 30 minutes of the washing at the bottom of each ramp. Water will be consistently applied at a specific rate (X gallons per square foot) that will be determined after several test washing are done. With this application rate, the amount of water applied to the down ramp would be more than 100 gallons. Wash water samples will be collected in duplicate before the ramps are paved at the bottom of each ramp. In addition, samples of city water will be analyzed for dissolved metals as control samples. Samples of wash water will be collected twice a month at both ramps for nine months and analyzed for total suspended solids and dissolved metals.

It should be anticipated that metals will be detected in soil/sediment and wash water samples in the areas where surface run-off collects from both the test and the control roadways. A large database exists on the results of column leaching tests of natural aggregates, monolith leaching tests of specimens of pavement constructed with natural aggregate, and field lysimeter tests with pavement constructed with natural aggregate. These results clearly indicate that natural materials will leach metals *albeit* at low rates. In addition, it would not be unexpected to anticipate that metal particulates originating from any number of natural and industrial sources might deposit atop the test and control pavement. Accordingly, the goal of this environmental testing is to determine if the presence of metals in surface run-off differs between the test and control pavement.

The data from the soil/sediment and wash water testing to evaluate the effects of surface run-off will be summarized and evaluated as it is generated. If, at any time, the chemical quality of the soil/sediment and wash water is statistically significantly different between the test and control pavements, risk assessment calculations will be executed to determine if there is a significant risk to human health and the environment. In the event that the calculations result in an estimate of significant risk, the experiment will be discontinued, and the test pavement will be removed and properly disposed. If appropriate statistical tests demonstrate that there is no statistical difference between the two pavements, then further risk modeling of the potential effects of surface run-off would not be required.

TABLE 3
ENVIRONMENTAL SAMPLING TO EVALUATE THE EFFECTS OF SURFACE RUN-OFF

MEDIUM	ANALYSES
City water	Dissolved metals (baseline)
Soil/sediment in area where run-off collects, up-ramp	Total metals (baseline and monthly for nine months)
	Total metals in synthetic acid rainwater leachate (baseline and monthly for nine months)
Up-ramp wash water at bottom of ramp	Total suspended solids (baseline and twice monthly for nine months) Dissolved metals (baseline and twice monthly for nine months)
Soil/sediment in area where run-off collects, down-ramp	Total metals (baseline and monthly for nine months)
	Total metals in synthetic acid rainwater leachate (baseline and monthly for nine months)
Down-ramp wash water at bottom of ramp	Total suspended solids (baseline and twice monthly for nine months) Dissolved metals (baseline and twice monthly for nine months)

XIII. SIMULATED WEATHERING OF ASPHALT ROADWAY CONTAINING H-POWER TEST ASH

A concern expressed by the Hawaii Department of Health was the issue of weathering on the leachability of metals in pavement using H-POWER combined ash as an aggregate substitute. In particular, the issue of sunlight was discussed. In addition, Professor Taylor Eighmy of the University of New Hampshire has reported that of several variables studied, cracking caused by weathering was the only factor that increased the rate of leaching of materials from ash amended pavement (Eighmy et al., 1995). Accordingly, on-site bench scale tests will be performed to simulate long-term weathering.

The scope of work examines four phenomena: impact of physical deterioration, impact of sunlight, impact of periodic wetting, and the direct comparison of the use of combined ash as aggregate and natural aggregate in asphalt pavement. To conserve resources, the scope of work focuses on selected entries in a 2x2x2x2 matrix. The entries in the matrix are:

1. Source:	Control (Natural Aggregate) vs Test (H-POWER Test Ash)
2. Physical State:	Intact pavement vs Cracked pavement (broken pieces)
3. Wetting:	Constant immersion vs periodic immersion
4. Light:	Sunlight vs Underwater

Treatment 1: Test Pavement, Broken, Constant Immersion, Dark (Underwater)
Treatment 2: Test Pavement, Intact, Periodic Immersion, Sunlight
Treatment 3: Control Pavement, Broken, Constant Immersion, Dark (Underwater)
Treatment 4: Control Pavement, Intact, Periodic Immersion, Sunlight

Four treatments will be tested. Both control and test pavement would be broken into pieces to simulate pavement cracking and kept constantly immersed in simulated rainwater (Synthetic Precipitation Leaching Procedure (Method 1312) Extraction Fluid #1 (pH 4.2)) for sixteen weeks outdoors. At the end of every month, the water would be completely mixed, samples of water would be submitted for metals analysis, and the water would be changed. There would be four sampling events. Samples from each test would be tested for total recoverable metals, pH and hardness *without field or laboratory filtration*. This will ensure that metals will be detected regardless of whether they are present on small particles or dissolved in the water column.

Also, control and test pavement would be tested intact in standard test cores of 4 inch diameter and 2-2.5 inch thickness in a periodic immersion experiment. The test articles would be placed outside under full sun and exposed to rainfall for one month on a screened platform above a rainwater collection container. The volume of rainwater will be measured, and samples of any rainwater that passed over the pavement and collected in the container would be collected. Then, the articles would be immersed in simulated rainwater (Synthetic Precipitation Leaching Procedure (Method 1312) Extraction Fluid #1 (pH 4.2)) for a full month after which the water would be complete mixed, the original volume would be reconstituted with synthetic rainwater, samples of the water would be submitted for chemical analysis, and the container would be emptied. This schedule would be repeated for four cycles (four months in full sunlight, four months immersed in rainwater). Samples from each test would be tested for total recoverable metals, pH and hardness *without field or laboratory filtration*. This will ensure that metals will be detected regardless of whether they are present on small particles or dissolved in the water column.

TABLE 4

WEATHERING EXPERIMENTS WITH TEST PAVEMENT

TEST SCENARIO	ANALYSES
Test Road, Constant Immersion (Broken)	Total metals (monthly for four months) pH (monthly for four months) hardness (monthly for four months)
Control Road, Constant Immersion (Broken)	Total metals (monthly for four months) pH (monthly for four months) hardness (monthly for four months)
Test Road, Periodic Immersion (Intact)	Total metals (monthly for nine months) pH (monthly for nine months) hardness (monthly for nine months)
Control Road, Periodic Immersion (Intact)	Total metals (monthly for nine months) pH (monthly for nine months) hardness (monthly for nine months)

XIV. BIOLOGICAL TESTING OF LEACHATE FROM WASH WATER AND SIMULATED ACID RAIN EXPERIMENTS

A literature evaluation did not identify any studies in which aquatic toxicity was tested with ash-amended pavement. In a study of cement-stabilized MWC ash, Hjelmar et al. (1994) performed a variety of toxicity tests on marine organisms with leachate from column experiments with pure MWC ash, but they did not perform tests on specimens of the ash-amended cement or leachates therefrom.

Despite the lack of precedents with ash-amended pavement, aquatic toxicity tests are executed routinely with effluents, including samples of urban run-off. It is proposed that a subset of the samples of wash water surface run-off from the control and test roadways be tested for toxicity to aquatic organisms. Three samples (first collection period, middle period, last period) from the control and the test roadway will be submitted to Ogden's aquatic toxicology laboratory for acute toxicity testing with Water Flea (*Ceriodaphnia dubia*) and Fathead Minnows (*Pimephales promelas*) after laboratory filtration. These assays include a dilution series (5), laboratory duplicates, and laboratory controls.

In addition, one sample from each of the weathering experiments will be submitted to Ogden's aquatic toxicology laboratory for acute toxicity testing with Water Flea

(*Ceriodaphnia dubia*) and Fathead Minnows (*Pimephales promelas*) after filtration. These assays include a dilution series (5), laboratory duplicates, and laboratory controls.

TABLE 5
AQUATIC TOXICITY TESTING

Test Roadway - Wash Water Surface Run-off	3 acute Daphnia tests
	3 acute minnow tests
Control Roadway - Wash Water Surface Run-off	3 acute Daphnia tests
	3 acute minnow tests
Test: Constant immersion, broken pieces	1 acute Daphnia tests
	1 acute minnow tests
Control: Constant immersion, broken pieces	1 acute Daphnia tests
	1 acute minnow tests
Test: Periodic immersion, intact	1 acute Daphnia tests
	1 acute minnow tests
Control: Periodic immersion, intact	1 acute Daphnia tests
	1 acute minnow tests

It should be anticipated that wash water surface run-off from both the test and the control roadways and leachates from test and control pavement specimens may both be toxic to the test organisms in their undiluted state. As noted above, the large database that exists on the leaching of metals from natural aggregates demonstrate that natural materials will leach metals *albeit* at low rates. In addition, it would not be unexpected to anticipate that metal particulates originating from any number of natural and industrial sources might deposit atop the test and control pavement. As stated above, the goal of this environmental testing is to determine if the whole effluent toxicity of the wash water surface run-off and the leachate differs between the test and control pavements. If appropriate statistical tests demonstrate that there is no statistical difference between the two pavements, then no further risk assessment modeling of the potential effects of leachate would be required.

To conserve resources, the wash water run-off and synthetic rainwater leachate from the control pavement will be tested first. If the wash water run-off is toxic to the test species throughout the standard dilution series, the test pavement will not be tested. If this situation were to occur, no useful information would be produced by the toxicity testing of the test pavement.

XV. RISK ASSESSMENT DOCUMENT TO SUPPORT USE OF ASPHALT CONTAINING COMBINED ASH

A separate scope of work will be prepared for the human health and environmental risk assessment to support the use of H-POWER Combined Ash as an aggregate substitute in asphalt paving mix that could be used throughout the Islands. This section outlines the broad aspects of the proposed risk assessment.

A. Major Aspects of the Use of H-POWER Combined Ash in Road Making

1. Transportation of the Processed H-POWER Combined Ash
2. Manufacture of Paving Mix
3. Construction of the Road
4. Road in Use
5. Demolition of Road
6. Disposal of Demolition Material
7. Alternate Use of Demolition Material

B. Specific Risk Assessment Tasks

1. Transportation of the Processed H-POWER Combined Ash

The H-POWER Combined Ash is currently being transported to the Waimanalo Gulch Landfill as a high moisture product in specially designed, covered trucks. In the proposed beneficial use, it would merely be screened and transported to a different location. It is recommended that this aspect of the proposed project be qualitatively evaluated.

2. Manufacture of Paving Mix

This aspect of the proposed project involves several activities in which exposures to Processed H-POWER combined ash could possibly occur. These include (a) delivery and stockpiling of processed H-POWER Combined Ash at site of manufacture of road mix; (b) manufacture of an aggregate mixture containing processed H-POWER combined ash and natural aggregate, and (c) manufacture of the paving mix. It is proposed that this aspect of the proposed beneficial use be quantitatively evaluated.

3. Construction of Road

During road construction, several activities can be assumed: (a) transportation of the paving mix to the site and (b) construction of the road. This aspect of the proposed project will be qualitatively evaluated for use of the ash in asphalt because:

a. the H-POWER Combined Ash will be a component of a paving mix;
b. transportation is not expected to cause significant exposures;
c. stockpiling does not occur for asphalt paving mix;
d. construction of the road is not expected to occur for a significant time period; and
e. construction of the road is not expected to generate significant dust

4. Road in Use

The road can be expected to remain in use for many years, and roads can be expected to be constructed in many different locations. It is recommended that this aspect of the proposed project be quantitatively evaluated. Possible concerns include generation of run-off that could affect nearby surface waterways or groundwater during precipitation events and generation of leachate through the pavement that could affect groundwater during precipitation events.

5. Demolition of Road

The road can be expected to be demolished at some point in the future. Typical procedures use machines that scrape and grind the road surface and deposit the material in trucks for disposal or re-use in future pavement. It is not inconceivable that such processes could generate metal-containing dust. It is recommended that this aspect of the project be quantitatively evaluated.

6. Disposal of Demolition Material

The demolition material, which would contain some fraction of the H-POWER Combined Ash would be ultimately disposed in a permitted sanitary landfill. Because the H-POWER Combined Ash is currently disposed in a landfill, it is not expected that disposal of road demolition material would have long-term environmental impacts different from the H-POWER Combined Ash as produced. However, the disposal of this demolition material could have dust associated with it if it were disposed in a dry, ground-up state. Accordingly, it is recommended that this aspect of the proposed project be quantitatively evaluated.

7. Alternate Use of Demolition Material

It is possible that a road could be demolished by removing large blocks of material that could then be used for other purposes. Large blocks of pavement might be used as "clean fill" or they might be used for erosion control in coastal areas. It is recommended that this aspect of the proposed project be quantitatively evaluated.

TABLE 6

PROPOSED SCOPE OF WORK FOR RISK ASSESSMENT

ASPECT	CURRENT RECOMMENDATION	NOTES
Transportation	Qualitative	
Manufacture of Road Mix	Quantitative	Can be done with current data & methods
Construction of Road	Qualitative	
Use of Road	Quantitative	Requires leaching and/or runoff data
Demolition of Road	Quantitative	Requires generic data on dust generation during demolition of roads
Disposal of Demolition Material	Quantitative	Requires generic data on dust generation during disposal of dry material similar in characteristics to ground-up asphalt
Alternate Use of Demolition Material	Quantitative	Requires leaching and/or runoff data

XVI. REFERENCES

Bialucha, R., J. Geiseler and K. Krass. 1994. Assessment of the Environmental Compatibility of Industrial By_products and Recycled Materials. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Environmental Aspects of Construction with Waste Materials (Elsevier: New York).

Eighmy, T.T. and H.A. van der Sloot. 1994. A Unified Approach to Leaching Behavior of Waste Materials. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Environmental Aspects of Construction with Waste Materials (Elsevier: New York).

Eighmy, T. T., D.Crimi, S.H.X. Zhang, and D.L. Gress. 1995. Influence of Void Change, Cracking and Bitumen Aging on Diffusional Leaching Behavior of Pavement Monoliths Constructed with MSW Combustion Bottom Ash. *Transportation Research Record* 1486:42-48.

Eymael, M.M. Th. , W. de Wijs, and D. Mahadew. 1994. The Use of MSWI Bottom Ash in Asphalt Concrete. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Environmental Aspects of Construction with Waste Materials (Elsevier: New York).

Gress, D., X. Zhang, S. Tarr, I. Pazienza, and T. Eighmy. 1992. Physical and Environmental Properties of Asphalt-Amended Bottom Ash. *Transportation Research Record* 1345:10-18.

Hartlen, J. and T. Lundgren. 1991. Utilization of ncinerator Bottom Ash- Legal, Environmental and Engineering Aspects. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Waste Materials in Construction. (Elsevier: New York).

Hjelmar, O., E. Aa. Hasen, K.J. Andersen, J.B. Andersen, and E. Bjornestad. 1994. An Approach to the Assessment of the Environmental Impacts of Marine Applications of Municipal Solid Waste Combustion Residues. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Environmental Aspects of Construction with Waste Materials (Elsevier: New York).

Hudales, J.B.M. 1994. The use of M.W.I. fly ash in asphalt for road construction. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Environmental Aspects of Construction with Waste Materials (Elsevier: New York).

Kosson, D.S., H. van der Sloot, T. Holmes. and C. Wiles. 1991. Leaching Properties of Untreated and Treated Residues Testted in the USEPA Program for Evaluation of Treatment and Utilization Technologies for Municipal Waste Combustor Residues. in

Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Waste Materials in Construction. (Elsevier: New York).

Kosson, D.S., B.A. Clay, H.A. van der Sloot, and T.T, Kosson. 1994. Utilization Status, Issues and Criteria Development for Municipal Waste Combustor Residues in the United States. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Environmental Aspects of Construction with Waste Materials (Elsevier: New York).

Kosson, D.S., H.A. van der Sloot, and T.T, Eighmy. 1996. An Approach for Estimation of Contaminant Release During Utilization and Disporal of Municipal Waste Combustion Residues. *Journal of Hazardous Materials* 47:43-75.

Musselman, C.N., M.P. Killeen, D. Crimi, S. Hasan, X. Zhang, D.L. Green, and T.T. Eighmy. 1994. The Laconia, New Hampshire Bottom Ash Paving Project. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Environmental Aspects of Construction with Waste Materials (Elsevier: New York).

Stegemann, J.A. and J. Schneider. 1991. Leaching Potential of Municipal Waste Incinerator Bottom Ash as a Function of Particle Size Distribution. (Elsevier: New York).

van der Sloot, H.A. 1991. Systematic Leaching Behaviour of Trace Elements from Construction Materials and Waste Materials. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Waste Materials in Construction. (Elsevier: New York).

van der Sloot, H.A., G.J.L. van der Wegen, D. Hoede, and G.J. de Groot. 1994. Intercomparison of Leaching Tests for Stabilized Waste. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Environmental Aspects of Construction with Waste Materials (Elsevier: New York).

van der Wegen, G. and C. van der Plas. 1994. Validation of leaching model on actual structures. in Goumans, J.J.J.M., H.A. van der Sloot, and Th. G. Aalbers (eds). Environmental Aspects of Construction with Waste Materials (Elsevier: New York).

Whitehead, I.E., T.T. Eighmy, D.L. Gress, and X. Zhang. 1993. An Environmental Evaluation of Bottom Ash Substitution in Pavement Materials. in VIP-32, Municipal Waste Combustion: Proceedings of an International Specialty Conference, Williamsburg, Virginia, March, 1993 (Air and Waste Management Association: Pittsburgh).

Appendix G

Performance Monitoring of the Test Road

Table G-1
Noncarcinogenic and Carcinogenic Risk Estimates
H-Power Risk Assessment: Waipahu Landfill

SCENARIO/RECEPTOR	PATHWAY	LOCATION	HAZARD INDEX	CANCER RISK
Closure - No Stockpile				
Worker	Ash ingestion	On-Site	0.094	8.4E-07
	Ash dermal	On-Site	0.025	6.9E-07
	Dust inhalation	On-Site	0.14	1.5E-06
		TOTAL:	0.26	3.0E-06
Trespasser	Ash ingestion	On-Site	0.079	7.0E-07
	Ash dermal	On-Site	0.005	1.4E-07
	Inh. of dust from work activities	Off-Site (north)	0.0005	5.2E-09
		TOTAL:	0.08	8.5E-07
Resident	Inh. of dust from work activities	Off-Site (south)	0.00023	2.5E-09
	Ash ingestion (tracking)	Off-Site (south)	0.00076	1.3E-08
	Ash dermal (tracking)	Off-Site (south)	4.80E-05	2.7E-09
		TOTAL:	0.001	1.8E-08
Closure - With Stockpile				
Worker	Ash ingestion	On-Site	0.094	6.1E-07
	Ash dermal	On-Site	0.025	5.1E-07
	Dust inhalation	On-Site	0.14	1.1E-06
		TOTAL:	0.26	2.2E-06
Trespasser	Ash ingestion	On-Site	0.16	1.0E-06
	Ash dermal	On-Site	0.0099	2.0E-07
	Leachate ingestion	On-Site	0.0073	7.8E-08
	Leachate dermal	On-Site	0.1	1.2E-07
	Inh. of dust from stockpile	On-Site	0.0019	1.4E-08
	Inh. of dust from stockpile	Off-Site (north)	0.00012	9.2E-10
	Inh. of dust from work activities	Off-Site (north)	0.0005	3.8E-09
		TOTAL:	0.28	1.4E-06
Resident	Inh. of dust from stockpile	Off-Site (south)	2.7E-05	2.1E-10
	Inh. of dust from work activities	Off-Site (south)	0.00023	1.8E-09
	Ash ingestion (tracking)	Off-Site (south)	0.0076	1.3E-08
	Ash dermal (tracking)	Off-Site (south)	4.8E-05	2.7E-09
		TOTAL:	0.0079	1.8E-08
Recreational User (West Loch)	Surface water ingestion	West Loch	2.8E-07	2.3E-11
	Surface water dermal	West Loch	4.8E-05	6.1E-09
	Sediment ingestion	West Loch	1.3E-06	1.1E-10
	Sediment dermal	West Loch	9.1E-07	2.0E-10
	Fish ingestion	West Loch	2.1E-03	6.1E-08
		TOTAL:	2.2E-03	6.7E-08

Table G-1
Noncarcinogenic and Carcinogenic Risk Estimates
H-Power Risk Assessment: Waipahu Landfill

SCENARIO/RECEPTOR	PATHWAY	LOCATION	HAZARD INDEX	CANCER RISK
Closure - With Uncovered Ash				
Worker	Ash ingestion	On-Site	0.094	8.4E-07
	Ash dermal	On-Site	0.025	6.9E-07
	Dust inhalation	On-Site	0.14	1.5E-06
		TOTAL:	0.26	3.0E-06
Trespasser	Ash ingestion	On-Site	0.16	1.4E-06
	Ash dermal	On-Site	0.0099	2.8E-07
	Leachate ingestion	On-Site	0.0073	1.1E-07
	Leachate dermal	On-Site	0.1	1.6E-07
	Inh. of dust from uncovered ash	On-Site	8.7E-05	9.2E-10
	Inh. of dust from uncovered ash	Off-Site (north)	1.8E-05	1.3E-10
	Inh. of dust from work activities	Off-Site (north)	0.0005	5.3E-09
		TOTAL:	0.28	2.0E-06
Resident	Inh. of dust from uncovered ash	Off-Site (south)	4.1E-06	4.3E-11
	Inh. of dust from work activities	Off-Site (south)	0.00023	2.5E-09
	Ash ingestion (tracking)	Off-Site (south)	0.00076	1.3E-08
	Ash dermal (tracking)	Off-Site (south)	4.8E-05	2.7E-09
		TOTAL:	0.0010	1.8E-08
Recreational User (West Loch)	Surface water ingestion	West Loch	9.2E-07	7.6E-11
	Surface water dermal	West Loch	1.6E-04	2.0E-08
	Sediment ingestion	West Loch	4.2E-06	3.7E-10
	Sediment dermal	West Loch	3.0E-06	6.6E-10
	Fish ingestion	West Loch	6.9E-03	2.0E-07
		TOTAL:	7.1E-03	2.2E-07
Post Closure				
Recreational User (On-Site)	Ash ingestion	On-Site	0.16	9.3E-07
	Ash dermal	On-Site	0.0099	1.9E-07
	Inh. of dust from exposed ash	On-Site	0.00021	1.5E-09
	Inh. of dust from exposed ash	Off-Site (north)	6.5E-05	4.5E-10
		TOTAL:	1.7E-01	1.1E-06
Recreational User (West Loch)	Surface water ingestion	West Loch	1.2E-05	6.3E-10
	Surface water dermal	West Loch	0.00065	8.0E-08
	Sediment ingestion	West Loch	2.5E-05	1.5E-09
	Sediment dermal	West Loch	1.2E-05	2.6E-09
	Fish ingestion	West Loch	0.13	8.0E-07
		TOTAL:	0.13	8.8E-07
Resident	Inh. of dust from exposed ash	Off-Site (south)	1.6E-05	1.1E-10
	Ash ingestion (tracking)	Off-Site (south)	0.00076	1.3E-08
	Ash dermal (tracking)	Off-Site (south)	4.8E-05	2.7E-09
		TOTAL:	0.00082	1.6E-08

Table G-2
Estimated Blood Lead Concentrations
H-Power Risk Assessment: Waipahu Landfill

Receptor - Scenario	Blood Lead Concentration (ug/dL)		
	50th %ile	95th %ile	99th %ile
Worker - Closure	2.3	4.09	5.2
Trespasser - Closure No Stockpile	1.17	2.09	2.65
Trespasser - Closure with Stockpile	1.51	2.69	3.41
Trespasser - Closure Uncovered	1.51	2.68	3.41
West Loch Recreator - Closure with Stockpile	0.84	1.50	1.91
West Loch Recreator - Closure Uncovered	0.85	1.51	1.91
West Loch Recreator - Post Closure	0.86	1.53	1.94
Onsite Recreator - Post Closure	1.50	2.67	3.39
South Resident - Closure No Stockpile	0.85	1.51	1.92
South Resident - Closure with Stockpile	0.85	1.51	1.92
South Resident - Closure Uncovered	0.85	1.51	1.92
Resident South - Post Closure	0.85	1.51	1.92

Table G-3
Summary of Estimated Cancer and Noncancer Risk
H-Power Risk Assessment: Waimanalo Gulch Landfill

RECEPTOR	PATHWAY		HAZARD INDEX	CANCER RISK
On-Site Exposures				
Worker 1 **	Ash ingestion		0.13	9.5E-06
	Ash dermal		0.034	7.9E-06
	Dust inhalation* - Daily Operations		0.19	1.7E-05
		TOTAL:	0.4	3E-05
Worker 2 **	Ash ingestion		0.13	9.5E-06
	Ash dermal		0.034	7.9E-06
	Dust inhalation* - Ash Mining		0.43	3.7E-05
		TOTAL:	0.6	5E-05
Adult	Ash ingestion		0.039	2.8E-06
	Ash dermal		0.0051	1.1E-06
	Dust inhalation* - Daily Operations plus Ash Mining		0.0014	1.2E-07
		TOTAL:	0.05	4E-06
Child	Ash ingestion		0.16	2.8E-06
	Ash dermal		0.0099	5.6E-07
	Dust inhalation* - Daily Operations plus Ash Mining		0.00093	1.9E-08
	Leachate ingestion		0.0037	1.1E-07
	Leachate dermal		0.050	1.6E-07
		TOTAL:	0.2	4E-06
Off-Site Exposures				
Adult	Dust inhalation* - Exposed Ash (at night)		9.8E-06	8.2E-10
	Dust inhalation* - Daily Operations plus Ash Mining		1.9E-04	1.6E-08
		TOTAL:	2E-04	2E-08
Child	Ash ingestion (tracking)		4.8E-04	8.5E-09
	Ash dermal (tracking)		3.0E-05	1.7E-09
	Dust inhalation* - Exposed Ash (at night)		1.4E-05	3.0E-10
	Dust inhalation* - Daily Operations plus Ash Mining		2.8E-04	5.8E-09
		TOTAL:	0.001	2E-08

Notes:

*: All inhalation risk estimates are based on the assumption that metals concentrations in dust are 100% ash-derived.

**: Risk estimates for workers assume disregard for personal protective equipment and personal hygiene practices required under applicable OSHA regulations for arsenic, cadmium, and lead.

Table G-4
Summary of Blood Lead Concentrations
H-POWER Risk Assessment: Waimanalo Gulch Landfill

Receptor	Blood Lead Concentration (ug/dL)		
	50th %ile	95th %ile	99th %ile
Worker 1 (daily operations)	3.0	5.3	6.7
Worker 2 (ash mining)	3.3	5.8	7.3
Child (on-site) (daily operations)	1.5	2.7	3.4
Adult (on-site) (daily operations)	0.79	1.4	1.8
Child (off-site) (daily operations, ash mining, and exposed ash at night)	0.85	1.5	1.9

Appendix H

List of Abbreviations

ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control
CPC	Compounds of Potential Concern
DTSC	California Department of Toxic Substances Control
EPA	Environmental Protection Agency
HDOH	State of Hawaii Department of Health
HDOT	State of Hawaii Department of Transportation
HIOSH	Hawaii Occupational Safety and Hazard Administration
H-POWER	Honolulu Program of Waste Energy Recovery
MITE	Municipal Solid Waste Innovative Technology Evaluation
MSW	Municipal Solid Waste
MWC	Municipal Waste Combustor
NRC	National Research Council
NREL	National Renewable Energy Laboratory
OSHA	Occupational Safety and Hazard Administration
TCLP	Toxicity Characteristic Leaching Procedure

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C.M. Jones, J.L. Han, B.H. Magee, N.Q.S. Yuen, K. Sandefur, J.N. Tom, C. Yap

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City and County of Honolulu
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13. ABSTRACT *(Maximum 200 words)* This ash study infestigated the beneficial use of municipal waste combustion combined ash from the H-POWER facility in Oahu. These uses were grouped into intermediate cover for final closure of the Waipahu landfill, daily cover at the Waimanalo Gulch Landfill, and partial replacement for aggregate in asphalt for road paving. All proposed uses exame combined fly and bottom ash from a modern waste-to-energy facility that meets requirements of the Clean Air Act Amendments for Maximum Achievable Control Technology.

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