Mercury Emissions from Crematoria

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Abstract

A previous preliminary pilot study indicated that concentrations of mercury in crematoria soils might be significantly higher than controls. The source of the contamination has been assumed to be dental amalgam from cremated cadavers. Amalgam fillings contain 50% mercury, which under cremation conditions is totally vaporised and emitted from the stack either as the metallic vapour or in the oxidised form. Mercury is a cumulative poison with varying biochemical effects according to concentration and species, *inter alia*. Although much research has centred on the affects of dental amalgam in the living, the problems arising from disposal in the dead have been largely overlooked.

This study investigated mercury emissions from crematoria by means of soil and air sampling programmes. The extent of exposure to the mercury by the crematoria workers was then determined by a hair-sampling programme.

The soil monitoring and analysis programme involved five crematoria and measurements were made both by using a mercury vapour meter and flameless atomic absorption techniques. Levels in each case were significantly higher than controls and gave good overall correlation with cremation output. Air measurements varied and in one case exceeded the occupational exposure standard. In all cases the levels exceeded a proposed ambient air level goal of 1 $\mu g\ m^{-3}$.

Hair levels in crematorium workers were significantly in excess of controls ($p<0.05$). Three percent of workers had levels in excess of 6 ppm, which is considered the 'tolerable' limit.

The risk to workers and the surrounding population, in particular children, including the unborn, may be too great to be ignored. The Environmental Protection Act, in its Process Guidance Note for Crematoria: PG 5/2 (91), failed to give consideration to mercury emissions; the use of control procedures should be addressed to modify further emissions.

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CONTENTS

APPENDICES

Appendices

1. Introduction

1.1 Mercury and the Environment

Mercury is ubiquitous in the environment and may be found in trace quantities in all compartments. This is a consequence of emissions from both natural sources, such as degassing from the earth's crust, and anthropogenic sources. The latter may be emitted as concentrated local discharges, associated with industrial activity and waste disposal, or diffuse discharges associated mainly with the combustion of fuels. It may be generally assumed that local releases are more likely to be associated with harm to human health. However there is increasing concern over the indirect consequences of diffuse emissions, such as the bioaccumulation of mercury in fish**[*ibid*.2.3.3.3]**. Transport of mercury in the environment is such that it may be deposited and revolatilized many times and move from one compartment to another. Unlike other heavy metal pollutants, there is no known natural role for mercury in any form whatsoever in the body.

1.2 Mercury Amalgam

Dental amalgam, commonly referred to as 'silver' filling material contains an average of fifty percent metallic mercury and each restoration has a life span of 7-9 years. The dangers of placing a potentially toxic substance into the mouth have been the subject of ongoing debate since 1826, when a Parisian dentist called Taveau first introduced the mercury-silver amalgam fillings. Initial problems with the material were said to have resulted in widespread sub-acute mercury poisoning**[1]**. The risks to dentists and their assistants are largely established, with stringent guidelines being laid down by Dental

Associations governing the handling of amalgam. Dentists in the UK have recently been advised by the Department of Health against the use of amalgam fillings for pregnant women (BBC News, 29.4.98). Little attention has been given to problems associated with the final disposal of the filled teeth.

1.3 Mercury and Cremation

Approximately 70% of all bodies in the UK are now cremated. In 1990, attention was first drawn to the possible risks associated with the thermal decomposition of amalgam during cremation; i.e. it had been found that the mercury vapour would be totally released at cremation temperatures**[2]**. With an average of 5 fillings per head and 0.6 g mercury per filling, totalling 3 g per person, calculations estimated that 11 kg would be released each year from one crematorium. A programme of ground and air sampling was suggested to assess the situation. The original figure of 11 kg was later disputed and recalculated to be 2.199 kg**[3]**, and the total released in England and Wales was estimated at 328 kg. A mathematical error was then pointed out in the latter calculation, which meant the figure for one crematorium was revised to 5.453 kg per year**[4]**. The total for England and Wales would therefore be 837 kg. With the increase in UK housing stock, more crematoria are now located in built up areas. There is therefore the possibility of a localised pollution problem in some residential areas from a neurotoxic species to which children and pregnant woman are known to be particularly susceptible**[5]**. The limit proposed for ambient air **[6]**is 1 $\mu g\ m^{-3}$, and the eight hour occupational exposure standard is now 25 $\mu g\ m^{-3}$ (see **appendix iv**). Preliminary studies of soil levels at one crematorium have shown levels to be higher than those of control samples and naturally occurring levels**[7]**.

1.4 Mercury as a Poison

Although the overall contribution to the global flux of mercury from crematoria may be relatively low compared to other anthropogenic emissions, there are world-wide measures to reduce all mercury emissions[***ibid.*** **2.2.2**]. There are a number of well known cases of industrial pollution resulting in numerous deaths and there is no known 'no observed effect level' (NOEL) for mercury. As an historical poison, mercury can claim numerous victims, the most famous of whom was probably Sir Isaac Newton. Although his most important work was in physics, Newton spent much of his life studying alchemy. He was a strange individual, often feuding with other scientists of the day, undergoing periods of apparent insanity. It is now believed that his experimentation had led him to suffer from mercury poisoning, from which he ultimately died[**8**]. The levels to which crematorium workers and the surrounding populace are likely to be exposed may certainly not be this critical. The recent concern over the use of dental amalgam and resultant exposure to mercury, however, has highlighted problems of chronic, low-level poisoning, or 'micromercurialism'. The usual industrial exposures probably lie somewhere between the two levels, i.e. that to which Newton was exposed and the level associated with dental amalgam. The exposure levels associated with crematoria and the possible health effects have yet to be ascertained.

1.5 Aims and Objectives

The aims and objectives of this study, therefore, may be summarized as follows:

1. To investigate and quantify mercury emissions from a number of crematoria by means of a soil and air sampling programme.

2. To investigate exposure to mercury in crematorium workers by means of a hair sampling programme.

3. To compare the mercury released with appropriate air quality standards and consider the necessity of suitable control procedures for reduction of emissions.

2. Mercury and the Environment

2.1 *Introduction*

The fate and distribution of any chemical in the environment are determined by a number of interrelating physicochemical factors. These include water solubility, lipid solubility, partitioning behaviour, vapour pressure, thermodynamic properties, pKa for ionic species and adsorption coefficients for elements of soils and sediments. These factors must then be related to the environmental conditions that serve to modify the processes. For toxicologically significant chemicals such as mercury, the mobility and disposition must in turn be related to their physicochemical form, or species. For a limited study, consideration must primarily be given to those species which firstly demonstrate high availability to man, and secondly, are most toxic to man.

2.2 *Properties, Production and Uses*

2.2.1 Physical and chemical properties

Elemental mercury is unique amongst metals for being liquid at room temperature. It has a vapour pressure of 0.16 Pa at 20 °C. Thus a saturated atmosphere at this temperature contains approximately 15 mg m^{-3}. Mercury has uniform volume expansion over its entire liquid range and has low electrical resistivity. It has the electronic configuration [Xe] $4f^{14}5d^{10}6s^{2}$, and due to the lanthanide contraction exhibits the inert pair effect, with 1st and 2nd ionisation potentials relatively high**[Appendix (i)]**. It exists in the mercurous form (Hg_2^{2+} oxidation state) and the mercuric form (Hg^{2+} oxidation state). The polycation tends cations form a number of inorganic compounds and complexes. The mercuric cation can also bond covalently to carbon to form organometallic species of the type RHgX, R_2Hg and RHgR', the most numerous being RHgX. The most common forms of R are the alkyl, phenyl and methoxyethyl radicals. If the anion is nitrate or sulfate then the species tends to be more ionic, with appreciable water solubility. The chlorides, however, are covalent, non-polar compounds with higher lipid solubility. The most important organic species in terms of the environment and toxicology are the alkylmercurials, for example methylmercuric chloride and dimethylmercury, the latter being a covalent liquid.

2.2.2 Mercury Production

Mercury composes 2.7×10^{-6} % of the lithosphere with concentrations ranging from 10 ppb in igneous rocks to 1 ppm in dried sediments**[9]**. It is most commonly found in the form of cinnabar, a mercury sulfide ore, but is present in at least 30 minerals at higher than trace levels**[10]**. It has long been known as a tracer metal in geochemical explorations**[11]**.

Mercury deposits are usually extracted by underground mining methods. Extraction involves heating in a retort or furnace to liberate the vapour, which is subsequently condensed under water**[12]**.

There has been a steady decline in mercury production over the last 20 years **(Figure 2.1)**. On a worldwide basis, the Organisation for Economic Co-operation and Development urged its member countries in 1973 to 'reduce and in some cases eliminate, certain uses of mercury, and to reduce emissions of mercury to the environment'**[13]**. A small decrease in mercury, and to reduce emissions of mercury to the environment'**[13]**. A small decrease in anthropogenic emissions has been observed in Europe over recent years**[14]**; for example, the Swedish Government has decided that, with few exceptions, use of mercury in processes and products must cease by the year 2000 **[15]**. With other countries following a similar policy it would be expected that production of mercury would continue to decrease. There is also significant secondary mercury production from recycling, recovery and reprocessing. With further reduction in mercury demand this could take over as the primary source.

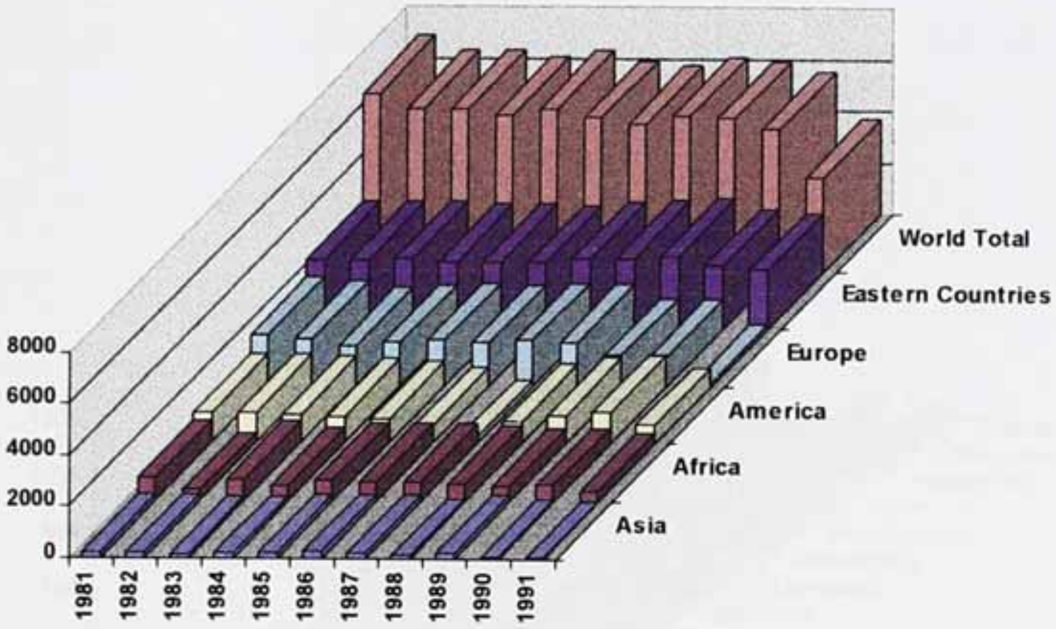

Figure 2.1 Production of Mercury from Ores in Metric Tonnnes

Produced from data published by Metallgesellschaft**[16]**

2.2.3 Mercury Usage

Mercury is used as a cathode for the electrolysis of brine in the chlor-alkali industry. Although this currently accounts for the majority of mercury use, it is gradually being mercury consumption can be accounted for by batteries and the electronics industry (electrical and measurement equipment). Mercury was used in dry cell batteries, but from 1994 has been present only in mercuric oxide batteries, which represent less than 1% by weight of all batteries sold**[17]**. Similar reductions have been made in the use of mercury in paint, the pulp and paper industry and agriculture. Use in dental fillings is also declining. Some mercury preparations are still used in the pharmaceutical industry and there will always be a demand for laboratory chemicals. **Figure 2.2** shows usage in the United States from 1959 to 1990**[13]**.

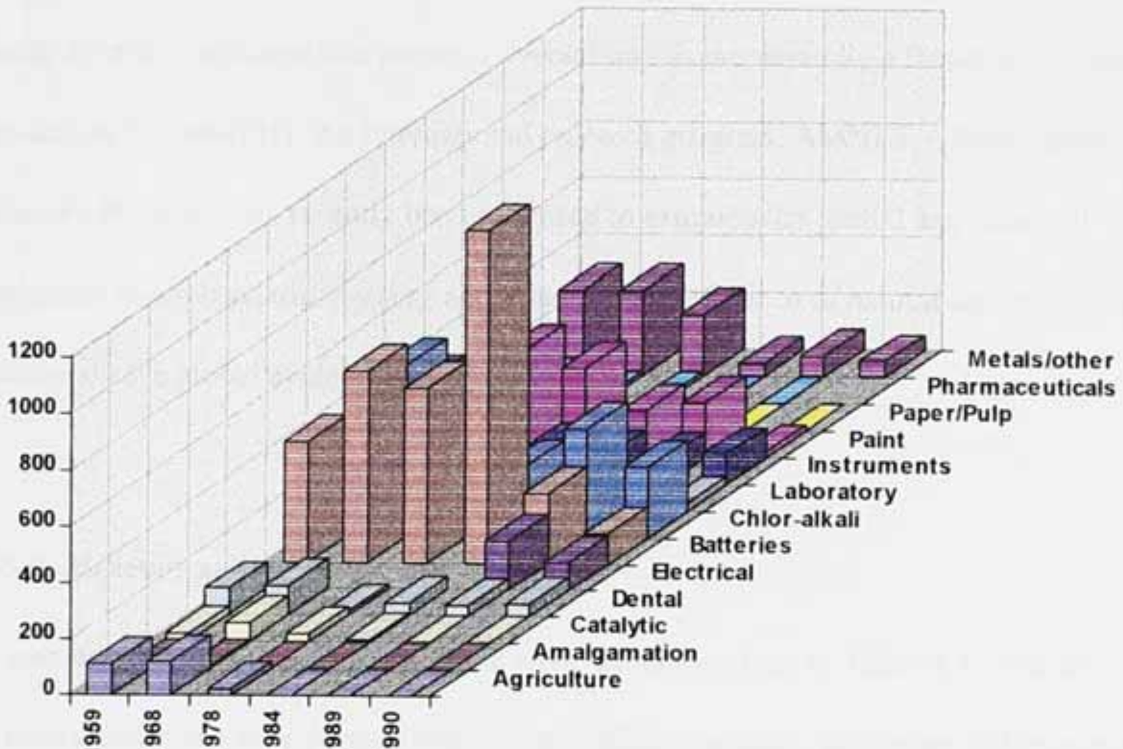

Figure 2.2 Use of Mercury in the United States (Metric tonnes per year)

2.3 Environmental Distribution of Mercury

Environmental mercury releases may be natural in origin or may occur from anthropogenic sources (such as industrial activities). The relative contributions of natural and anthropogenic mercury to the global cycle are in some dispute. It has been suggested that anthropogenic sources may be negligible or that as much as 70-80% of mercury volatilized from oceans is recycled from anthropogenic sources (Review**[18]**). Total emissions have, for example, been estimated at 2000-3000 MT yr^{-1} **[19]**, and increases in mercury of 0.16-1.46% recorded in the atmosphere over the Atlantic between 1970 and 1990 have been attributed to anthropogenic sources**[20]**. A study of seven remote lakes in North America indicated that mercury deposition has increased by a factor of 3.7 since pre-industrial times**[21]**. An international research program, AMNET - Atmospheric Mercury Network, has recently been proposed to examine the spatial and temporal variations in atmospheric mercury and to assess the influence of natural and anthropogenic sources on the global cycle**[22]**.

2.3.1 Mercury arising from natural sources

A summary of background levels in the environment is given in **Table 2.1**. Natural mercury emissions arise predominately from volcanic activity, degassing and evaporation from the oceans**[23,24,25]**. Estimated figures from the various compartments are given in **Table 2.2**. Several estimates have been made for total global emissions from natural sources, and these include 25 - 50 $\times 10^9$ g yr^{-1}**[23]**, 0.1 - 4.9 $\times 10^9$ g yr^{-1}**[24]**, and 25 - 150 $\times 10^9$ g yr^{-1}**[25]**.

Compartment	Concentration
Air	2.4 ppt
Igneous Rocks and Minerals	0.1 - 0.03 ppm
Agricultural Soil	0.03 - 0.15 ppm
Plants	0.005 - 0.1 ppm
Animal Tissue	0.03 - 0.3 ppm
Rivers	0.01 - 6 ppt
Sea Water	0.05 - 3.0 ppt
Ground Water	0.5 - 15 ppt

Table 2.1 Naturally Occurring Levels of Total Mercury [26,27]

Compartment	Amount (10^9 g yr^{-1})
Wind-borne soil particles	0 - 0.1
Sea salt sprays	0 - 0.04
Volcanoes	0.03 - 2.0
Wild forest fires	0 - 0.05
Biogenic continental particulates	0 - 0.04
Biogenic continental volatiles	0.02 - 1.2
Marine	0.04 - 1.5
Total	**0.1 - 4.9**

Table 2.2 Estimated Mercury Emissions from Natural Sources [24]

2.3.2 Anthropogenic Sources

It has been estimated that approximately half of all anthropogenic emissions of mercury enter the global cycle, while the remainder is deposited locally. Over the last century these emissions have tripled the global atmospheric and aquatic concentrations. Elimination of the anthropogenic load would take 15 to 20 years following termination of the emissions**[28]**. Principal anthropogenic source contributions to the global cycle include mining, coal combustion, waste incinerators and chlor-alkali plants. The complexity of source identification and flux rates makes estimates of global emissions extremely difficult. **Tables 2.3.1**, **2.3.2** and **2.3.3** give estimates for various source inputs to the atmosphere, soil and aquatic systems.

Category		Amount (tonnes /yr)
Coal combustion	- electric utilities	155 – 542
	- industry & domestic	495 - 2 970
Pyrometallurgical production	- Lead	7.8 - 16
	- Copper-nickel	37 - 207
Refuse incineration	- municipal	140 - 2 100
	-sewage sludge	15 - 60
Deforestation		117 - 585
Total Emissions		**1027 - 6 785**

Table 2.3.1 Estimated Global Mercury Emissions to Atmosphere from Anthropogenic Sources (Metric tonnes per year) (From ref. **[29,30]**)

Category		Amount (Metric tonnes /year)
Domestic wastewater		0 - 0.6
Steam electric		0 - 3.6
Base metal mining and dressing		0 - 0.15
Smelting and refining		0 - 0.04
Manufacturing processes	- metals	0 - 0.75
	- chemicals	0.02 - 1.5
	- petroleum products	0 - 0.02
Atmospheric fallout		0.22 - 1.8
Sewage sludge		0.01 - 1.31
Total		**0.3 - 8.8**

Table 2.3.2 Estimated Global Mercury Emissions from Anthropogenic Sources: Inputs to Aquatic Ecosystems (From ref. **[29,30]**)

Category	Release Factor
Water	$ng\ l^{-1}$
Domestic wastewater	0 - 0.009
Steam electric	0 - 0.6
Base metal mining and dressing	0 - 0.3
Smelting and refining	0.001 - 0.002
Manufacturing processes - metals	0 - 0.03
- chemicals	0.004 - 0.3
- petroleum products	0 - 0.08
Soils	$\mu g\ g^{-1}$
Agriculture and food wastes	0 - 0.1
Animal wastes, manure	0 - 0.1
Logging and other wood wastes	0 - 0.2
Urban refuse	0 - 0.6
Municipal sewage sludge	0.5 - 9.0
Miscellaneous organic wastes	0 - 0.1
Solid wastes, metal manufacture	0 - 0.1
Coal fly ash and bottom ash	0.1 - 1.3
Fertilizer	0 - 0.02
Peat	0 - 0.05

Table 2.3.3 Estimated Global Mercury Emissions from Anthropogenic Sources: Release Factors to Soil and Water (From ref. [29,30])

The major inputs to the global atmosphere are seen to be from coal combustion and waste incineration. Regional patterns closely follow the global situation. **Figures 2.3.1** and **2.3.2** illustrate the difference in relative contributions to UK emissions between 1970 and 1994**[31]**.

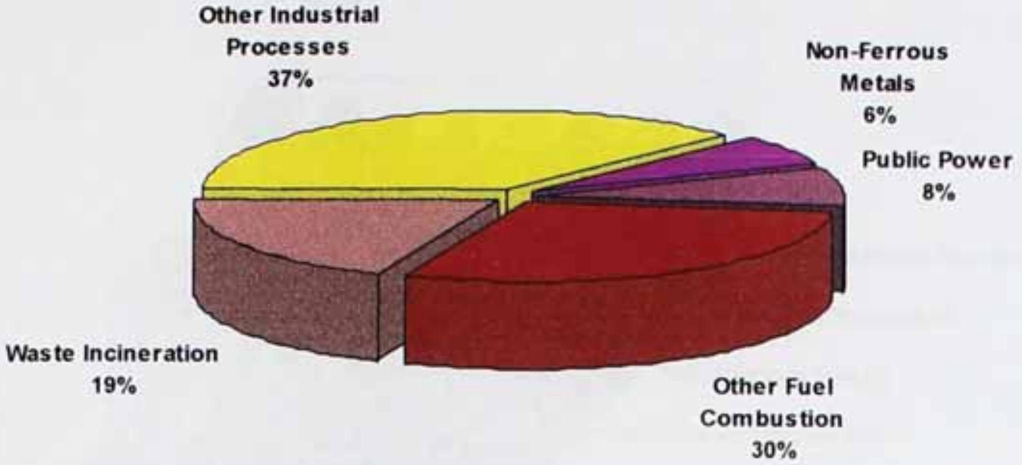

Figure 2.3.1 UK Emissions of Mercury 1970 (Total 39.16 tonnes)

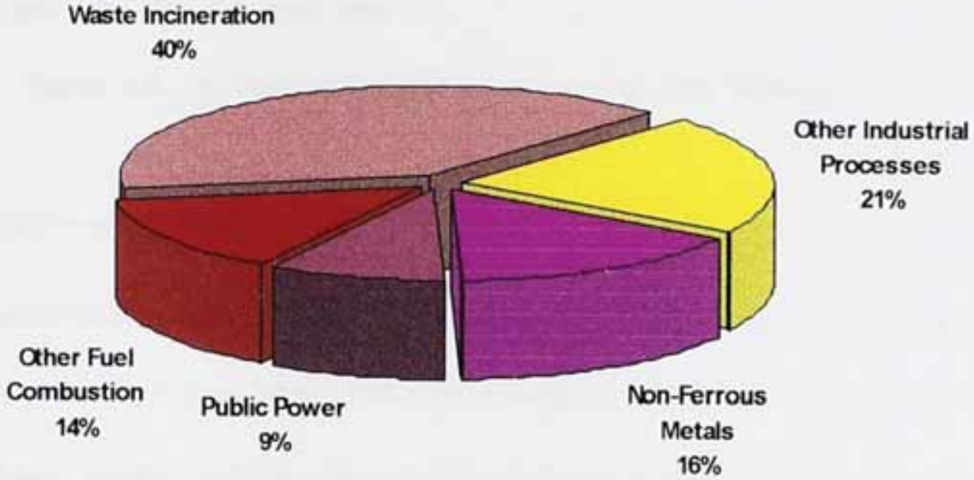

Figure 2.3.2 UK Emissions of Mercury 1994 (Total 19.5 tonnes)

The largest reduction since 1970 is in 'other fuel combustion', which includes all combustion sources except public power. 'Other industrial processes' include cement, glass, chlor-alkali and coke production. Waste incineration and related sources form the major part of 1994 emissions (40%), although from **Figure 2.4** it can be seen that in terms of tonnage there has been little change since 1970. Contributions to this category include municipal waste, clinical waste, sewage sludge incineration and crematoria.

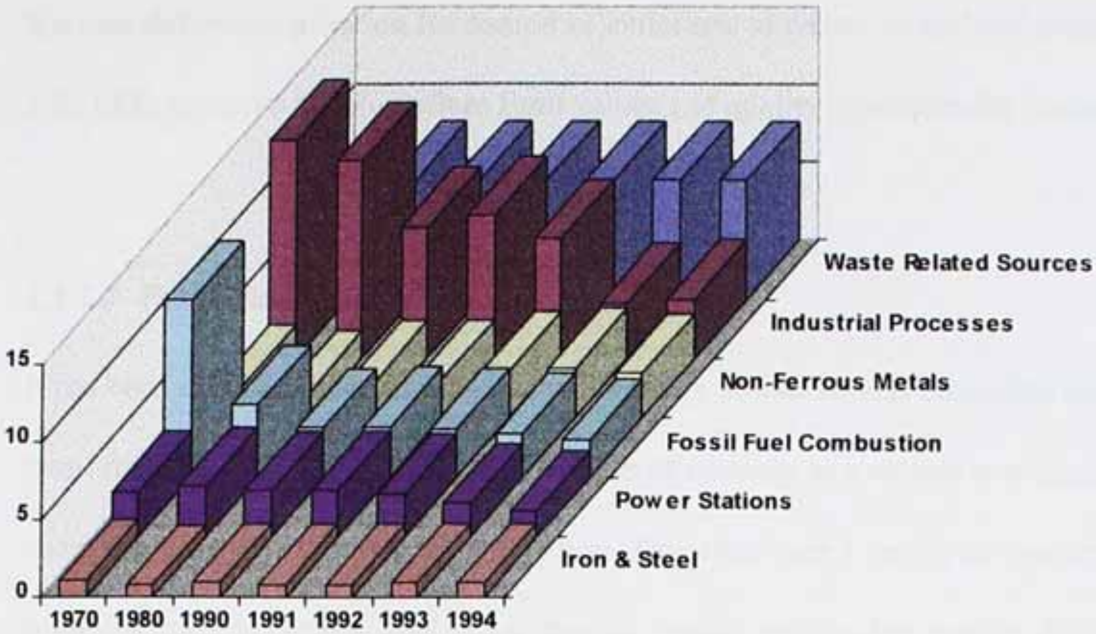

Figure 2.4 UK Mercury Emissions from 1970 to 1994 (tonnes)

2.3.2.1 Chlor-alkali Works

Large quantities of mercury are used in the electrochemical process of chlorine and sodium hydroxide production from brine. Although the liquid mercury electrode is recycled there is nevertheless an unacceptable amount released to the environment**[32]**. The alternative mercury-free diaphragm process has been introduced worldwide in an effort to reduce emissions and eliminate occupational exposure to mercury. It also has the advantage of enabling easier production of mercury-free chemicals. Total emissions are a major part of the industrial contribution to the total global flux, and there are well-studied localized pollution problems. There is also continued mercury release from the waste deposits (usually large sludge basins). Studies have shown that at low air temperatures the atmospheric concentrations of mercury around these deposits are only slightly elevated, falling to background level within a radius of 2 kilometres. However, with a mean air temperature of 29.4 °C, levels rise to 991 ng m^{-3} within a radius of 0.5 kilometres **[33]**.

Various different legislation for control of emissions to water, air and soil exists. For the UK, EEC directive 82/176 defines limit values and quality objectives for discharges.

2.3.2.2 Fossil Fuel Combustion

It has been estimated that 20-30% of total mercury emissions arise from the combustion of fossil fuel**[34]**. Coal contains 0.014 - 0.7 ppm of mercury as a natural component and huge quantities are burned for energy production. There has been a recent movement in several countries towards burning coal rather than oil, which contains less mercury**[35]**. The burning of peat and wood also releases mercury to the atmosphere.

2.3.2.3 Gold-mining activities

Small scale alluvial gold mining activities in parts of the Amazon have resulted in levels in local tributaries of up to 10 mg kg^{-1}, which is 25 times the global oceanic sediment value**[36]**. It has been suggested that mercury from the gold amalgamation process has a higher bioavailability than naturally occurring mercury from soil minerals**[37]**. Releases into the atmosphere from the Amazon ecosystem have been estimated at 100 t yr^{-1} over the last 20 years**[38]**.

2.3.2.4 Waste Incineration and Related Sources

Municipal incinerators are said to contribute 140-2100 x 10^3 kg yr^{-1} of mercury to the atmosphere**[Table 2.3.1]**. Only 2% of the waste mercury content is retained in the slag, with 96% in the fume and a further 2% in the fly ash **[39]**. Crematoria may be considered in the same category, although it has been estimated that this contribution accounts for only 0.61- 1.53% of the total waste incineration emissions**[40]**. When industrial waste products are not incinerated, the alternative is landfill. More countries are turning to incineration rather than landfill and this would indicate an increase in mercury emissions to the atmosphere. However, the largest source of mercury in waste products has for many years been batteries, followed by paint residues and pigments. It would therefore be expected that significant reductions in mercury containing waste would be seen in the near future, as a result of reduction in usage. This should offset the expected increase. Furthermore, there is increasing use of emission control technology. Given the appropriate flue gas cleaning system, the majority of mercury could be retained in slag and fly ash, which would necessarily go to landfill. Landfills lead to release of mercury to air and groundwater but emissions are difficult to quantify because too little is known about processes controlling the release**[41]**.

2.3.2.5 Historic Contributions

High background concentrations in the global environment have been attributed in part to the use of mercury in the patio process for silver ore processing, dating back to the 16th century**[42]**. The process involved mixing mercury in the open air and subsequent heating to drive off the mercury. It is almost certain that processes such as these, which went on for hundreds of years, made a significant contribution to the global cycle.

2.3.3 The Mercury Cycle

A diagrammatic summary of mercury interconversions in nature may be seen in **appendix (ii)[43]**. The cyclic pathways in the total environment are shown in **appendix (iii)[44]**. These processes are dynamic, with mercury being continuously removed from the soil through volatilization or biogenic uptake with subsequent volatilization. In one study exchange rates calculated from atmospheric concentration gradients indicate that mercury emission is about three times more frequent than dry deposition over background soils, with consistant emissions over contaminated areas**[45]**. Studies of atmosphere - surface exchange rates in forests have shown that 10% of soil emission is deposited in the canopy. The concentration gradient of vapour in air above the forest showed the canopy to be a sink during some periods, and the soils to be a source during some periods. The overall effect, however, is a net flux in the upward direction**[46]**. Mercury content of lakes and streams in non-industrialized areas arises primarily from atmospheric deposition, which in turn is dominated by the quantity of precipitation. One regional study showed annual emission estimates to exceed depositions by a factor of two, indicating long range transport of mercury**[47]**. Between 1970 and 1990, atmospheric loads of mercury have steadily increased at the rate of 1% per year in the southern hemisphere and slightly more in the Northern Hemisphere**[48]**. A similar increase is seen in forest top-soil and both are thought to be due to increased bioaccumulation in lake systems.

2.3.3.1 Methylation of Mercury by Micro-organisms

Non-enzymatic methylation of inorganic mercury in the laboratory occurs through the transfer of the carbanion, CH_3^-, to the Hg^{2+} ion. It has been shown that in lakes and sediments certain micro-organisms can convert inorganic mercury to methylmercury **[49]** and this is of great concern in the aquatic mercury cycle. Methylmercury can also be microbially degraded **[50]**, but a disturbance of this naturally mediated cycle, such as is seen in newly formed freshwater reservoirs, leads to increasingly high concentrations in fish**[51]**. Biotic and abiotic methylation is also known to occur in soils**[52]**. Global warming and increased UV radiation may affect the global budget of methylmercury, including formation and degradation in biotic and abiotic systems**[53]**.

2.3.3.2 Mercury in the Atmosphere

Studies have shown that the residence time of mercury vapour in the atmosphere is measured in months or years, so that local releases are probably distributed globally. Speciation is an important factor in determining the radius of influence of emissions from a point source. Divalent gases and particulates tend to be deposited within 100 km of source. Studies of concentration gradients around a municipal waste incinerator demonstrated the radial point of impact to be 1.7 km. These species are much more readily removed by dry and wet deposition than elemental vapour. The latter may be oxidized in the atmosphere by ozone**[54]**.

The northern hemisphere contains levels (about 4 ng m^{-3}) which are twice those of the southern hemisphere. The use of atmospheric pollutant dispersion models is now quite common, requiring input of source data and knowledge of transformation processes. One European mercury model is capable of simulating long-range transport from Central Europe to Scandinavia**[55]**. Over 90% is in the form of gaseous mercury vapour, with less than 1% in the particulate form**[56]**. The pathways of return to the surface are not well understood but for wet and dry deposition the mercury would generally be in the oxidized form, whereby it either would be solubilised in rain water, or deposited as a particulate.

2.3.3.3 Mercury in the Aquatic Environment

The main source of mercury to the oceans is wet deposition. Concentrations vary from 0.4 ng dm^{-3} in the northwest Pacific to 0.8 ng dm^{-3} in the northwest Atlantic, probably reflecting increased industrial activity in the northern hemisphere. Mean residence time in the oceans is about 350 years, relatively short in geochemical terms**[57]**. A mercury model, capable of analysing field data of all major transport and transformation processes, has been developed as a computer simulation of the biogeochemical cycling in lakes.**[58]**.

In the aquatic ecosystem, methylmercury may be taken up by small organisms such as plankton and readily accumulates in larger species. It is poorly eliminated and thus the concentration increases during the lifetime of the fish so that large, long-lived, predatory fish such as tuna and swordfish display the highest concentrations. The bioaccumulation factor may exceed 10 million for some species**[59]**.

2.3.3.4 Mercury in Soil

Background levels in soil occur through natural processes such as decaying vegetation and weathering. Major anthropogenic inputs occur from fall-out and the spreading of sewage sludge and fertilizers. Organic mercury was used in seed dressings which made a significant contribution, but this practice has now ceased. Mercury is taken up by plants and is readily transported and distributed, behaving in a similar way to a macronutrient. In experiments with tobacco plants (*Nicotania miersii*), it has been shown that exposure to elemental mercury from the atmosphere results in accumulation of mercury in the shoots, without movement to the roots. However, exposure of the roots to mercuric chloride results in accumulation in the roots with progression to the shoots**[60]**.

Mercury has an affinity for organic species in soil, with raw humus concentrations ranging from 0.2 to 1.5 ppm in uncontaminated soil. In the near vicinity of a base metal smelter, humus mercury levels have been found to reach levels 250 times the background concentration (400 ppb). This enrichment was not reflected in the underlying surficial sediments**[61]**. In nearly neutral soils, low in organic matter, iron and clay minerals may be important absorption sites. At low pH the stability of complexes of organic matter with mercury is high and mobility is increased.

Recent research involves a new clean-up procedure for mercury-polluted soil**[62]**. It involves the insertion of a synthetic gene, merApe9, into the genome of a mustard plant, *Arabidopsis*. The sequence encodes the production of mercuric ion reductase which enables the plant to take up mercury from the soil and reduce it to elemental vapour.

Long-range transport and increased deposition have increased the mercury content of organic rich top soil in Central European and Scandinavian soils by five to ten times**[63]**. This is despite the fact that mercury emissions to the atmosphere have been considerably reduced over the last decade. It is estimated that a reduction by 80% of the current input to soils is needed for equilibrium to be attained**[64]**.

3. Crematoria and Emissions to the Atmosphere

3.1 Introduction

Prior to 1990, there was a general lack of information in scientific literature relating to crematoria as a source of atmospheric pollutants. Compared to municipal incinerators and solid fuel plants it could be expected that the relative releases would be low from individual cremators. However, with the trend moving away from burial to cremation and particularly with increased tendency to site large crematoria within urban areas, it has been recognised that emissions of certain pollutants may make a significant contribution to the global flux. Further, there may be localised deposition resulting in contamination of the surrounding area and health risks to the local populace, including the crematorium workers.

3.2 Source of Pollutants

The types of material introduced to the cremator for combustion are well known, and thus an indication of the chimney emissions may be calculated. Firstly, there is the wood itself, together with varnish, resins, wood treatments, preservatives and adhesives. Incomplete combustion could result in harmful emissions from all of these substances. Handles and decorative materials are usually plastic and PVC in particular can release dioxin under certain conditions. Metal fitments may be zinc or other metal alloys. Lead and zinc are now prohibited by the Process Guidance Note for Crematoria**[65]**. In the body itself the main consideration is given to the sodium chloride content. On combustion there is a release of chlorine and, subsequently, hydrogen chloride gas. It has also been found that metal residues from implants are likely to become increasingly problematic. The most common are hip and knee replacements, but other interesting items found include coins, forceps, a micrometer and a pair of scissors. Stainless steel and cobalt-chrome would both melt if the primary chamber reached 1350 °C**[66]**.

3.3 Release of Mercury

It has been shown that thermal decomposition of dental amalgam occurs at cremation temperatures, beginning at 200 °C, accelerated above 400 °C and essentially complete by 700 °C**[67]**. Various estimates have been made of total emissions, taking account of the number of people cremated and average number of fillings per person according to age category. The first study suggested a figure of 11 kg per year for one crematorium**[67]**. This figure was challenged and a revised estimate suggested 2.1 kg to be more appropriate**[68]**. However, a basic mathematical error in the latter calculation revealed this to be an underestimation**[69]** and emissions to atmosphere measured from one crematorium in Switzerland gave good agreement with the original estimate**[70]**.

3.3.1 Emissions to the Atmosphere

The cremation process typically lasts 60 minutes, but may be as long as 90 minutes. The cremator is heated by gas or burners to 800 °C prior to charging with the coffin. The temperature may then rise to up to 1300 °C. The mercury is emitted 8 to 12 minutes after charging and emission continues for approximately 10 minutes. Levels vary according to the number of fillings. From gases collected in the stack one metre from the ejector fan, maximum levels were found to be 60 mg Nm^{-3} from one Swedish crematorium**[71]**.

3.3.2 Crematoria Soil Concentrations

A recent study has been made of mercury levels in soil around crematoria in New Zealand. From a depth profile, it was found that the mercury was largely confined to the top 5 cm of soil. For a crematorium carrying out an average of 1740 cremations per year since 1957, the soil levels were found to be 350 ppb (geometric mean above background). The study came to the tentative conclusion that an increase of 100 ppb might be expected for every 18000 cremations performed. Highest concentrations were found at a distance of 15 m from the stack and concentrations rapidly fell away at 30 m. An estimation of total soil content was made based on a cylinder of soil with radius 30 m and depth of 5 cm. For the crematorium mentioned the total mass was calculated as 53.44 g. This has been estimated to be 0.05 % of total emissions**[72]**.

3.4 Implications of the Environmental Protection Act, 1990

The Environment Protection Act of 1990 has imposed new regulations to control prescribed industrial processes and one of these concerns the operation of crematoria. Requirements are given under the Secretary of State's Guidance Note: Crematoria PG 5/2 (91). The objective set down in Section 7(2)(a) of the EPA is for Local Authorities and operators to comply with regulations:

> "ensuring that, in carrying on a prescribed process, the best available techniques not entailing excessive cost (BATNEEC) will be used -

> (i) for preventing the release of substances prescribed for any environmental medium into that medium or, where that is not practicable by such means, for reducing the release of such substances to a minimum and for rendering harmless any such substances which may be released; and
>
> (ii) for rendering harmless any other substances which might cause harm if released into any environmental medium"

Under the Act, operators of crematoria are required to obtain a licence from the Local Authority.

Emissions governed by the Process Guidance Note may be summarised as follows:

3.4.1 Smoke

From point 11:

> "(a) During any period of eight hours the aggregate of the periods of emission of dark smoke should not exceed five minutes.
> (b) No single emission of dark smoke should exceed two minutes.
> (c) There should be no emission of black smoke."

3.4.2 Emission Limits

From point 17: - Pollutant concentrations expressed at reference conditions:

273 K, 101.3 kPa, and 11 % oxygen, dry gas

Category	Concentration
Chlorides	100 mg m^{-3}
Total particulates	80 mg m^{-3}
Organic compounds	20 mg m^{-3}
Carbon monoxide	50 mg m^{-3}

The only mention of heavy metals relates to coffins and mercury is not included.

3.4.3 Odour

From point 14:

> "All emissions should be free from offensive odour beyond the process boundary as perceived by the inspector."

3.4.4 Operational Regulations

The guidance note requires gases to be resident in the secondary combustion zone for at least two seconds at 850 °C minimum. The chimney height should be at least 8 metres above ground level and assessed on the basis of estimated ground level concentrations of residual pollutants. Further guidance is available for calculation of chimney heights and criteria such as local topography and meteorological conditions must be taken into account. The chimney should be designed for an efflux velocity of not less than 15 $m\ s^{-1}$ in normal operation. If adequate dispersion of the final emission can be demonstrated, however, existing plant may continue to operate at a lower efflux velocity.

The overall effect of the regulations should ensure that mercury is dispersed into the wider environment. Obviously the extent of the sink depends on individual operating conditions and a number of local geographical considerations.

3.5 Control Procedures

Undoubtedly the most effective way to eliminate mercury from crematoria emissions would be to remove the fillings at the outset. Devices such as pacemakers are already subject to such removal. For humanitarian reasons, however, this is unlikely to become an acceptable option.

A wide range of pollution control equipment is available, including filter systems, electrostatic precipitators, dry sorbent injection units and wet scrubbers. Filter systems are already in operation in a number of European countries, and studies have been carried out on their effectiveness with respect to removal of mercury. With the combustion process being invariably incomplete, apart from smoke and other pollutants, fly ash particles, usually less than 1 μm in diameter are emitted. Larger particles are often packed with much smaller ones and this results in a large surface area per unit weight. Pollutants concentrate and accumulate on such particles and to some degree this may be applicable to mercury. A filter system demonstrated at Velson crematorium in Holland is designed to trap all fly ash particles, gases and odour components through three separate compartments. The filters have a lifetime of 12 months and the trapped fly ash is collected in hermetically sealed tubes and taken to a chemical wastes disposal centre. Analysis has indicated significant amounts of cadmium, mercury and zinc. It is not known to what extent the level of mercury vapour was reduced but there was total elimination of observable smoke and detectable odour was reduced by 85%. The cost of the system amounted to £300 000**[73]**.

Mercury emissions from a hazardous waste incinerator (rotary kiln) equipped with a wet scrubber system have been examined. The mercury was found to behave generally as expected, with no remainder detected in the kiln ash samples. The chlorine content of the synthetic waste feed was varied from 0 - 3.4 %. Combustion temperatures were varied from 538 °C to 937 °C, which would be lower than the range expected from a cremator. It was found that mercury content of the scrubber water varied, with a collection efficiency of 67 % to >99 %. Chlorine content affected the results significantly; detection of higher mercury concentrations with high waste chlorine was thought to be the result of mercuric chloride formation. Mercury partitioning was not seen to be affected by kiln exit gas temperatures**[74]**.

Tests carried out for pollution control on power plants have shown that conventional technology such as electrostatic precipitators, fabric filters and flue gas desulfurization systems are not effective for mercury**[75]**. An integrated approach would have to be adopted to ensure all other pollutants were within limits.

A further pro-active approach may be suitable for general use. A Swedish company, Ecopro, in association with the Emcoplate AB company, has released a product designed to control mercury emissions, which is relatively cheap and simple to use. It consists of an ampoule of selenium, housed in a small wooden block. The product is called 'Quicksafe' and is designed to be placed on the coffin. The mercury selenide combustion product remains with the ashes. When tested on cremations carried out in a Swedish crematorium it was found to reduce emissions by 80-85 %**[71]**

The alternative approach to control would rely on advances in dental technology and pressure from the client (dental patient). With reduction in dental caries and increased use of alternative materials, high levels of mercury emissions will eventually cease. However, the effect would not be seen for a considerable number of years, at least until the end of the lifetime of the restorations currently in place.

4. Mercury and Health

4.1 Mercury as a poison - a brief history.

Mercury and mercury salts have long been known to be virulent poisons. Mercury chloride, 'corrosive sublimate', was probably made by alchemists in the tenth century and was thought responsible for many sudden violent deaths in medieval England **[76]**.

Lemery, in 1663 **[77]** gave the following explanation of the effect of mercury vapour:

> " those who draw it out of Mines, or work much with it, do often fall into the Palsie, by Reason of Sulphurs that continually stream from it; for these Sulphurs consisting of gross Parts, do enter through the Pores of the Body, and fixing themselves rather in the Nerves, by reason of their coldness, than in the other Vessels, do stop up the Passage of the Spirits, and hinder their Course. "

Many of the historical references to mercury reflect an extremely casual attitude to its toxic properties and harmful effects. Smelters, while distilling crude mercury, turned their backs to the wind to avoid the fumes which "loosen the teeth"**[78]**. There is also reference to a crude preventative medicine whereby mercury miners swallowed a "double duckat of gold, rolled up"**[79]**. In the mercury and silver mines at Huancavelica in the Andes the working life expectancy of a miner was about 6 months **[76]**.

4.1.1 Disease or Cure?

During Medieval times, mercury and its compounds became extremely popular as medicines. Mercury poisoning over the 300 years from around the middle of the 16th century could be described as one of the worst examples of iatrogenic illnesses to date. One famous physician, Thomas Dover (1660-1742), prescribed mercury almost universally in his best-selling book, 'The Ancient Physician's Legacy to his Country'. His defence against mercury as a poison was, "Quicksilver always retaining a globular figure, together with the softness of the body, no harm can happen from the use of it."

Mercury was used in a number of preparations for treatment of syphilis for 500 years, until 1911. One protocol in Elizabethan times involved sitting the naked patient in a large wooden tub with only the head protruding from the top. Mercury vapours were admitted by way of a tube from a retort in which cinnabar was roasted. Deaths were more likely to have been from mercury poisoning rather than syphilis**[79]**.

During the Victorian era teething powders containing calomel (mercury (I) chloride) were widely prescribed to infants. It was not until around 1950 that pink disease (acrodynia) was attributed to these powders and recognised as a form of mercury poisoning. Unfortunately one of the symptoms of poisoning is inflammation of the gums and this probably resulted in even more use of the powders, exacerbating the situation**[76]**.

4.1.2 Minamata Disease (Methylmercury poisoning)

The Minamata disaster is one of the most widely known environmental incidents of this century and has led to much valuable research into mercury poisoning. The first cases of illness were noted in 1953 in Kyushu, Japan, but it was May 1956, in Minamata City, the south-west region of Yushu Island, before they were first officially recognised as being attributable to methylmercury poisoning. Some of the difficulty in diagnosis lay in the fact that the symptoms were unlike those of inorganic mercury intoxication and there was a firm belief that the mercury lost from a nearby chemical plant was inorganic. The amounts ingested by the victims were not particularly high and limitations in the analysis techniques further hindered the investigation. The symptoms, particularly the effects on the brain, resembled those reported for a research assistant and a technician both of whom had died from exposure to organic mercury species with which they had been experimenting at St Bart's in London in 1863**[80]**. Eventually it was established that the factory effluent did contain small quantities of methylmercury which was taken up by the shellfish ingested by the victims, and the diagnosis was confirmed. The total number of associated deaths in the Minamata area to date number approximately 2000.

Since the first recognition of the disease at Minamata, several outbreaks have occurred in developing countries due to the misuse of alkylmercurial fungicides. The worst case was in 1971-2 in Iraq where there were more than 600 deaths and 6000 cases of severe poisoning. Farmers had been using fungicide treated grain for baking bread rather than planting. A long term study of a family in the USA suffering from symptoms of mercury intoxication suggested that these were due to their consumption of methylmercury contaminated pork approximately 20 years previously. The children, aged 20, 13, 8 and a neonate had all developed severe neurological signs before death. The youngest had quadriplegia, blindness and severe mental retardation**[81]**. Notwithstanding, the usual means of ingestion is still fish, wherein levels are now closely monitored.

4.2 Toxicology of Mercury

Toxicity of mercury species is related to cationic mercury whereas solubility, biotransformation, and tissue distribution are influenced by valence state and anionic component. Although direct occupational exposure relates largely to elemental mercury vapour, the mercury cycle ensures that emissions give rise indirectly to exposure to other forms of mercury.

4.2.1 Disposition of Mercury in the Body

4.2.1.1 Elemental Mercury

Human exposure to metallic mercury is usually by inhalation. It is estimated that approximately 40 000 individuals worlwide are currently occupationally exposed to this form of mercury**[82]**. The vapour is lipid soluble and diffuses across the alveolar membrane. It has an affinity for red blood cells and the central nervous system. Oxidation to divalent mercury, thought to be catalase mediated, occurs once the vapour is absorbed by the cells **[83]**. Approximately 80% of the inhaled vapour is retained by the body. The overall half-life in the body is 50 days and it has been shown that a steady state is attained after 6 months exposure (5 half-lives)**[80]**. The main target organs are the brain and kidneys. Mercury vapour has a greater prediliction for the central nervous system than inorganic mercury salts but less than organic mercury. Elimination of mercury vapour is by way of exhaled breath, perspiration, faeces and urine, faeces being the predominant route.

One study investigated levels of mercury in different organs in the general Swedish population. Average concentrations in the occipital cortex, abdominal muscle, pituitary gland and kidney cortex were 10.6, 3.3, 25.0 and 229 $\mu g\ kg^{-1}$ wet weight respectively. Total mercury only was measured, but on the whole it was thought to have arisen mainly from amalgam fillings, i.e. mercury vapour. However, this might include some organic mercury from the diet, with the possibility of exposure to contaminated fish**[84]**.

Partition coefficients for mercury vapour in air and various biological fluids have been measured**[85]**, as well as kinetics for the oxidation of Hg^0 within red blood cells**[86]**. Oxidation kinetics are zero order for vapour concentrations greater than 6 $mg\ ml^{-1}$, dependant only on peroxide concentration. At lower vapour concentrations the kinetics are first order and therefore depend on the vapour concentration. It was calculated overall that with an inhaled dose of 50 $mg\ m^{-3}$, 97% of the absorbed dose would not be oxidised by the time it reached the brain and could therefore easily penetrate the blood-brain barrier.

One study correlated mercury levels in the brain with the number of amalgam fillings. Results showed a significant correlation between the levels in the occipital lobe cortex and the number of fillings. However, in 9 cases (from 34) where alcohol abuse was suspected, the mercury levels were lower than would be expected based on the regression line **[87]**. It has been found that prior ingestion of alcohol causes an appreciable reduction of mercury absorption from the lungs (from 80 % to between 47 and 69 %)**[88,89].**

Elemental mercury in the liquid phase is thought to be relatively non-toxic. The extent of absorption depends only on the vapour released. If ingested, only about 1% is absorbed by the alimentary canal. Any inhaled aerosols from this source are deposited in the respiratory tract and the mercury absorbed at a rate dependant on the particle size. In a case of attempted suicide by injection of mercury metal, the result was mercury embolism to the heart and lungs. However, the patient lived for five months and eventually died from the toxicity combined with loss of blood from an incised radial artery. Metallic mercury droplets were found embedded in a granuloma in the apex of the right ventricular chamber**[90]**.

4.2.1.2 Inorganic Mercury Salts

Exposure to inorganic mercury salts is predominantly by way of ingestion. Absorption depends strongly on water solubility but is usually less than 20%. For mercuric chloride, percentage absorption increases with concentration, probably due to damage to membranes at higher levels. Mercurous salts are of limited solubility and poisoning events are rare. Mercuric ions entering the bloodstream are thought to distribute themselves in a 1:1 ratio between plasma and red cells. This may be useful for diagnostic purposes, indicating recent exposure, but concentration in the blood does not necessarily give useful information about body burden. Highest concentrations of mercury from inorganic salts accumulate in the kidneys, predominantly in the cells of the renal tubules. In descending sequence, mercury content falls in the order: kidney, liver, spleen, brain and other organs. Half-life has been calculated as 42 days, although this varies for individual organs, with the kidneys in particular being longer. Elimination of mercury is predominantly by way of faeces, but the faeces:urine ratio decreases with time and dose. Excretion is in two phases, initially rapid, and then slow. A very small fraction is reduced to elemental mercury and eliminated by exhalation**[91]**.

4.2.1.3 Organic Mercury

Exposure to organic mercury species is usually by ingestion, although it can also occur by skin absorption or inhalation of the vapour. Studies have concentrated on ethyl and methyl mercury, rather than aryl mercury species. The latter are fairly quickly metabolised to mercuric mercury, as are longer chain alkyl species. Absorption of methylmercury from the diet is at least 90%**[92]**. Distribution is to all regions of the body and highest levels in the brain occur after 5-6 days. Within the blood compartment the plasma:cell ratio is around 1:20 and this may be a good indicator for methylmercury poisoning. Blood levels are useful for estimation of tissue concentrations, and a hair:blood ratio of 250:1 may also be of diagnostic importance. Methylmercury readily crosses the blood-brain and placental barriers and levels are higher in cord than maternal blood. The mercury-carbon bond resists metabolic attack but conversion to inorganic mercury does occur. The percentage of inorganic mercury depends on exposure duration and time since cessation. After two weeks high oral methylmercury intake the following values have been reported for inorganic mercury in tissues: whole blood, 7%; plasma, 22%; breast milk, 39%; urine, 73%; liver, 16-40%**[93]**. Overall half-life for a single-compartment model shows first order kinetics and is around 70 days. For continuous exposure a steady state will be attained after one year, with the maximum amount accumulated equal to one hundred times the daily dose. A much longer half-life has been associated with the CNS and several years after exposure significant amounts remain in the brain**[94]**. As with mercury vapour, elimination is predominantly by way of faeces and in the form of inorganic mercury.

4.2.2 In-vivo Methylation

It has been shown that oral bacteria are capable of methylating inorganic mercury *in vitro***[95]**. Methylmercury has been detected in the saliva of subjects with amalgam fillings in a controlled study, whereby the subjects and controls had methylmercury levels measured before and after rinsing their mouths with deionised water**[96]**. Other studies, mainly with animals, have shown some evidence of *in vivo* methylation**[97,98]**. However, a further study in 1994 showed no evidence of *in vivo* methylation, and suggests previous results may have been due to bias from fish consumption or analytical shortcomings**[99]**. It is also necessary to consider that the research has concentrated on the effect of methylating bacteria on divalent inorganic mercury. Environmental exposure to mercury is usually in the form of elemental vapour. Once intra-cellular oxidation has taken place, the mercury would no longer be exposed to the methylating bacteria.

4.3 Molecular and Cellular Basis to Mercury Toxicity

Mercury forms dative covalent bonds with atoms donating electron pairs, complexing readily with amines, halide and hydroxyl ions and reacting readily with sulphur, phosphorus and selenium. The mercuric ion forms strong complexes (linear>tetrahedral>others, high spin favoured). Biological substances containing phosphate, carboxyl and sulfhydryl groups, such as amino acids, proteins and nucleic acids are therefore targeted. The highest affinity is for -SH groups, as can be seen in Table 4.1.

LIGAND	Log k_1
Cl^-	6.74[11]
I^-	12.87[11]
OH^-	10.3[12]
NH_3	8.8[13]
Imidazole	3.57[13]
Ethylenediamine(N-N)	14.3[13]
Cysteine (N-S)	45.3[13]
Glycine(N-O)	10.3[13]
Histidine	7.9[13]

Table 4.1 Stability Constants of 1:1 Mercuric Complexes**[100]**

Mercury is capable of disrupting enzyme systems containing sulfhydryl groups although where other ligands are available at the active site, these can also be utilised. Effects may be excitory or inhibitory and have been extensively studied and reviewed**[100]**.

Investigations of cellular mechanisms in the brain have largely focussed on disruption of astrocytic function. Astroglial cells constitute more than half of the brain cell number in higher mammals and it has long been known that they tend to accumulate both mercury and lead. They have the capacity to regulate ionic and amino acid concentration in the extracellular micromilieu, brain energy metabolism and cell volume. At high metal concentrations astroglial glutamate uptake is impaired. High extracellular glutamate is cytotoxic and sensitive neurones may be damaged, particularly in the hippocampus, resulting in permanent cognitive defects and memory disturbances**[101]**.

Both *in vivo* and *in vitro* experiments have shown that mercury chelated to amino acids maintains an abnormal polymerization state of tubulin. Tubulin is a brain neuronal dimeric protein, responsible for microtubule formation of brain neurons. Abnormal tubulin produces neurofibrillar tangles which are a recognised lesion seen in Alzheimer's disease**[102]**.

4.4 Symptoms of Mercury Poisoning

4.4.1 Mercury vapour poisoning

Acute exposure to mercury vapour causes chest pains, coughing, shortness of breath, fatigue, aching muscles, fever and in the worst cases, respiratory failure. Renal toxicity can also occur. Chronic symptoms, either as a follow-up to acute exposure or as a result of longer-term exposure show more evidence of CNS damage. This includes headache, irritability, anxiety, mood swings, depression and aggressive behaviour. This may progress to tremors of fingers, lips and eyelids, and eventually violent chronic spasms of the whole body. Tremor may affect speech, with slight stammering, slurring of words and difficulties in pronunciation. Another characteristic is excessive salivation and gingivitis. There may also be numbness and pain in the extremities. The eyes can be affected, firstly by constriction of visual fields and lens reflex changes, and secondly with defects in accommodation and muscular balance**[103]**.

4.4.1.1 Erethism

Erethism is a neurological symptom which is characteristic of poisoning by mercury vapour and methylmercury. The symptoms are self-consciousness, timidity, embarrassment with insufficient reason, anxiety, indecision, lack of concentration, depression, resentment of criticism, irritability or excitability. Overall there seems to be a complete change of personality and in more advanced cases there may be hallucinations and memory loss. Erethism tends to be difficult to evaluate as it can often be attributed to anxiety or neurasthenia, especially in the absence of other symptoms such as tremor**[102]**.

4.4.1.2 Micro-mercurialism (Asthenic-vegetative syndrome)

This condition is said to account for those symptoms observed in persons frequently exposed to low levels of mercury vapour. This would include most cases of occupational exposure and probably exposure from dental amalgam. It refers to psychological changes such as memory defects, depression, irritability, fatigue and insomnia. It is obviously very difficult to diagnose, and confirmation would usually be by measuring mercury levels in urine or blood. If the exposure had ceased some time previously, however, it would be necessary to administer a chelating agent to mobilise the mercury, and then test urine levels. This is known as the mercury challenge test**[104]**.

4.4.2 Pink Disease

Pink disease, also known as acrodynia, is a form of mercury poisoning usually associated with children. It was seen regularly in infants poisoned with teething powders**[*ibid* 4.1.1]**. The name arises from the observed symptoms. The hands, feet and face discolour to a purply-red and there is patchy peeling of the skin. Abnormal sensation, photophobia and irritability are also common features, although individual responses vary considerably. In severe cases the hair falls out and the teeth loosen, with inflamed gums. The disease is more common in childhood, although it is not unknown in adults acutely exposed exposed to mercury vapour**[105]**.

4.4.3 Inorganic mercury poisoning

Acute poisoning from ingestion of mercury (II) chloride causes severe vomiting and diarrhoea, bleeding from the intestinal tract with intense epigastric pain. If death from shock, sudden fluid and electrolyte losses does not quickly ensue, then there will be severe kidney damage and possibly kidney failure. Death follows from uremia. If there is survival through the first day then the lesions begin to heal and there is a second phase of deterioration from excretion of mercuric ions. Over the following weeks production of mercury-containing saliva leads to stomatitis and gingivitis, and the abdomen becomes distended . The colon reacts with ulcerative colitis and heavy blood loss. Although this may not be fatal there is also likely to be renal insufficiency from tubular necrosis. Recovery may take up to four weeks but death sometimes occurs meanwhile from secondary infections such as pneumonia.

4.5 Effects of Mercury on Different Organ Systems

4.5.1 Acute Exposure Studies

4.5.1.1 Respiratory Effects

Acute inhalation of mercury vapour predominantly affects the lungs at high dose levels. Four fatalities occurred in 1991 when an occupant of a private home was smelting silver from dental amalgam**[106]**. The four occupants were admitted to hospital within 24 hours with breathing difficulties. Survival was between 9 and 23 days with death attributed to adult respiratory distress syndrome. Post mortem revealed the lungs to be heavy, firm and airless with severe diffuse alveolar damage and fibrosis. In addition, there was acute proximal tubular necrosis, vacuolar hepotoxicity and central nervous system damage.

4.5.1.2 Skin and Eye Irritation

A non-allergic skin reaction, diagnosed as *erythema exudatiuum multiforma*, resulted from exposure to mercury vapour for 7 hours a day over 7 days, from the cleaning up of broken thermometers. The trunk and extremities were affected and there was also purulent conjunctivitis, multiple vesicles and erosive lesions. Only trace levels of mercury were found in the blood, and the skin lesions disappeared after 7 days[**107**].

4.5.1.3 Sensitisation

Experimental patch tests have shown that skin responses resulting from exposure to both mercury vapour and mercuric chloride can be attributed to contact dermatitis. This is a systemic allergic reaction characterised by erythema on the trunk, thighs and arms[**108**].

4.5.2 Chronic Exposure Studies

4.5.2.1 Effects on the Nervous System

The majority of epidemiological studies have been cross-sectional, with the exposed group usually selected from the chlor-alkali industry. The very large number of studies, however, does include other occupationally exposed groups such as dental workers and thermometer manufacturers. Studies have also attempted to correlate exposure levels, and/or blood or urine levels with results of tests. The focus has been on neurobehavioural and neurophysiological tests, with some clinical neurological examination and also questionnaires for self-reporting of symptoms. Tests are commonly designed to examine motor system abnormalities, cognitive functioning and nerve conduction. Hand-tremor tests have often been carried out, for example using accelerometers to measure frequency and acceleration or hand-tremometers to investigate hand-arm steadiness.

In one study 185 industrial workers exposed to mercury vapour for up to 11 years were compared to unexposed matched controls. Twenty-four subjective symptoms of nervous system disorders were examined by questionnaire and of these, 22 symptoms were found to be more prevalent in the exposed group. These included memory disturbances, fatigue, waking up, increased irritability and trembling of fingers and eyelids. No clear dose-effect relationship was demonstrated between psychomotor disorders and blood or urine levels. However, it was found that abnormal values in some tests were more common ($p<0.05$) when blood levels were between 50 and 100 nM and urinary mercury exceeded 50 $\mu g\ g^{-1}$ creatinine[**109**].

Residual long term exposure effects were studied in a group of ex-mercury miners, some 18 years after the end of exposure. Comparison was with age matched, sex matched and education matched controls. Motor co-ordination, reaction time and short term memory had significantly deteriorated in the exposed group. Variables related to exposure, e.g. duration, correlated significantly with poor neurological performance as measured by hand-eye co-ordination, tapping and a colour card reading test. The number of years since cessation of exposure correlated with better reaction time and digit span[**110**].

A group of dentists whose tissue burden of mercury, as determined by X-ray fluorescent techniques, was found to be above 20 $\mu g\ g^{-1}$, were examined by a number of electrodiagnostic and neuropsychological tests. The results were compared with an age-matched control group of dentists with no detectable tissue mercury levels. The sample group showed significant impairment of several peripheral nerve functions, sural sensory nerve and median motor nerve showing slower conduction velocity, longer F-wave latency and longer distal latency ($p<0.05$) [**111**].

4.5.2.2 Kidney Effects

Several animal studies have suggested an immunological mechanism for mercury-induced nephrotoxicity. For example, Brown Norway rats developed an auto-immune glomerulonephritis after sub-cutaneous dosing with mercuric chloride. This was characterised by deposits in the glomerular basement membrane (GBM) and circulating anti-GBM antibodies**[112]**. Studies in humans have so far failed to suggest an immunological mechanism. Those studies available have largely focussed on groups of exposed workers, wherin glomerular and tubular damage has been indicated. This has been shown from elevated urinary levels of β-galactosidase and high molecular weight proteins. These biochemical indicators of early nephrotoxicity suggest overall a NOAEL[#] for urinary mercury of 20 μmol Hg/mol creatinine**[113]**.

4.5.2.3 Genotoxicity

There have been a number of epidemiological studies on the genotoxic effects of mercury, with various outcomes. They usually involve cytogenetic monitoring of peripheral blood lymphocytes in exposed workers, investigating micronucleation, sister chromatid exchange, aneuploidy or polyploidy. Increases in all these factors have been reported, although other studies have failed to detect either increased incidence or a dose-response relationship. A study of exposed fishermen found a statististical correlation between micronucleus frequency and total blood mercury concentration**[114]**. Mercury compounds have not been shown to induce point mutations in bacteria. In cultured human cells

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[#] No observed adverse effect level.

inorganic compounds have been found to induce the generation of reactive oxygen species and cause glutathione depletion. In male rodents treated with methylmercuric chloride, renal carcinogenicity has been demonstrated with possible genotoxic and non-genotoxic mechanisms**[115]**.

4.5.2.4 Carcinogenicity

There are only sparse data available on carcinogenicity of mercury and mercury compounds, with comparatively few epidemiological studies. Mercury (II) chloride has shown carcinogenicity in male rats**[116]** and some studies of exposed occupational groups do indicate a possibility of increased risk of lung, kidney and CNS tumours, but they lack power to significantly demonstrate the increase**[117]**. However, the influence of toxic heavy metals, including mercury, on thyrocytes, has been shown to play a major role in the aetiology of thyroid cancer**[118]**.

4.5.2.5 Effects on the immune system

Several heavy metals have strong associations with autoimmunity. There is increasing evidence that mercury can induce autoimmune disease both in humans and experimental animals**[119]**. One common finding in cases of mercury poisoning is that there are substantial individual differences in susceptibility. For example, following a domestic mercury spill a family of four were exposed to mercury vapour. While two of the members (14 year old daughter and 41 year old father) had acrodynia, the mother had nephrotic syndrome and the 10 year old son was well. This case was particularly unusual in that whereas children often show higher susceptibility, the youngest family member, who in fact had brought the mercury into the home, remained unaffected**[120]**. Susceptibility can be separated into genetic, constitutional and environmental factors and mechanisms include toxicodynamic and toxicokinetic interactions. The causes of hypersusceptibility and its effects on toxic responses are little known**[121]**. It has been suggested that where local and systemic hypersensitivity reactions occur, these will be linked to certain MHC genotypes. With particular reference to dental amalgam, where there is exposure to other metals besides mercury, there may well be a synergistic affect which could lower the threshold for adverse immunological reactions. Silver, in particular can induce autoimmunity in genetically susceptible mice**[122]**. Mercury is also indicated as an aetiological factor in known autoimmune diseases such as multiple sclerosis**[123]**. A MELISA test (memory lymphocyte immuno-stimulatory assay) has been adapted for the study of metal-induced sensitization. The patients studied had been suffering from chronic fatigue over many years. Mercurials were shown to induce a strong lymphocyte proliferative response in symptomatic subjects, but not in similarly exposed unaffected controls. Results with identical twins again suggested genetic dependency**[124]**.

Studies with animals suggest that the safety margin may be narrow for genetically susceptible individuals. Systemic autoimmunity was induced in susceptible mice by exposure to mercury vapour. The lowest observed adverse effect level (LOAEL) for serum IgG antinuclear antibodies (ANoA) was 170 $\mu g\ wk^{-1}\ kg^{-1}$. Glomerular, mesangial IgG immune complex (IC) deposits were observed. Overall the dose response studies showed the LOAEL to vary in the order of ANoA < B cell stimulation < IC deposits**[125]**. When cultured lymphocytes were treated with mercury (II) chloride a high proliferative response in T cells resulted, with a shift in the interleukin profile. Different activation conditions produced varying results**[126]**. A variety of autoimmune resonses have been observed in brown rats after exposure to mercury (II) chloride, including glomuleronephritis, characterised by autoantibodies to renal antigens**[127]**.

4.6 The Dental Amalgam Controversy

The recent concerns over the use of mercury in dentistry have led to much research and served to highlight the problems of chronic, low-level exposure to mercury. The controversy, however, originally started last century when in 1843 the American Society of Dental Surgeons condemned the use of all filling materials other than gold. Use of mercury -silver amalgams had produced disastrous side-effects**[128]**. They were re-introduced in 1895 by Dr G.V.Black who had eventually found a more stable composition and who at the same time laid down the foundations for modern dentistry practice. A German chemist, Professor A. Stock, in the 1920's, was the first to demonstrate the now classic experiment of breathing into a bag to produce a microscopically small globule of mercury metal. He also showed that the urine of dentists' contained excess mercury and reported measurable levels in the urine of patients with amalgam fillings where none was found prior to placement**[129]**.

4.6.1 International aspects

The increasing weight of scientific evidence against the use of amalgam in dentistry has forced a number of studies by national dental organisations to investigate the situation. Unfortunately, the argument has developed into one of a more political rather than scientific nature. Even where there have been regulations introduced placing limitations on the use of amalgam, the reasons given have been environmental rather than health based. For example, in Sweden, where use of amalgam is soon due to be phased out and is already banned for children, the National Board of Health and Welfare published a report in 1994 entitled 'Possible health effects and dental amalgam - a scientific review from an expert group'. The report concludes:

> "Scrutiny of the results of recent research , including material presented to the expert group by the Swedish Association of Dental Patients has not shown that mercury from amalgam has an adverse effect on health, with the exception of isolated cases of allergic reactions. ...There are at present no medical indications for recommending amalgam removal in order to relieve symptoms of general ill-health."

This seems to be the general consensus amongst dental organisations. However, there are numerous studies supporting the view that amalgam does have an adverse effect on health, and very few that arrive at the opposite conclusion. In the United States it has been suggested that there is a 'witch hunt' with regard to outspoken mercury-free dentists. A dentist (who had published warnings on amalgam toxicity**[130,131])** was recently struck off for practising medicine without a licence for removing mercury fillings after 'diagnosing' amalgam poisoning from urinary mercury levels.

4.6.2 Exposure levels from dental amalgam

Dental amalgam typically contains 50% mercury, the remainder being silver, tin and copper. According to the World Health Organisation, the main source of mercury exposure and absorption is from dental amalgam fillings**[132]**. They estimate the intake levels to be between 3 and 17 μg /day. There have been a number of studies to determine intra-oral, saliva, urine and faecal levels, and correlations of these levels with number of amalgam surfaces. The main results of these studies are summarised in table **4.1**. Bruxism (teeth-grinding), chewing and drinking hot liquids have all been shown to increase release of mercury from fillings**[133,134]**.

Mercury release from amalgam may also be considerably accelerated by the effects of corrosion. Contact with a dissimilar metal, such as gold, sets up a galvanic cell in the mouth, the so-called 'battery reaction'. The higher the current, the more mercury is released. Mercury migrates through the root to the surrounding tissue. Root biopsy shows up to 200 - 300 micrograms mercury per gram of tissue. When an amalgam layer has been covered with a gold crown the surrounding tissue contains up to 1200 micrograms per gram**[135]**.

Nature of Study	Amalgam Group	Control Group	Author
Intra-oral air	**10 μg m^{-3}**	**----**	**Stock 1926[136]**
Intra-oral air during dental prophylaxis	**85-326 μg m^{-3}**	**----**	**Haikel *et al* 1990[137]**
Before§ & after¶ chewing	**64-244 ng/10 breaths**	**§14-22 ng/10 breaths**	**Gay *et al* 1979[138]**
Calc. intra-oral air	**15 - 30 μg / day**	**----**	**Vimy *et al*1985[139]**
Brain - grey matter **Brain - white matter**	**15.21 (3-121.4) ng/g** **11.22 (1.7-110) ng/g**	**6.7 (1.9-22.) ng/g** **3.8 (1.4-7.1) ng/g**	**Eggleston *et al* 1987[140]**
Est. intra-oral air and tracheal concs	**3 μg / day**	**----**	**Langworth *et al* 1988[141]**
Intra - oral air **Urine** **Faeces** **Systemic uptake** **Worst case**	**22 μg / day** **3 μg / day** **60 μg / day** **12 μg / day** **70 μg / day**	**----**	**Skare 1995[142]**
Est. from intra-oral air	**1.7 μg / day**	**----**	**Berglund *et al* 1990[143]**
Urine (median)	**1(1-2) ng / ml**	**0(0-0.6) ng / ml**	**Eti *et al* 1995[144]**
Urine (24hr sample) **Blood**	**23-60 μg / day** **12-23 μg / l**	**Gen. population** **2-5 μg / l**	**Barregard *et al* 1995[145]**
Urine before§ & after¶ amalg. removal (1yr)	**1.44 (0.57 - 4.38) μg / g creatinine**	**¶ 0.36 (0.13 - 0.9) μg / g creatinine**	**Begerow *et al* 1994[146]**
Faeces before§ & after¶ amalgam removal (60 day)	**120 ng /g wet wt**	**¶ 22 ng /g wet wt** **Control - 11 ng/g**	**Bjorkman *et al* 1996[147]**
Effect of nicotine **Plasma** **chewing gum** **Urine**	**27 nmol/l** **6.5 nmol/mmol creat.**	**4.9 nmol/l** **1.2 nmol/mmol creat.**	**Sallsten *et al* 1996[148]**
24hr urine in children	**0.66 μg / l**	**0.16 μg / l**	**Schulte *et al* 1980[149]**
Intra-oral air **Urine** **Faeces** **Estimate mean uptake**	**Up to 125 μg / day** **0.4-19 μg / day** **1-190 μg / day** **12 μg / day**	**----**	**Skare *et al* 1994[150]**
Est. from intra-oral air	**4.8 μg / day**	**----**	**Halbach 1995[151]**
Occipital lobe cortex **Kidney cortex**	**10.9 (2.4-28.7) ng/g** **433 (48-810) ng/g**	**----** **49 (21-105) ng/g**	**Nylander *et al* 1987[152]**
Uptake calc. from urine level	**4 - 19 μg / day**	**----**	**Weiner & Nylander 1995[153]**

Table 4.2 Summary of studies investigating levels of Hg resulting from amalgam fillings.

4.6.3 Health effects of dental amalgam

4.6.3.1 Mercury allergy

Mercury hypersensitivity is an allergic response mediated by the immune system which manifests with symptoms such as dermatitis, eczema, edema and itching, occurring mainly on the upper torso, face, neck and limbs. Hypersalivation, alterations in taste and erosive oral lesions are also reported. Confirmation of the diagnosis can be obtained with standard sensitivity tests. Oral lichen planus[#], the cause of which is unknown, has recently been connected to mercury allergy**[154]**.

4.6.3.2 Mercury poisoning from amalgam

A number of cases of abatement of symptoms after the removal of dental restorations have been reported**[155,156,157]**. Drilling of amalgam fillings during removal releases large amounts of vapour from which the uptake can be very high. There are strict procedures, e.g. use of a rubber dam, which can reduce the intake, but enforcement is difficult. Thus, those people with suspected amalgam illness report acutely worsened symptoms lasting a few weeks after the drilling**[158]**.

Although there is disagreement on the amount of mercury emitted from amalgam, most of the figures are too low to account for the levels of inorganic mercury found to accumulate

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[#] Oral lesions characterised by white striae in netlike patterns radiating outwards from the edge of the lesion.

in the human brain**[159,160]**. There are linear correlations beween the number of amalgam surfaces and the mercury concentration in the brain, kidneys and pituitary glands.

People with suspected systemic reactions to amalgam fillings report symptoms similar to those known to have occupational intoxication from mercury. These include disabling fatigue, headaches, impaired short-term memory, insomnia, anxiety and depression. A study by Siblerud investigated the relationship between amalgam fillings and the cardiovascular system. The amalgam group had significantly higher blood pressure, lower haemoglobin and haematocrit levels, and a greater incidence of chest pains, tachycardia, chronic fatigue and anaemia**[161]**. It has been shown by animal experiments that mercury from amalgam can induce antibiotic resistance and mercury resistance in bacteria in the mouth and gastrointestinal tract**[162]**.

One of the reasons given for refuting the large amount of evidence against the use of amalgam is the extent and variety of adverse effects. It is stated that if mercury poisoning can be produced by release of the metal from amalgam restorations, then one would expect to consistently see the ill effects corresponding to established patterns of mercury toxicity**[163]**. However, it is well known that the presence of various and diverse symptoms is one certain characteristic of mercury poisoning. This is why the disease tends to be difficult to diagnose. Furthermore, when cells in the brain are damaged there is no available repair mechanism and recovery is effected by the use of alternative pathways. It is therefore apparent that for any substance that is slowly and persistently causing cell death, when any neurological symptoms do appear, a considerable amount of damage must already have been achieved. As Professor Stock stated in 1926, it may one day be realised that the use of mercury amalgam in dentistry is a "great sin against humanity".

4.7 Treatment of Chronic Mercury Poisoning

Chelation therapy is now recognised as the most effective means of mobilising stored mercury in order to eliminate it. Many chelating agents are in ionised form and therefore unable to penetrate cell membranes. 2,3,-Dimercaptopropanol (British anti-lewisite, BAL) has commonly been used as a mercury antagonist, being a dithiol which successfully competes with protein sulfhydryl groups. There is a tendency towards redistribution rather than elimination, which for inorganic mercury decreases the renal concentration, thus protecting the kidneys. However, it is definitely contra-indicated for organic mercurials with which it has been shown to accelerate the uptake to the brain**[164]**. An attempt to use intravenous ascorbic acid to increase urinary excretion of mercury in subjects with relatively low levels of mercury from amalgam, food, etc., was found to be unsuccessful**[165]**.

2,3-Dimercapto-1-propane-sulphonic acid sodium salt (DMPS) is now commonly used and is regarded as a metal complexing agent rather than a chelation agent. Extensive research has been carried out for use with mercury, and it is known to be less toxic than BAL**[166,167,168]**. A provocation test is indicated primarily. In the Iraqi outbreak of alkyl mercury poisoning it was found to be more effective than other agents, including penicillamines, and reduced the half-life in blood from 65 to 10 days**[169]**.

4.8 Risk Assesssment

The basis of risk assessment and the setting of exposure limits for any toxic species is well covered in a number of publications, government official**[170]** or otherwise**[171]**, and outside the scope of this study. Briefly, a number of elements are taken into account, and standards are layed down which may vary from country to country. It should be noted, however, that from health criteria for mercury species, although exposure limits have been set **[Appendix iv]**, the World Health Organisation have been unable to specify a NOAEL for mercury species**[172]**

5. Experimental

5.1 Introduction

Mercury emissions from crematoria may be monitored by the analyses of soil and air. Soil analysis is frequently used as an indicator of general atmospheric pollution although it is also common to use various biological indicators such as lichen or sphagnum moss**[173]**. A disadvantage with species such as lichen is that it necessarily has to be present at all sites monitored. For soil analysis the major disadvantage is the lack of homogeneity, so that sampling techniques have to be extremely stringent. Mercury levels in the soil of the crematoria grounds give some indication of the extent to which the atmospheric deposition is localized, which may be compared to general background levels and also to levels measured in control samples from the vicinity.

Five crematoria were chosen for the preliminary soil investigations, permission being obtained in writing from the managers or superintendents. Mercury measurements were made using a dedicated mercury vapour meter . Soil from the two largest crematoria was reanalysed by cold vapour atomic absorption spectroscopy. Air samples from these two crematoria were also measured for mercury content by means of the vapour meter.

Hair has long been used as a means of monitoring exposure to heavy metals. Although no standard method has as yet been established for determination of mercury in hair, it has become more prevalent recently as a means of monitoring exposure to mercury**[174]**. It is particularly useful for population studies, being a non-invasive method. Mercury is incorporated into newly formed hair and the concentration remains constant thereafter. It is not without disadvantages, however, not least the occasional difficulty in obtaining adequate samples. There has been opposition to its use, mainly due to the lack of standard procedures for sampling, sample treatment, analytical techniques and quality assurance**[175]**. It has been shown to be particularly useful as a means of following mercury elimination from the body over a long time period, as hair grows at a constant rate of about 1 cm per month for Caucasians. Analysis of consecutive sections therefore gives a retrospective time profile. Good correlation has been found with blood levels in some cases, and levels in various organs. There are appreciable problems with measurements of mercury in both urine and blood for diagnostic purposes. Blood levels, for example, may reflect only recent exposure. Urine levels are an indication of elimination from the body and therefore may not reflect organ levels**[177]**.

Mercury content of hair samples from crematorium workers at a number of different sites was measured by cold vapour atomic absorption spectroscopy. Control samples were taken from a non-occupationally exposed population sample.

5.2 Crematoria

5.2.1 Kettering Crematorium

For plan see **appendix (xv)**

At the time of sampling two new cremators had recently been installed in order to comply with the Environmental Protection Act (1990). The cremators were charged at 650 ^{0}C. No filters had been installed and the stack height had been increased by 1.5 metres. In 1997, 2 440 cremations were carried out.

5.2.2 Counties Crematorium, Northampton

For plan see **appendix (xii)**

One new cremator was in the process of being installed when the samples were taken. Operating temperature would be increased from 800 to 1100 ^{0}C on completion of the installation. No filters were installed. The stack height was due to be increased from 40 ft to 50 ft. The crematorium carried out an average of 2 000 cremations yearly.

5.2.3 Canley Crematorium, Coventry

For plan see **appendix (xxii)**

The stack height conformed to the minimum requirements. Four cremators were in operation and these were due to be replaced over the 9 months following the soil sampling. Old flues had had to be sealed after they were found to be asbestos lined. The doors on the cremators were opened towards the end of the run to check that combustion was complete. No filters were planned. Three of the cremators had been replaced by the time air samples were taken. These new computer controlled cremators operated from 850 ^{0}C (charging temperature) to 1200 ^{0}C. A typical cremation would proceed at an average of 1000 ^{0}C. Flue temperature reached between 250 and 350 ^{0}C.

5.2.4 Milton Keynes Crematorium

For plan see **appendix (xviii)**

Two cremators were in operation at temperatures up to 1100 ^{0}C and these were due to be replaced to bring them up to specification. A further metre was to be added to the height of the stack. No filters were planned. In 1997, 1 407 cremations were carried out.

5.2.5 City of London Crematorium

For plan see **appendix (xxx)**

There were two crematoria on the same site. One had not been used since the 1960's but was due to be recommissioned with three new cremators. The working crematorium had seven cremators. Four of these were due to be replaced and the other three were being retained and eventually used only for emergencies. There were generally five of the seven in operation whilst awaiting the beginning of operations in the other crematorium. In 1997, 4 155 cremations were carried out. Cremators were charged at 700 ^{0}C and reached temperatures up to 1300 ^{0}C. The seven cremators shared two flues but the site is in a dip which leaves the stack too low. A sufficiently high efflux velocity must therefore compensate and the new cremators were to have their own separate flues with burners installed. No filters were to be installed although in this case the possibility had been investigated. The superintendent had visited a crematorium in Belgium which had had filters installed. He noted that efflux velocity and temperature were reduced by the filters such that the operations would not achieve the specifications of the Environmental Protection Act.

5.2.6 Controls

A number of control samples were taken from soils in the same area as the crematoria, but two to three miles away. There were no other known sources of mercury contamination in the vicinities.

5.3 Determination of mercury in soil

5.3.1 Soil Sampling and Preparation Procedures

Soil samples from each crematorium were taken as shown on the plans **[appendices (xv), (xii), (xxii), (xviii) and (xxx)]**.

Approximately two kilograms were taken from each sampling point, where possible, from just below the surface level. An attempt was made to take samples from regular compass points around the stack, firstly as close as possible to the stack and secondly approximately 80 to 100 metres away. The nature of the sites often made this difficult because much of the area was lawned or paved. At the London and Coventry sites very little soil on open ground was available. Observations on the nature of the sample, and for example the position being very sheltered, were noted where appropriate. These are given in **appendix (v)**. Samples were stored in a freezer while awaiting processing.

Each sample was reduced to approximately 50 g in the laboratory by cone and quartering. It was then air dried at room temperature and passed through a 0.1 mm sieve. A moisture determination was carried out on each sample. After preliminary determinations using the mercury vapour meter, the samples were further homogenised with the use of a liquidizer.

Mercury was determined by use of the mercury vapour meter and, for two crematoria, cold vapour atomic absorption spectroscopy.

5.3.2 Analysis of Soil using Mercury Vapour Meter

Diagrams of the apparatus are shown in **appendices (vi) and (vii).**
The mercury vapour meter was designed and built by C.H.James and J.S.Webb of Leicester University**[176]**. The original purpose was the detection of mercury vapour at sites of geological interest. Mercury has long been used as a pathfinder for mineral deposits**[177]**. The instrument is capable of detecting as little as 10^{-4} μg mercury. The apparatus consists of the sampling train, vacuum pump, UV light source, power supply, multimeter and the meter itself.

5.3.2.1 Principles of Operation

The dried sample is drawn through the meter by means of the vacuum pump. The flow is split into two, each half passing through flow meters which may be adjusted to maintain the balance. One half of the sample passes through a column of palladium chloride impregnated glass wool into a reference chamber. Any mercury present is removed by means of the reaction:

$$PdCl_2 + Hg^{\circ} \rightarrow Pd^{\circ} + HgCl_2$$

The reaction proceeds spontaneously in the cold, and is specific for mercury.

The other half of the sample is drawn though to the sample chamber via a balancing column containing plain glass wool. UV light at 253.7 nm passes through sample and reference chambers and is detected by two photocells. These are connected in series across a stabilised D.C. power supply. A millivolt meter is connected between the centre point of the photocells and a potentiometer, also connected across the power supply.

When the instrument is switched on and allowed to equilibrate for fifteen minutes the reading on the millivolt meter is adjusted to zero. Firstly the balance shutter, an iris diaphragm in front of the sample photocell, is adjusted, followed by the coarse and fine controls for the potentiometer. Any subsequent current through the millivolt meter reflects the differential output from the photocells caused by an absorbance in the sample chamber.

The principle is similar to that of cold vapour atomic absorption. With CVAAS the absorbance is due to the presence of mercury vapour measured against a reference of air. The mercury vapour meter depends on the difference in absorbance between the sample and the reference where the reference is the sample minus any mercury present. The meter firstly has the advantage of a longer path length, giving lower detection limits, and secondly does not require the sample to be pure mercury. The same interfering species are present in both sample and reference chambers and therefore do not affect the result.

Concentration of mercury in the sample is directly proportional to the reading on the millivolt meter. The highest reading obtained after introduction of a sample is used. The instrument is calibrated by injecting known volumes of mercury saturated air.

5.3.2.2 Sampling Train

The apparatus is set up as in the diagram (**appendix (vii)**). The air being drawn into the apparatus is cleaned of mercury by passing through a glass tube containing palladium chloride coated glass wool. The sample is placed into a borosilicate glass tube and the ends plugged with glass wool to prevent the sample being sucked out of the tube. A small amount of 'Drierite' is placed into the end of the tube on the meter side. This removes any water vapour and increases the lifetime of the drying tube further along the train. Preliminary experiments showed that 'drierite' fails to absorb mercury vapour and should not interfere with the results. A thermocouple, connected to a digital temperature display, is placed inside the sample tube. The reference tube contains a small amount of glass wool and 'drierite' in order to maintain a similar air flow when the flow is switched between sample and reference side. The switch is by means of two two-way taps before and after the sample and reference tubes. Tubing connections are silicone rubber. A hypodermic needle is inserted through the tubing connecting the two-way tap with the drying tube. Calibration standards are introduced via this needle.

5.3.3 Procedures

5.3.3.1 Instrument calibration

The instrument was switched on and allowed to equilibrate for fifteen minutes before zeroing. The temperature of the bottle containing the mercury reservoir was noted and a volume of mercury saturated air above the liquid was withdrawn by means of a glass hypodermic syringe. A series of different volumes at different temperatures were injected to construct calibration graphs. The meter reading was allowed to return to zero before the next standard was injected. The mass of mercury injected was determined by calculation from known physical data (see results for example).

5.3.3.2 Soil Samples

Between 0.01 and 0.10 g sample was accurately weighed into a borosilicate glass sample tube. The tube was plugged with glass wool at both ends and a small quantity of 'drierite' placed in the end towards the vapour meter. The tube was placed into the sample side of the sampling train with the temperature probe inserted in one end. Heat was applied with a bunsen burner to 450 ^{0}C. After maintaining the temperature for a few seconds, both two-way valves were operated simultaneously, allowing the vapour from the tube to pass through to the vapour meter. The highest reading on the millivolt meter was recorded and after the reading returned to zero the valves were switched back to the reference circuit.

It was observed that although the calibration standards and some samples gave clear readings, increasing and decreasing sharply as the vapour passed through, other samples were more difficult, occasionally giving two peaks. The procedure was therefore moderated for later samples, from Milton Keynes, Coventry and the City of London, as follows.

A chart recorder was connected to the output of the vapour meter in parallel with the millivolt meter. An amplifier was included in the circuit between the meter and chart recorder for impedance matching purposes. Thereafter, the mass of mercury was proportional to the peak area from the chart output. Because of the clear difference between standard peak shapes and sample peaks, measurement was made by cutting out and weighing the peaks.

5.3.4 Results

5.3.4.1 Calculation of mass of mercury injected for calibration graphs

See **appendix (viii)** for chart of calculations for different volumes over a range of temperatures.

Example:

Temperature = 21 °C

Vapour pressure = 1.3235×10^{-3} mm Hg (From literature **[178]**)

Mole fraction = $1.3235 \times 10^{-3} / 76$

= 1.7414×10^{-6}

Volume of 1 mol = $T_2 \times R / T_1$

$= (273 + 21) \times 22.414 / 273$

$= 24\ 138.1538\ \text{cm}^3$

Concentration Hg $=$ Vol / mol fraction

$= 24\ 138.1538 / 1.7414 \times 10^{-6}$

$= 7.2145 \times 10^{-11}\ \text{mol cm}^{-3}$

Ar Hg = 200

Therefore conc. Hg $= 7.2145 \times 10^{-11} \times 200\ \text{g cm}^{-3}$

$= \underline{1.4429 \times 10^{-8}}\ \text{g cm}^{-3}$

5.3.4.2 Calibration Graphs

See **appendix (ix)** for calibration data and graphs

5.3.4.3 Results Summary

Data and Calculations:

Control samples	See **appendix (x)**	Northampton	See **appendix (xi)**
Kettering	See **appendix (xiv)**	Milton Keynes	See **appendix (xvii)**
Coventry	See **appendix (xx)**	City of London	See **appendix (xxviii)**

Results plans:

Northampton	See **appendix (xiii)**	Kettering	See **appendix (xvi)**
Milton Keynes	See **appendix (xix)**	Coventry	See **appendix (xxiv)**
City of London	See **appendix (xxxi)**		

Site	Hg Conc./ng g-1	Std Deviation	Coef. of Variation	n
Controls	275.36	72.83	26.4	16
Northampton	405.4	95.68	23.6	24
Kettering	946.47	602.27	63.63	28
M.Keynes *	911.02	300.19	32.95	21
Coventry **	1212.5	372.85	30.7	18
City of London	2979.18	2971	99.7	36

Table 5.1 Summary of mercury levels in soil as determined by vapour meter

* Mean excludes 1 sample, considered an outlier, of 11 522.38 ng g^{-1}.

(n = 3, s.d. = 1 676.3, coef. of var. = 14.55)

** Mean excludes 1 sample, considered an outlier, of 8 731 ng g^{-1}.

(n = 2, s.d. = 150.59, coef. of var. = 1.7)

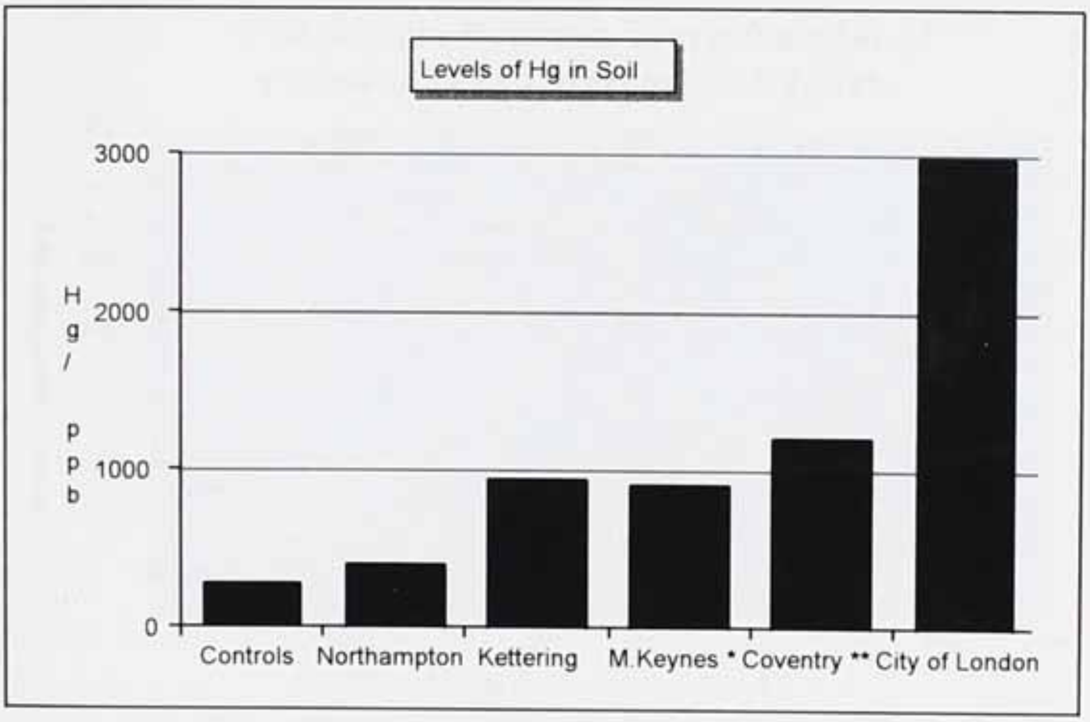


Figure 5.1 Mean levels of mercury in different crematoria soils

	Controls	**Kettering**	**Northampton ***	**M. Keynes**	**London**	**Coventry ***
No. of Cremations yearly	0	2440	2000	1407	4155	3200
Hg Conc / ng g^{-1}	275.36	946.47	405.4	911.02	2979.18	1212.5
Standard error	25.7	213	33.8	113	721	124

Table 5.2 Summary of data relating mean soil concentration to number of yearly cremations.

Figures for yearly cremations relate to 1997, other than crematoria marked with an asterisk, for which only estimated average number of cremations were supplied. The following chart demonstrates the relationship to soil concentrations with both linear and exponential trendlines, including correlation coefficients, shown. Error bars denote plus/minus standard error of the mean.

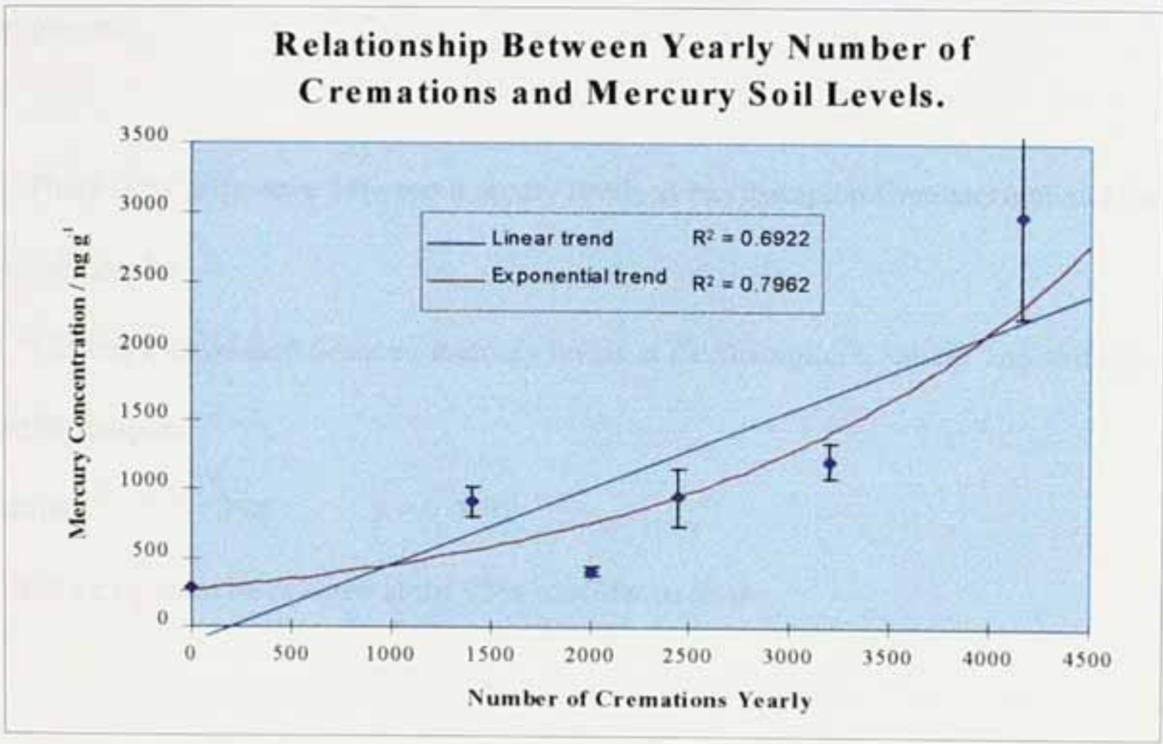


Figure 5.2 Scatter graph of yearly cremations vs. mercury soil concentrations.

5.3.4.4 Statistical Analysis

See **appendix (xxxv)** for details.

Differences between groups: Analysis of variance:

Null Hypothesis, H_0: There is no difference between levels of mercury in soils from different crematoria.

Alternative Hypothesis, H_1: There is a difference between mercury levels from different crematoria soils.

Result: $F = 4.49$, $p = 0.002$

Therefore H_0 must be rejected at the 95 % confidence level.

The levels at the Counties Crematorium, Northampton were the closest to the control group. A t-test was therefore performed to establish a definite difference between these two groups.

H_o: There is no difference between mercury levels at Northampton Crematorium and the control samples.

H_1: There is a difference between mercury levels at Northampton Crematorium and the control samples.

Results: $t = 3.06$ $p = 0.0091$

Therefore H_o must be rejected at the 95% confidence level.

Differences within groups: Analysis of variance:

See **appendix (xxxvi)** for details.

Analysis of variance was also carried out on results from each crematorium, including the construction of 95 % confidence intervals for each sampling position. In each case there were found to be significant differences between mercury soil levels at the different positions on the sites ($p<0.05$). The tests were repeated after exclusion of outliers, which were determined visually from the graphical representation of the confidence intervals. For the City of London site there was no significant difference between the remaining samples ($p = 0.099$). Significant differences between samples were still demonstrated for the other crematorium sites ($p < 0.05$).

5.3.5 Analysis of Soil by Cold Vapour Atomic Absorption Spectroscopy

5.3.5.1 Introduction

Sample Digestion

Many of the problems arising in mercury analysis in the past, in particular with soils and sediments, have been due to losses during sample preparation. Official methods invariably involve acid digestion with or without additional oxidants such as potassium permanganate.

Various measures are taken to avoid sample losses. The USEPA method no. 7471 involves either heating the sample with *aqua regia* in a water bath at 95°C or using an autoclave. Other methods, such as the AOAC official method no. 25.142 use specially constructed digestion apparatus for a sulphuric/nitric acid digestion. More recently there has been an increase in the use of microwave technology for the preparation of samples. This has the advantage of speed primarily, but for mercury in particular the totally closed system minimises analyte losses**[179]**.

The crematoria soil samples are digested in a sulphuric/nitric acid mixture using a commercial microwave digestion system. The samples are contained in closed vessels with a pressure seal and overflow tube in the lid for safety. The seal is designed to rupture above the maximum allowed pressure. One of the vessels is fitted with a temperature probe and pressure sensor. The 'worst' sample is chosen for this; i.e. the one most likely to display an extremely rapid reaction. Soils with a high organic content are the most problematic, the immediate gaseous emission causing a relatively rapid pressure increase. A much smaller sample size is therefore necessary compared to other soil types. The vessels are fitted into a rotating turntable. The unit is programmed for either a specific pressure or temperature profile with time, while the parameter not under control is maintained within a specified limit. The program is adapted according to the nature of the samples to give a steady increase in temperature and pressure initially and the levels are then maintained for the rest of the digestion period. Precise programming is important. For example a reaction under pressure control for which there was too rapid an initial pressure increase would then have difficulty reaching the desired temperature.

Organic mercury species such as methylmercury may not be completely oxidised by acid digestions. A further strong oxidising agent must be used. The closed pressurised system also traps a large quantity of NO_2 in solution. Hydrogen peroxide is therefore added to complete the oxidation and eliminate interference from NO_2.

Cold Vapour Atomic Absorption Spectroscopy

Historically a variety of different methods have been used for mercury analysis, including gravimetry (Au amalgamation), colorimetry (dithizone), titrimetry (SCN) and flame emission or absorption spectroscopy. The methods lacked either sensitivity or precision at low concentrations. The cold vapour system was developed in 1970 and now forms the basis of most, if not all, regulatory body standard methods. Variations on cold vapour detection include atomic fluorescence and gold foil resistivity.

The principle of AAS is based on the fact that elements in the ground state will absorb light of frequency present in the emission spectra of that element. The usual procedure is for the element of interest, in solution, to be aspirated into the reducing part of a flame set in the light path of the emission line, generated by a hollow cathode lamp. Absorbance by ground state atoms is proportional to concentration. Mercury has the advantage of an appreciably high vapour pressure. If a solution is aspirated into a flame then only a small proportion of atoms are in the ground state. Sensitivity is greatly increased therefore by generating the mercury as a cold vapour (maximum number of ground state atoms) which is purged into the light path. No flame is required.

Mercury vapour is generated from Hg^{2+} in solution with reduction by either tin(II) chloride or sulphate, or sodium borohydride. The reactions are as follows:

$$Hg^{2+}_{(aq)} + H^{+}_{(aq)} + BH^{4-}_{(aq)} \rightarrow Hg^{0}_{(g)} + B_4O_7^{2-}{}_{(aq)} + H_{2(g)}$$

$$Hg^{2+}_{(aq)} + Sn^{2+}_{(aq)} \rightarrow Hg^{0}_{(g)} + Sn^{4+}_{(aq)}$$

The procedures may be carried out as a continuous or batch processes. For the continuous process the reagents, tin(II) chloride in this case, and sample (or acid blank) are drawn by a peristaltic pump into a mixing coil. They pass through to a gas-liquid separating assembly. Nitrogen gas is used to flush the mercury vapour through to a quartz T cell mounted in the light path of the spectrophotometer. A Calibration curve is constructed for known standards, from which unknowns may be empirically derived.

5.3.5.2 Apparatus & Instrumentation

Microwave oven - CEM Corporation, MDS 2100

AA Spectrophotometer - Pye Unicam , Model SP2900

Peristaltic pump (two channel)

Vapour generator - See **appendix (xxxvii)**

5.3.5.3 Procedures

Sample collection and preparation have been described previously (***ibid.*5.3.1**).

Sample Digestion - See **appendix (xxxviii)** for microwave program and example of reaction profile.

Each soil sample (between 0.5 and 3.5 g) was accurately weighed into a microwave digestion vessel. A concentrated nitric/sulphuric acid mixture (4:1, 10 cm^3) was added and the vessel pressure sealed. Vessels were mounted on a microwave oven turntable and a pressure sensor and temperature probe attached to the one containing the sample visually appearing to have the highest organic content. The microwave program was set to run at a pressure of 190 p.s.i. with a maximum temperature of 200 ^{0}C. Digestion time totalled 15 minutes.

After cooling, hydrogen peroxide was added dropwise until the brown colour disappeared. The samples were transferred to a volumetric flask (25 cm^3) and made up to the mark with distilled water. Analyses were performed in duplicate.

CVAAS Determination

Instrument Conditions

Vapour System:

Sample/Blank channel	Nitric acid, 2 %
Flow rate	10 cm^3 min^{-1}
Reductant channel	Tin(11) chloride, 12.5% in 20% HCl
Flow rate	4 cm^3 min^{-1}
Nitrogen flow	200 cm^3 min^{-1}

AA Spectrophotometer:

Wavelength	153.7 nm

Slit width	0.7 nm
Lamp current	7 mA
Mode	Absorbance

Procedures

The apparatus was assembled according to the diagram in **appendix (xxxvii)**. The T cell was mounted on the burner within the spectrophotometer and the height and position adjusted to give a minimum absorbance reading. The peristaltic pump speed and nitrogen flow were adjusted to give a maximum absorbance reading for the calibration standards. Standards of 0.5 and 1.00 ppm in 20% nitric acid were used to construct calibration curves. The standard or sample was drawn into the mixing coil together with the tin(ii) chloride reagent until a steady reading was obtained on the spectrophotometer. The system was then purged with the acid blank until the reading returned to zero.

5.3.6 Results

See **appendix (xxxix)** for calibration curves.

See **appendices (xxi)** and **(xxix)** for results and calculations.

See **appendices (xxv), (xxvi)** and **(xxxii), (xxxiii)** for site plans of results.

Summary:

Coventry Crematorium	Mean soil value 1 174 ng g^{-1}	
	Std Dev. 502	Coef. of Var. 42.8 %

City of London Crematorium	Mean soil value 1480 ng g^{-1}	
	Std Dev. 1 329	Coef. of Var. 89.8 %

5.3.7 Statistical Analysis

Differences within groups: Analysis of variance

See **appendix (xL)** for details.

Analysis of variance was carried out on results from each crematorium, including the construction of 95 % confidence intervals for each sampling position. At both Coventry and London there were found to be significant differences between mercury soil levels at the different positions on the sites ($p<0.05$).

Comparison of CVAAS and vapour meter results

See **appendix (xLi)** for details.

t-tests were carried out on data for soil analysed by both CVAAS and vapour meter methods. As soil was taken from the same positions for both methods, correlation coefficients were also calculated. For individual positions, any significant difference between results was also determined by Mann Whitney tests.

Coventry Results

t-test - Difference between CVAAS and vapour meter results:

$p = 0.16$, therefore no significant difference at 95% confidence level.

Correlation coefficient = 0.73

Mann Whitney tests: no significant difference at 95% confidence level between CVAAS and vapour meter results for any individual position.

London Results

t-test - Difference between CVAAS and vapour meter results:

$p = 0.31$, therefore no significant difference at 95% confidence level.

Correlation coefficient = 0.44

Mann Whitney tests: no significant difference at 95% confidence level between CVAAS and vapour meter results for any individual position.

5.4 Analysis of Mercury in Air

5.4.1 Introduction

Standard methods of analysing mercury vapour in air usually involve collecting samples on a sorbent, which is then digested and the mercury determined by cold vapour atomic absorption. Some dedicated instruments are now available, however, for continuous monitoring. The vapour meter previously described for analysis of soil could be used for continuous monitoring purposes; however it is not easily portable. Sampling tubes are therefore used to trap the mercury vapour. The reaction previously described:

$$PdCl_2 + Hg^0 \rightarrow Pd^0 + HgCl_2$$

proceeds readily in the cold and is reversed on heating. Tubes used for sampling are therefore packed with palladium chloride coated glass wool. The mercury is released when the tube is heated in the sampling train.

5.4.2 Procedures

Glass wool was soaked in a 1% solution of palladium chloride, drained and dried in an oven at 70 ^{0}C. Pyrex glass tubes, approximately 15 cm long and diameter 1.5 cm, were packed with the glass wool up to 3 cm from the ends.

The tube was connected to the inlet of a sampling pump. Air was drawn through the tubes at a constant rate of 1.5 or 2.0 $dm^3\ min^{-1}$, for 5 to 30 minute intervals, at locations as indicated on the crematoria plans**[Appendices (xxvii)** and **(xxxiv)]**. The crematoria chosen for sampling were Coventry and the City of London. Five random samples were taken from each site, followed by timed series of 1 hour total on another occasion. Control samples were taken from sites two to three miles away from the crematoria.

The tubes were analysed by the method previously described for soil, using the mercury vapour meter. A chart recorder was connected, but where the reading occasionally went off scale, being higher than expected, a minimum estimate was made from the output on the millivolt meter.

5.4.3 Results

See **appendices (xxvii)** and **(xxxiv)** for site plans of results.

See **appendix (xxii)** for calculations and results, calibration data and graphs.

Summary:

Coventry Crematorium	Mean air value 31 141 ng m^{-3}	
	Std Dev. 16 829	Coef. of Var. 54.04 %
Timed series	Mean air value 3 112 ng m^{-3}	
	Std Dev. 1 117	Coef. of Var. 35.89 %
City of London Crematorium	Mean air value 10 151 ng m^{-3}	
	Std Dev. 5 181	Coef. of Var. 51.04 %
Timed series	Mean air value 8 585 ng m^{-3}	
	Std Dev. 3 022	Coef. of Var. 35.20 %
Control samples	Mean air value 742 ng m^{-3}	
	Std Dev. 35.13	Coef. of Var. 4.74 %

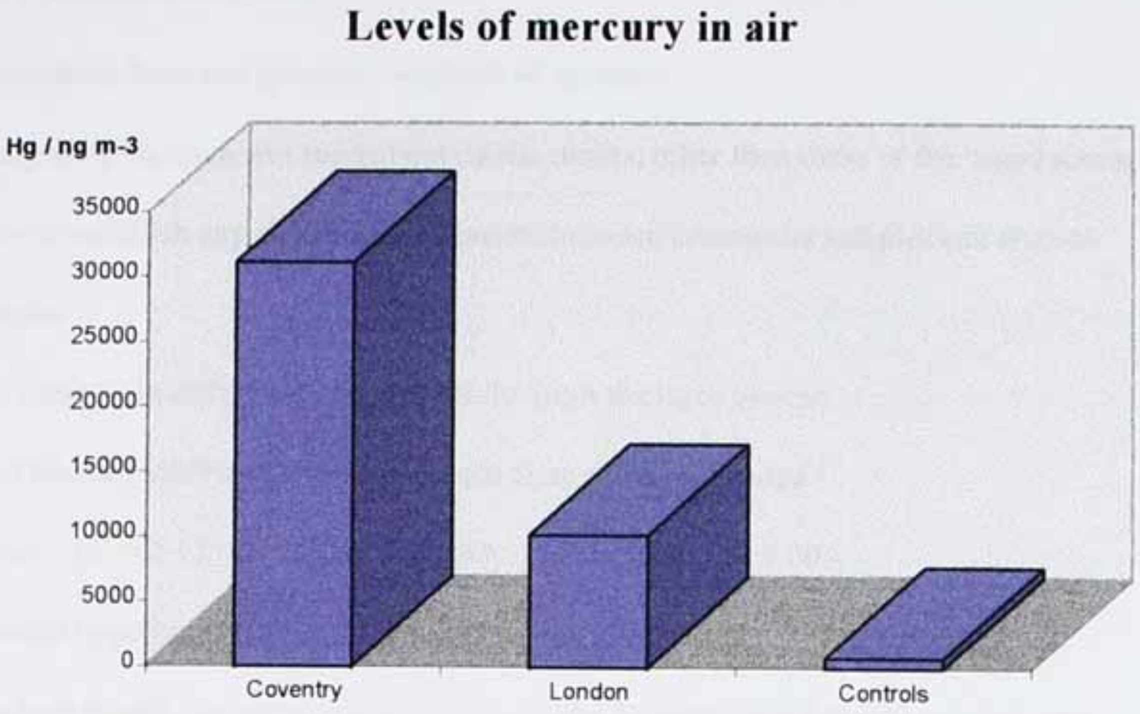


Figure 5.3 Mean air mercury concentrations from different crematoria

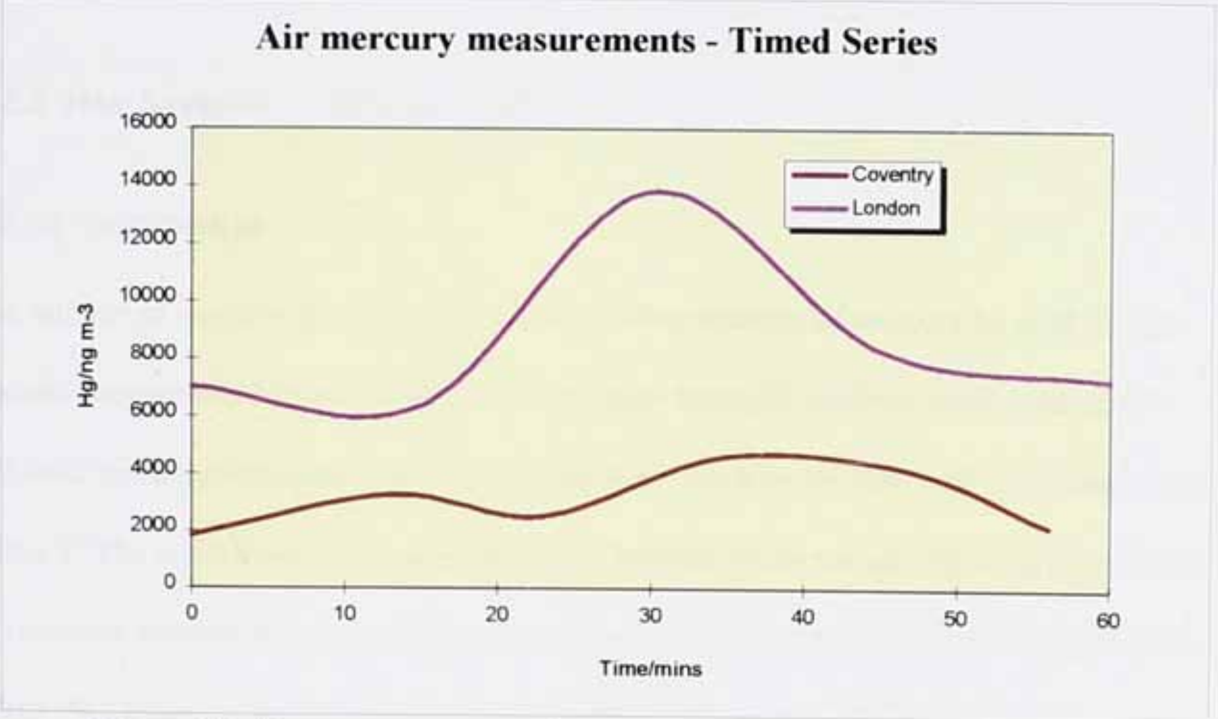


Figure 5.4 Mercury concentrations measured over a continuous period

5.4.4 Statistical Analysis

Differences between groups: Analysis of variance

Analysis of variance was carried out on the results, other than those of the timed series, in order to establish any significant difference between crematoria samples and control samples.

H_0: There is no difference between results from the three groups.

H_1: There is a difference between results from the three groups.

Result: d.f. = 2,11; $\alpha = 0.05$; $F = 9.91$; $F_{crit} = 3.98$; $P = 0.003$

The null hypothesis is rejected at the 95% confidence level.

The least significant difference was between the Coventry and London samples, and therefore both are significantly higher than the control samples.

5.5 Hair Samples - Method Validation

5.5.1 Introduction

A number of methods are well established for determination of mercury by cold vapour atomic absorption. Firstly the reduction itself may be under acidic or basic conditions. Acidic conditions are generally favoured, probably because the flow cell is less subject to attack. The majority of differences arise only in terms of the sample digestion procedures. These are dependent on the sample matrix. There appears to be no established standard for hair. No digestion procedures have been found which can reliably distinguish between methylmercury and inorganic mercury, although some procedures are known to be more rigorous than others, and ensure total digestion. Determination of organic mercury species is usually carried out by capillary gas chromatography.

A total of four sample preparation procedures were investigated here, one of which involved an attempt to be able to selectively analyse for methylmercury and inorganic mercury. The other three involved acid digestions with or without additional oxidants. All four procedures involved standard additions of Hg^{2+}. Any differences in results from the acid digestions could be further investigated with the view to designing procedures for selective digestions. It was unnecessary at the first stage, therefore, to make standard additions of methylmercury until there was at least some indication of it being present at detectable levels.

The first sample preparation procedure was an adaptation of the Magos method for selective determination of methylmercury and inorganic mercury in undigested biological samples**[180]**.

In the original method the sample was a whole rat rather than hair and the AA method was manual rather than automated. There was firstly, therefore, a considerable reduction in scale and a necessity to concentrate the sample as far as possible. Sodium hydroxide was used for sample dissolution, which leaves the methylmercury intact, unlike acid digestion procedures. In the presence of cysteine, methylmercury is reduced by tin (11) chloride at a rate of 0.4 % per day. However, Magos found that the rate of reduction in the presence of a cadmium salt is increased to that of inorganic mercury. Thus, if the sample is first complexed with cysteine, addition of tin(11) chloride will reduce the inorganic mercury, and subsequent addition of a tin(11) chloride - cadmium chloride reagent will reduce the methylmercury.

The second sample preparation involved an overnight digestion with nitric acid. The extent to which any methylmercury would be oxidised was not known.

The third preparation procedure was adapted from the Official Canadian Method B for determination of total mercury by automated flameless atomic absorption, suitable for biological materials. The sample was digested by a mixture of sulphuric and nitric acid.

The fourth preparation procedure was adapted from the USEPA method 245.2 CLP-M The sample was digested in aqua regia and further oxidised with potassium permanganate and potassium persulphate. Excess oxidant was reduced by hydroxylamine hydrochloride prior to determination. The method has been shown previously to give 100% recovery for organomercurials.

Although it is ideally desirable to selectively determine methylmercury and inorganic mercury, the majority, if not all of the mercury in hair is likely to be inorganic. Any methylmercury present could arise firstly from contaminated food and would therefore probably only be detectable in large fish eaters. If the proportion of methyl mercury found was consistently high, however, this would suggest the possibility of *in vivo* methylation.

For all procedures the final determination of mercury was made by cold vapour atomic absorption, theoretical considerations of which were discussed previously. However, a commercial instrument was used for vapour generation.

5.5.2 Instrumentation and Materials

Phillips PU9360 Continuous Flow Vapour System (See **appendix (xLii)**)

Perkin Elmer Atomic Absorption Spectrophotometer Model SP2900

Chemicals: Merck '*Aristar*' or other grades low in mercury used where available.

5.5.3 Procedures

5.5.3.1 Sample Preparation

A large sample of recently washed and cut hair from the same head was homogenised and used throughout. Five determinations were carried out by each method, and a standard addition of 0.25 μg Hg was made to one of each. Hair samples (0.02 - 0.08 g) were accurately weighed into glass tubes (5 cm^3).

5.5.3.2 Sample Digestion

Method 1 Sodium hydroxide (1 cm^3, 45% w/v), sodium chloride (1 cm^3, 20% w/v) and cysteine hydrochloride (0.1 cm^3, 1% w/v) were added to the sample, which was then heated to boiling point in a block heater. The sample was then transferred to a boiling water bath and left for 2 hours. The volume was made up to 10 cm^3 in a volumetric flask with sulphuric acid (5% v/v).

Method 2 Concentrated nitric acid (2 cm^3) was added to the sample. After the initial reaction had subsided the sample was heated in a boiling water bath for 2 hours. It was then made up to 10 cm^3 in a volumetric flask with de-ionised water.

Method 3 Concentrated sulphuric acid/nitric acid (2 cm^3, 4:1) was added to the sample. It was then treated as in (2), above.

Method 4 Aqua regia (1 cm^3, H_2O:HCl:HNO_3, 4:3:1) was added to the sample, which was then heated without boiling for 5 minutes. Potassium permanganate (3 cm^3, sat.) and potassium persulphate (0.5 cm^3, 5% w/v) were added and the sample boiled for 45 minutes. Hydroxylamine hydrochloride (0.3 cm^3, 20% w/v) was added within 1 hour prior to analysis.

5.5.3.3 Mercury Determination

Samples were filtered through a Whatman 541 paper and aspirated into the vapour system for measurement in the atomic absorption spectrophotometer. Sample aspiration was interspersed with standards of 0.005, 0.01, and 0.02 ppm Hg, used to construct calibration curves.

5.5.3.4 Instrument Conditions

Vapour System:

Acid channel	Hydrochloric Acid, 5% (v/v)
Flow rate	7 $cm^3 min^{-1}$
Reductant channel	Tin(11) chloride, 10% (w/v) in HCl, 20% (v/v)
Flow rate	3 $cm^3 min^{-1}$
Nitrogen flow	180 $cm^3 min^{-1}$

AA Spectrophotometer:

Wavelength / nm	153.7
Slit width / nm	0.7
Lamp current / mA	7
Mode	Absorbance

5.5.4 Results

See **appendix (xLiii)** for calibration data and graph

See **appendix (xLiv)** for results and calculations

	Mean Result/ppm	Std Deviation	% Recovery
Procedure 1	0		0
Procedure 2	0.64	0.06	99
Procedure 3	0.54	0.1	78
Procedure 4	0.5	0.07	85

Table 5.5 Results of hair mercury measurements

5.6 Analysis of Hair

5.6.1 Introduction

The procedure used for the hair analysis was that giving the lowest standard deviation and the highest (closest to 100) percentage recovery, which was the nitric acid digestion [method 2, ***ibid*** **5.5.3.2**].

The population to be tested consisted wholly of crematorium workers. Details were obtained on the nature of their occupation and also the number of their fillings, which may be a confounding factor. A control sample was taken from the general population, ensuring that the mean number of fillings matched those of the experimental sample.

5.6.2 Procedures

Samples of hair were obtained from crematorium workers at a number of sites across the country. Details are given in **appendix (xLv)** , including crematoria, numbers of fillings and worker occupation. Information was also obtained on the number of cremations at each crematorium and whether or not operation was fully compliant with the Environmental Protection Act. Control samples were obtained from the general population and the average number of fillings for control and experimental samples were matched.

Samples were prepared as previously described **[*ibid.* 5.5.3.1]** and digested according to method 2**[*ibid.* 5.5.3.2]**. Mercury determination was carried out according to previous procedures[***ibid.*** **5.5.3.3]**. Duplicate samples were analysed where possible, but the hair samples were often too small to allow this.

5.6.3 Results

See **appendix (xLvi)** for data, calculations and calibration curves.

Summary

Mean concentration of mercury in control group hair : 0.97 ppm (n = 46, s.d. = 0.76)

Mean concentration of mercury in trial group hair : 1.68 ppm (n = 97, s.d. = 1.59)

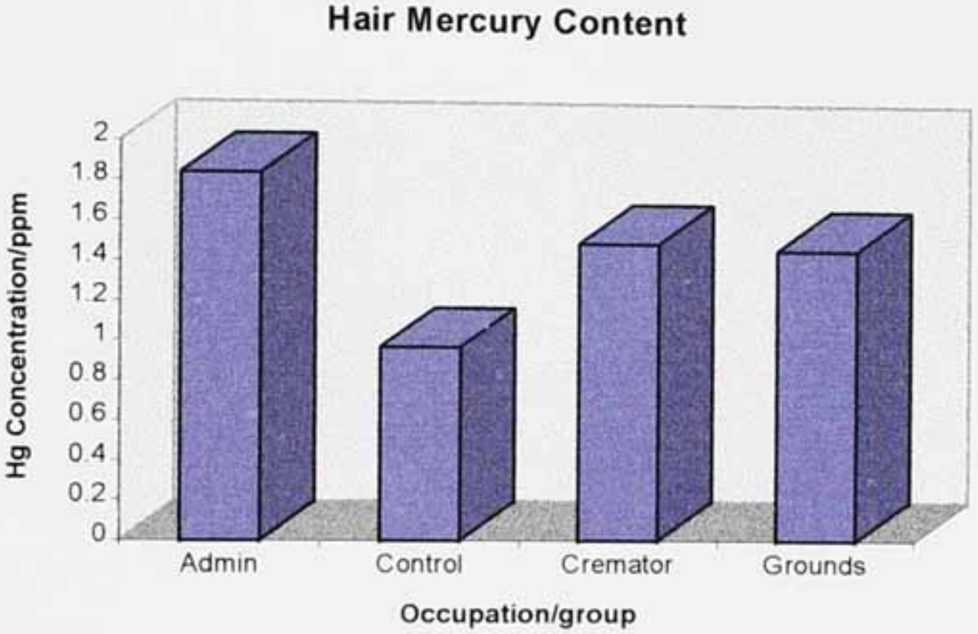


Figure 5.6 Hair mercury concentrations of different groups

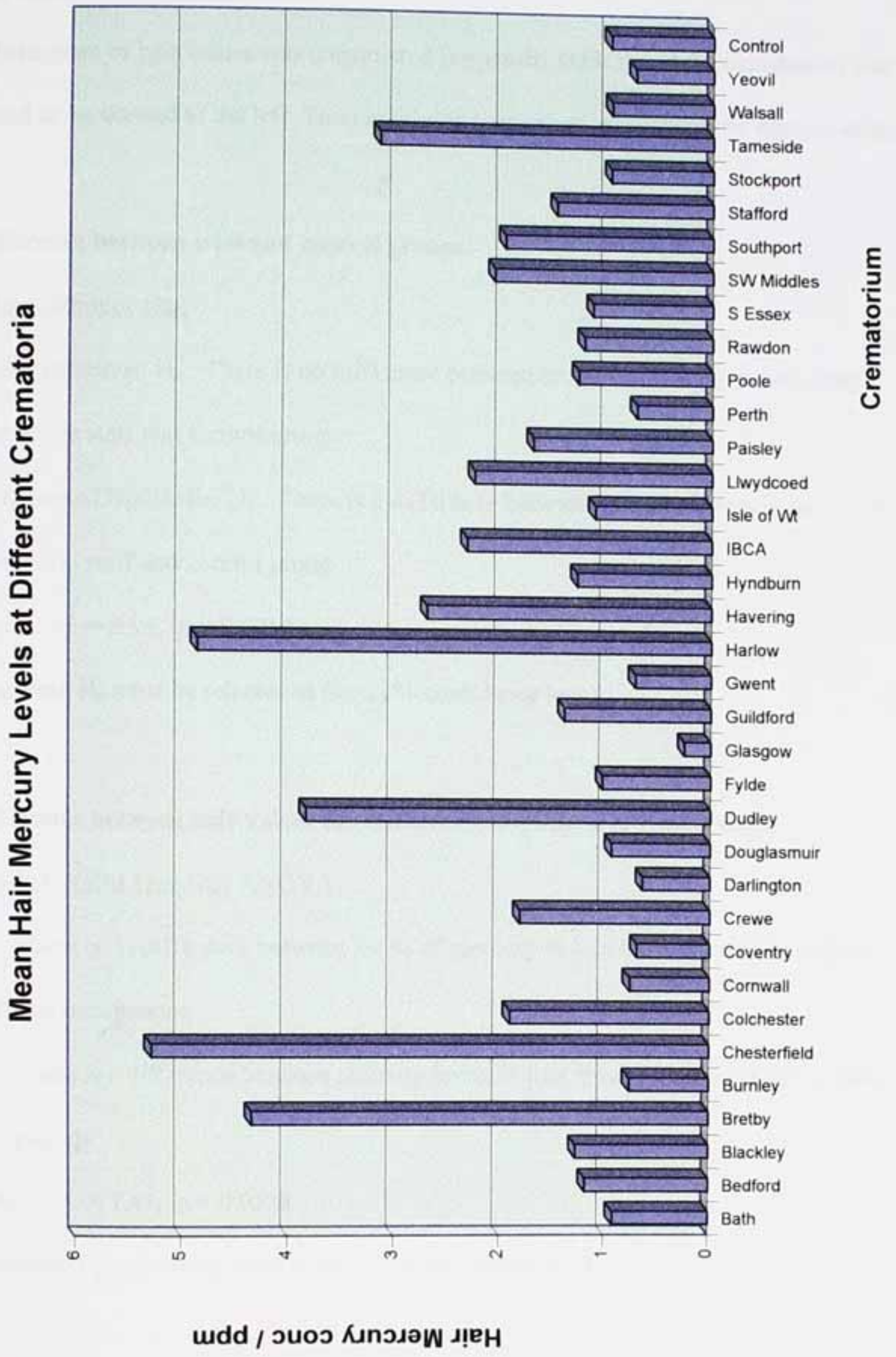
Occupation	Number	Hair Mean / ppm	Hair Std Dev.	Fillings (mean)
Administration	38	1.84	1.29	6.84
Cremation operative	48	1.60	1.77	5.85
Groundsman	11	1.47	2.00	4.82

Table 5.6 Hair mercury levels and filling numbers for different occupations

Hair mercury levels for different crematoria (See bar chart)

See **appendix (xLviii)** for data.

Percentage of crematoria with higher mean levels than control = 66%


Mean Hair Mercury Levels at Different Crematoria
Hair Mercury conc / ppm
0
1
2
3
4
5
6
Crematorium
Bath
Bedford
Blackley
Bretby
Burnley
Chesterfield
Colchester
Cornwall
Coventry
Crewe
Darlington
Douglasmuir
Dudley
Fylde
Glasgow
Guildford
Gwent
Harlow
Havering
Hyndburn
IBCA
Isle of Wt
Llwydcoed
Paisley
Perth
Poole
Rawdon
S Essex
SW Middles
Southport
Stafford
Stockport
Tameside
Walsall
Yeovil
Control

5.6.4 Statistical Analyses

See **appendix (xLvii)** for details

A histogram of hair values was constructed **[appendix (xLix)]** and the distribution was found to be skewed to the left. Tests involving hair values were therefore non-parametric.

Difference between trial and control groups:

Mann-Whitney test:

Null Hypothesis, H_0: There is no difference between levels of mercury in hair from crematoria staff and control group.

Alternative Hypothesis, H_1: There is a difference between mercury levels in hair from crematoria staff and control group.

Result: $H = 9.94$, $p = 0.0016$

Therefore H_0 must be rejected at the 95 % confidence level.

Difference between hair values for different occupations of trial groups:

Kruskal-Wallis One-way ANOVA

H_0: There is no difference between levels of mercury in hair from crematoria staff in different occupations.

H_1: There is a difference between mercury levels in hair from crematoria staff in different occupations.

Result: $H = 7.47$, $p = 0.0238$

Therefore H_0 must be rejected at the 95 % confidence level.

Difference in number of fillings between trial and control groups:

t-test

H_0: There is no difference in number of fillings between trial and control groups.

H_1: There is a difference in number of fillings between trial and control groups.

Result: $t = 0.596$, $p = 0.559$

Therefore H_0 must be accepted at the 95 % confidence level.

Difference between numbers of fillings for different occupations of trial groups:

Kruskal-Wallis One-way ANOVA

H_0: There is no difference between numbers of fillings for crematoria staff in different occupations.

H_1: There is a difference between numbers of fillings for crematoria staff in different occupations.

Result: $H = 2.37$, $p = 0.305$

Therefore H_0 must be accepted at the 95 % confidence level.

Association between hair mercury levels and numbers of fillings:

Control group selected

Correlation coefficient: $r = 0.10$

Difference between hair values for EPA and non-EPA compliant crematoria staff:

Mann-Whitney test

H_0: There is no difference between levels of mercury in hair from EPA and non-EPA compliant crematoria staff

H_1: There is a difference between mercury levels in hair from EPA and non-EPA compliant crematoria staff

Result: $H = 0.00$, $p = 0.989$

Therefore H_0 must be accepted at the 95 % confidence level.

Association between hair mercury levels and cremation load:

Correlation coefficient: $r = 0.01$

Difference between hair values for staff from crematoria with high or low outputs:

Mann-Whitney test

H_0: There is no difference between levels of mercury in hair from crematoria with high or low outputs

H_1: There is a difference between mercury levels in hair from crematoria with high or low outputs

N.B. Crematoria holding more than 1600 cremations per year are defined as high output.

Result: $H = 4.242$, $p = 0.039$

Therefore H_0 must be rejected at the 95 % confidence level

6. Discussion

6.1 Mercury soil levels - Vapour meter determination

For each crematorium the statistical analysis showed variations between mercury soil levels at individual sampling positions. A previous study has found highest levels at 15 metres from the stack, decreasing with distance**[*ibid.* 3.3.2]**. Other factors affecting the levels would be the usual direction of the wind, the nature of the sample and the extent of shelter from shrubs and trees. Overall levels would be expected to reflect the cremation burden, either in terms of the number of cremators operating (or average number of cremations per year) and/or the total number of cremations carried out since the start of operation. The study previously mentioned, carried out in New Zealand, tentatively suggested an increase in soil mercury of 100 ppb for every 18000 cremations. It should be noted, however, that only three crematoria were included in the study and the data were therefore insufficient to give a reliable correlation coefficient.

Results from the Counties Crematorium, Northampton gave a mean level of 0.405 ppm, a significant increase of 0.130 ppm above the control samples($p<0.05$). Concentrations were comparable to those in New Zealand for a crematorium of similar output, where the mean level was 0.386 ppm, being 0.186 ppm above background. At Northampton the least sheltered part of the site is to the south-east where the highest levels of 0.50 ppm (positions 1 and 3 on the map) are closest to the stack. Considerable shelter from trees is given to position 7 with a relatively low concentration of 0.36 ppm. The lowest concentration of 0.23 ppm (significantly lower from statistical analysis) was at position 5 which was closest to the stack. There was some shelter, but no more than for position 6 (0.47 ppm). The furthest position from the stack, no 8, was also low at 0.31 ppm. This would suggest that the outfall firstly increases and then decreases with distance from the stack, which again agrees with the findings from the New Zealand study and also reflects the prevalent wind direction, from the north-east.

Kettering results showed a mean concentration of 0.95 ppm. This included two significantly high results. Position 8 with a level of 2.04 ppm, appeared to have a very high organic content and the result would therefore most likely be due to bioaccumulation**[*ibid*.2.3.3]**. Position 5 was fairly rich, peaty soil, but it may be that the level of 1.71 ppm was reasonably high in any case due to the wind direction and proximity to the stack. Position 4 was further away in the same direction but still high at 0.95 ppm. Position 3, in the same overall direction was lower at 0.58 ppm, but heavily sheltered. In the opposite direction, closest to the stack, the level was 0.76 ppm. Further out the concentrations fell to between 0.44 and 0.55 ppm. The overall picture, apart from the two anomalies accounted for, is that concentrations decreased with distance from the stack and were higher in the south-westerly direction of the prevalent winds.

At Milton Keynes crematorium the sample of moss at position 6 was particularly high at 11.52 ppm. Bioaccumulation has been previously recorded in moss samples**[181]**. The only other significantly high sample according to the statistical analysis is at position 7, 1.49 ppm, SSW of the stack. Samples in the southerly direction are higher overall, apart from sample 1, which is NW and close to the stack. Samples 1 and 8 are both sheltered to some extent by shrubbery and it may be that in this case the shrubs have served as a trap for the vapour and led to some bioaccumulation in the soil beneath. Position 4 has a relatively low level, but is close to the stack in a north easterly direction. This is in keeping with other observations of the levels initially increasing with distance, particularly with the proximity of the sample to the side of the building.

Canley crematorium at Coventry showed higher levels overall, and the nature of the samples was very varied, as outlined in **appendix (v)**. There was very little open soil. The pine needle sample, number 3, again demonstrated bioaccumulation, being extremely high at 8.73 ppm. The soil beneath the pine needles measured only 0.93 ppm. The lowest sample in the easterly direction, 1.03 ppm, was also taken from beneath pine needles. Other samples in the south and westerly direction, numbers 4 and 5, were in fact the lowest overall, at 0.69 and 0.76 ppm. Of the high samples, numbers 9 and 10, at 1.49 ppm and 1.51 ppm respectively, were fairly close to the stack. Positions 6 and 8 were both approximately 100 metres from the stack. Sample 6, 1.66 ppm, had a high organic content, being covered by woodchip, and sample 8, 1.61 ppm, being at the base of a tree would also have had a high content due to washout from the canopy catchment.. The overall pattern is higher levels to the north and east, and concentrations decreasing with distance. The number of anomalies does make the latter observation difficult to see, but it is particularly apparent from samples 10,5,9 and 7.

The crematorium at the City of London shows high levels throughout. It is particularly complicated by the presence of a disused cremator in the same grounds. There are three anomalously high readings for numbers 4, 8 and 15. The first two were largely moss and the third consisted of pine needles. The overall pattern shows lower levels to the far south-west of both stacks. Similar levels arise to the east of the stacks, but close to the disused stack. Concentrations directly around stack 1 and between the stacks are significantly higher overall. Although the second cremator has been disused for 27 years, there still appears to be a residual contribution to the levels although probably quite small. It is surrounded by trees and the building alone should give some shelter to the soil on the east side. However, the levels here are similar to those to the west and south of stack one. The appearance overall is again of concentrations decreasing with distance from the stack.

The mean levels of soil mercury at each crematorium are depicted by a bar chart**[Figure 5.1]**. The trend corresponds well with the number of cremations carried out yearly, as shown by the scatter graph**[Figure 5.2]**. The exponential model gives slightly better correlation than the linear model. The latter would be more appropriate for a plot of the cumulative number of cremations against concentration, as mercury would have built up over the years since the crematoria were commissioned. The flux, however, would vary from one crematorium to the other. Mercury vaporisation from the surface, and deposition, depends on local climate and topography. Previous discussion of variations in concentration with position demonstrates the latter. Surface loss also depends on air movement. A site totally surrounded by trees, for example, or in a dip such as is the City of London, would be sheltered from prevailing winds resulting in a lower surface efflux. The exponential model is still difficult to justify on a theoretical basis, however, and probably arises as a result of various confounding factors, such as number of years since commissioning.

6.2 Mercury soil levels - CVAAS determination

The principle reason for carrying out a further analysis of soil from the two crematoria exhibiting the highest levels was that the CVAAS method has been well established for mercury determination**[*ibid.* 5.3.5.1]**. The mercury vapour meter, in contrast, has been the subject of very little research.

The results obtained from the CVAAS method were very variable. In view of the limitations of a small sample, through use of the microwave digestion system, the determinations were carried out at a level quite close to the limit of detection. This resulted in high coefficients of variation in some cases. Although when Mann Whitney tests were carried out to test the difference in results from the two methods, no significant difference was established, this was largely the result of the high variation coefficients in the CVAAS method. For Coventry crematorium the correlation coefficient was quite high, at 0.73. A comparison of the results, as shown on the site plan **[appendix xxvi]**, demonstrates apparently appreciable differences for some samples. It cannot be said, however, that one method must, because of the reproducibility, be more precise than the other. There are undoubtedly shortcomings and advantages associated with both. Soil, in any case, is a notoriously difficult matrix with which to work, firstly because of the lack of homogeneity and secondly because of the numerous possible species involved. Sample sizes for the vapour meter were less than 0.05 g. Rigorous sampling techniques were employed to endeavour to obtain a representative sample. However, when starting with 2 kilograms, the procedure will preliminarily eliminate a large part before the remainder is more thoroughly mixed. The second sampling for the CVAAS determination would have been taken from a different part. This, however is only one possible source of the variation.

The vapour meter detected those species that could be said to be 'unbound'. They are released simply as a result of heating the sample. In view of this, they are probably those of major environmental importance. If a species is not available for re-release to the atmosphere and therefore not contributing to the overall flux, then it poses less of a health threat. Mercuric sulfide, for example, is thermodynamically stable, very insoluble, and could be regarded as a preferential environmental form.

Digestion of the sample, followed by cold vapour atomic absorption spectroscopy, should in theory measure total mercury. It would have been expected, therefore, that results would be either the same or higher than those from the vapour meter measurements. Anomalous results are most noticeable for samples 1 and 8 at Coventry. Sample 1 was taken from the base of a tree and therefore probably had a high content as previously explained. Historically, many of the variations on the official CVAAS digestion methods have been the result of difficulty in firstly minimizing sample losses, and secondly, obtaining total digestion of organic mercury species. The problem has been one of a 'balancing act'; More rigorous digestion conditions results in an increase in sample loss. It is likely, therefore, that where samples had a high organic content, recovery was lower than usual and the results from the vapour meter gave a better indication of the true figures. For sample 1, the lower figure may be appropriate in terms of the decrease in outfall with distance, but is enhanced due to washout from the trees, as shown by the higher figure. Both results, therefore, give meaningful information. This is applicable also to sample 3, which was a wholly organic sample of pine needles.

At the City of London crematorium the correlation coefficient was much lower, at 0.44. Samples 15, 8 and 4, all with high organic content, gave increased results by the vapour meter method, as expected from previous discussion. Very few of the samples gave higher results by the CVAAS method and no distinct pattern could be seen. With the high output from this crematorium compared to the others, it may be that levels remained fairly high throughout the grounds. There was also heavily wooded areas around the disused block which further complicated the situation.

The overall effects of shelter seem to vary. Firstly, where samples are taken from soil sheltered by trees, the levels may be lower. On the other hand, samples taken directly beneath shrubbery or at the base of trees, although sheltered, exhibit bioaccumulation effects and tend to be higher. An attempt to construct a mathematical model of the general fallout pattern has therefore not been possible with these data due to the number of different variables.

6.3 Air measurements

Mean air concentrations varied from between four and forty-two times the background (control) levels measured. Variation would be expected according to the number of fillings in the deceased persons being cremated. The highest mean level was 31 $\mu g\ m^{-3}$ at Coventry crematorium. This is in excess of the current occupational exposure standard of 25 $\mu g\ m^{-3}$ **[appendix iv]**. However, the lowest mean level was also at Coventry, when a timed series was measured over one hour. This amounted to 3 $\mu g\ m^{-3}$. For the timed series at the City of London crematorium the mean value was 8.6 $\mu g\ m^{-3}$. It can be seen from the plot that the level increased after approximately 18 minutes, rising to a peak of 14 $\mu g\ m^{-3}$ at 30 minutes and returned to the base level after another 13 minutes. The overall increase therefore lasted 25 minutes. It is not known how many cremations were taking place during this time so it not possible to definitely associate the output with particular cremations which started at given times. The pattern is similar, however, to a previous Swedish study which has already shown time series for individual cremations**[182]**. In this study the measurements were made one meter from the ejector fan, inside the stack. Mercury emission commenced between 8 and 12 minutes after charging and lasted for about 10 minutes. The highest level for one cremation was 60 $mg\ m^{-3}$, or 12.5 mg Hg / s, with a minimum of zero. The average total emission for one cremation amounted to 2 g. The City of London measurements reflect the level at head height, and probably at least two cremations with corpses bearing mercury fillings. The thousandfold order of difference between the studies undoubtedly reflects the dilution between the stack and this level. The City of London cremators were not compliant with The Environmental Protection Act at the time of sampling and were scheduled to be replaced. It would therefore be expected that there would be some reduction of these levels after compliance. However, the stack emission could not be expected to decrease. With four new cremators operating in one crematorium and three in the other crematorium on the same site, the maximum output expected, as calculated from the Swedish data, would be 420 mg m^{-3}. Although there are no set limits for emissions from crematoria, for energy production from coal burning EEC directives and BATNEEC apply. In this case there is a maximum air emission limit for mercury of 0.6 mg m^{-3}**[183]**. With an output maximum of 420 mg m^{-3} the mean output over ten minutes would be 297 mg m^{-3}. An estimated cremation cycle of 90 minutes gives the average output over eight hours as 33 mg m^{-3}. This is far in excess of the emission limit for coal burning. Critical concentrations for air levels of mercury amount to 60 mg m^{-3} (non-specific CNS symptoms), and approximately 10 mg m^{-3} (micromercurialism).

The measurements made at head level at Coventry and London more appropriately reflect immediate exposure than the actual emission levels, although the latter are important for the purposes of comparison with statutary limitations. As stated, it was shown that for one series of measurements, the occupational exposure standard (OES) was exceeded. The OES refers to an eight hour time weighted average. The ceiling occupational exposure limit is 0.1 mg m^{-3} **[appendix iv]** and at no time was this seen to be exceeded. However, these limits are necessarily calculated to reflect the tolerance of an average working person and refer to a workplace setting. One air sample at Coventry taken outside of the crematorium (position 5 on plan) was in excess of the OES. Although the soil distributions do show that there is a fall off with distance, this is unlikely to be the case once the EPA is fully effective**[*ibid.*3.4.4]**. There is a need, therefore, to consider the effects on the population as a whole, and in particular the more susceptible groups such as children and expectant or nursing mothers. The variation in effects and differences in individual sensitivity have been discussed[***ibid.*4.5.4.5**]. Crematoria are often sited in built-up areas, including residential locations, such as Canley Rd in Coventry. An ambient air level limit of 1 μg m^{-3} has been proposed**[184]** and this level was certainly exceeded. Although no regulatory limit exists for mercury, the US Environmental Protection Agency (EPA) have suggested that 0.3 μg m^{-3} would be an appropriate no-effect level for chronic inhalation exposure.

6.4 Hair Determinations - Method Validation

For the first procedure, the adaptation of the Magos method, the acid reduction system failed to release the mercury from the Hg-cysteine complex. The original procedure involved an alkaline reduction and a very large sample (a whole rat). A batch rather than continuous process was used. It is difficult to obtain large hair samples and the detection limits with the vapour system were not as low as expected. Any attempt to quantify organic mercury would therefore necessarily fail with a small sample. The probability of there being high enough levels present was indicated from the other results to be unlikely. It would be expected that a more rigorous digestion procedure would give higher results for total mercury if organic mercurials were present. However, statistical analysis (95% confidence level) showed procedure 4 to give lower results than procedure 2. The presence of organic mercury species in significant quantities was therefore unlikely as procedure 4 was well established as one which would digest these species. No other differences could be shown to be significant. Thus, the procedure used for subsequent samples was that giving the lowest standard deviation and the optimal percentage recovery, which was the nitric acid digestion.

6.5 Hair Analysis

It would have been desirable to test those people living in the immediate vicinity of crematoria sited in residential areas. However, this may have caused unnecessary alarm and as such required more justification than the evidence to hand. The study was therefore confined to those people working in crematoria, some of whom had been subject to similar environmental health studies on previous occasions. Almost all of the crematoria approached agreed to participate, with their staff contributing on a voluntary basis. It was difficult in some instances, however, to obtain a sufficient sample.

The samples for control and trial groups were matched for numbers of fillings by a t-test on the means. No significant difference was found ($p > 0.05$)[***ibid*. 5.6.4.3**], and the groups were therefore taken as matched. The control group was tested for correlation between numbers of fillings and mercury levels and no relationship was found ($r = 0.1$). Studies have shown that amalgam fillings make a significant contribution to mercury intake[***ibid.* 4.6**]. However, correlation has been difficult because the rate of release of mercury from the filling surface decreases with time following placement and also varies with activities such as chewing, etc. There are therefore likely to be a number of confounding variables from one individual to the next. Provided that the mean number of fillings for each group is the same, and the sample size is large enough, the inability to correct results for contributions from fillings should not affect other tests.

The main experimental hypothesis refers to the difference in hair mercury levels between the two groups. The level in crematorium workers is 1.68 ppm, compared to 0.97 ppm in the control sample, which is a highly significant difference (p = 0.0016). The mean levels for different occupations at the crematorium ranged from 1.47 to 1.84 ppm. The highest of these was the administration staff, which includes managerial levels. There was little difference between the other two levels, the cremator operatives and the grounds staff. It was noted that there was often little distinction between the different occupations, with many staff having dual roles. However, it would still have been expected that those staff working with the cremators and in the grounds would be exposed to a higher level than would the office staff. The difference was quite small, but nevertheless significant and opposite to the trend expected. It may be that the levels of fillings had some effect. Although no significant difference was found between the different occupations of the trial group, the trend for fillings is similar to the hair levels, with administration staff having higher numbers. It may be possible therefore that exposure from fillings affected these results and no reliable conclusions can be drawn concerning the levels of mercury between the different occupations. An alternative explanation for the high mercury levels in administrative staff could be that within the grounds the mercury vapour would be subject to weather conditions and freely dissipate quite quickly. Any vapour within the buildings, however, would be trapped and would circulate with the external atmosphere far more slowly.

Of the 36 crematoria taking part in the study, 66% had mean mercury levels for staff higher than the control mean. There was no definite correlation between the number of cremations carried out and the hair mercury levels of staff. However, when the crematoria were divided roughly in half, between those having outputs higher than 1600 per year and those having 1600 or less per year, there was a significant difference between the two groups ($p = 0.039$), with means for hair mercury of 1.96 and 1.47 ppm respectively.

No difference at all could be established between levels for staff at crematoria compliant with the Environmental Protection Act (1990) and those non-compliant. Unfortunately it would be necessary to hold other factors, i.e. numbers of fillings and crematoria output, constant, in order to establish a definite effect, and this would reduce sample levels and statistical power. Given a large difference, however, this could be seen in any case, but has not been found.

Critical levels for hair are 50 -125 ppm for paraesthesia effects**[185]**. There is no definite standard, but a 'tolerable' level is thought to be 6 ppm or less**[186]**. Of the 97 crematorium workers examined, 3% had levels higher than this. No safe level has been established, and mercury vapour crosses the placental barrier as does methylmercury. A peak maternal hair level of greater than or equal to 10 ppm following methylmercury exposure is thought to present a 5% risk of cognitive impairment**[187]**. It would not be unrealistic to assume a similar risk factor for mercury vapour. In built up areas there are also other contributory factors, such as lead pollution from traffic. This is yet another neurotoxin and the synergistic effects have been given little consideration in current research. It is well known that the neurotoxicity of some pesticides increases 100 fold in the presence of PCBs**[188]**.

The excess exposure to mercury vapour suffered by either crematorium workers, or the surrounding population, may well be low in relation to other known occupationally exposed groups. such as dentists or chlor-alkali workers but there is sufficient evidence to warrant emission controls. Sweden already has ongoing projects to install selenium filters for crematoria**[183]**. For those crematoria not yet compliant with the Environmental Protection Act (1990), it would still be possible to investigate viable alternatives for multi-filter systems. This most important points of the Secretary of States Guidance Note for Crematoria relate to control of emissions. It may be that using filters does not allow some points to be complied with, such as the efflux velocity. It would obviously be far better, however, to reduce emissions than to demonstrate wider dispersal. At least 50% of crematoria will by now have brought cremators up to standard, with new plant etc. Subject to further research it may be possible to employ selenium ampoules as a control measure**[*ibid.*3.5]**.

The choice of abatement technology with respect to the mercury would have to be made with prior knowledge of the mercury species involved. For coal combustion the emission species consist of 40 - 50 % elemental vapour (Hg^{o}), 20 - 30 % oxidised form (Hg^{11}) and 10 - 20 % particle bound mercury. The picture for waste incineration is quite different, with 10 -20 % elemental vapour, 10 -20 % particle bound and 50 - 70 % oxidised form**[189]**. No such data are available for crematoria but it could be envisaged that the result would lie somewhere between the two when considering the high carbon content of the body.

It is important that the use of mercury in dentistry is phased out completely as soon as possible. Removal of placements prior to cremation of the deceased is unlikely to be seen as a viable option and therefore the problem of mercury emissions is not likely to cease for a considerable number of years. With increased dental hygiene, however, the continuing replacement of amalgam fillings (some of which may only have a lifetime of around ten years) with alternative materials, the emissions should have significantly decreased in, say, twenty years time.

7. Conclusions

Soil levels in the crematoria sampled were significantly in excess of controls ($P<0.5$) and typical background levels. Mean concentrations ranged from 0.4 to 3.0 ppm and gave good correlation with the number of cremations at each site. Measurements of air emissions varied considerably, with the highest mean level being 31 $\mu g\ m^{-3}$, in excess of the OES of 25 $\mu g\ m^{-3}$. The lowest mean level was 3 $\mu g\ m^{-3}$. This is in excess of the proposed ambient air level goal of 1 $\mu g\ m^{-3}$, and 10 times the no-effect level suggested by the US EPA. It can thus be concluded that a risk to the crematorium workers cannot be ruled out. In respect of the local population, where crematoria are sited in built up areas, exposure will almost certainly be above the no-effect level and ambient air level goal. Children, including the unborn, will be at highest risk, together with any particularly susceptible individuals.

Results from the hair sampling programme lent support to the emissions data, with there being a significant increase in worker levels of hair mercury over controls ($p<0.5$). Sixty-six percent of crematoria had mean levels for staff higher than controls. There was considerable variation in hair levels between and within crematoria, but mean hair levels were higher for staff of crematoria with outputs greater than 1600 cremations per year. It may again be concluded, therefore, that some crematoria workers are at risk from the mercury emissions, with variations arising from individual susceptibility, although office workers did appear to be more at risk than other occupations. Three percent of workers had levels above 6 ppm which is thought to be the 'tolerable' limit. It may be that these people are suffering from some form of micromercurialism, but without a mercury challenge test the diagnosis would be difficult. A parallel could be drawn with those people thought to be suffering from amalgam poisoning from their fillings. Sub-chronic effects tend to prevent the full functioning of the organism but the symptoms may only be vaguely apparent. Effects on the brain may not be noticeable at all until a reasonable amount of damage has been done.

Even if the placement of mercury fillings was to be stopped now, there is likely to be a continuing problem with disposal of the deceased for the lifetime of the cremators now in use. It is unlikely that there would be any support for the option of removal of fillings prior to cremation. It is therefore essential that some form of control technology be utilized. Further investigation needs to be carried out on the use of selenium ampoules, which would be a relatively cheap option. The ideal solution would be an integrated multi-abatement system to remove not only mercury, but also other pollutants for which compromises have been made under the Environmental Protection Act. Other forms of waste disposal have for some time been operating with various forms of control technology as a necessity. There needs to be widespread acceptance of this concept for crematoria. It is assumed to be an hygienic alternative for disposal of the dead and should therefore continue to be seen as such.

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Appendix i

Mercury - Physical Data

Mercury - Physical Data

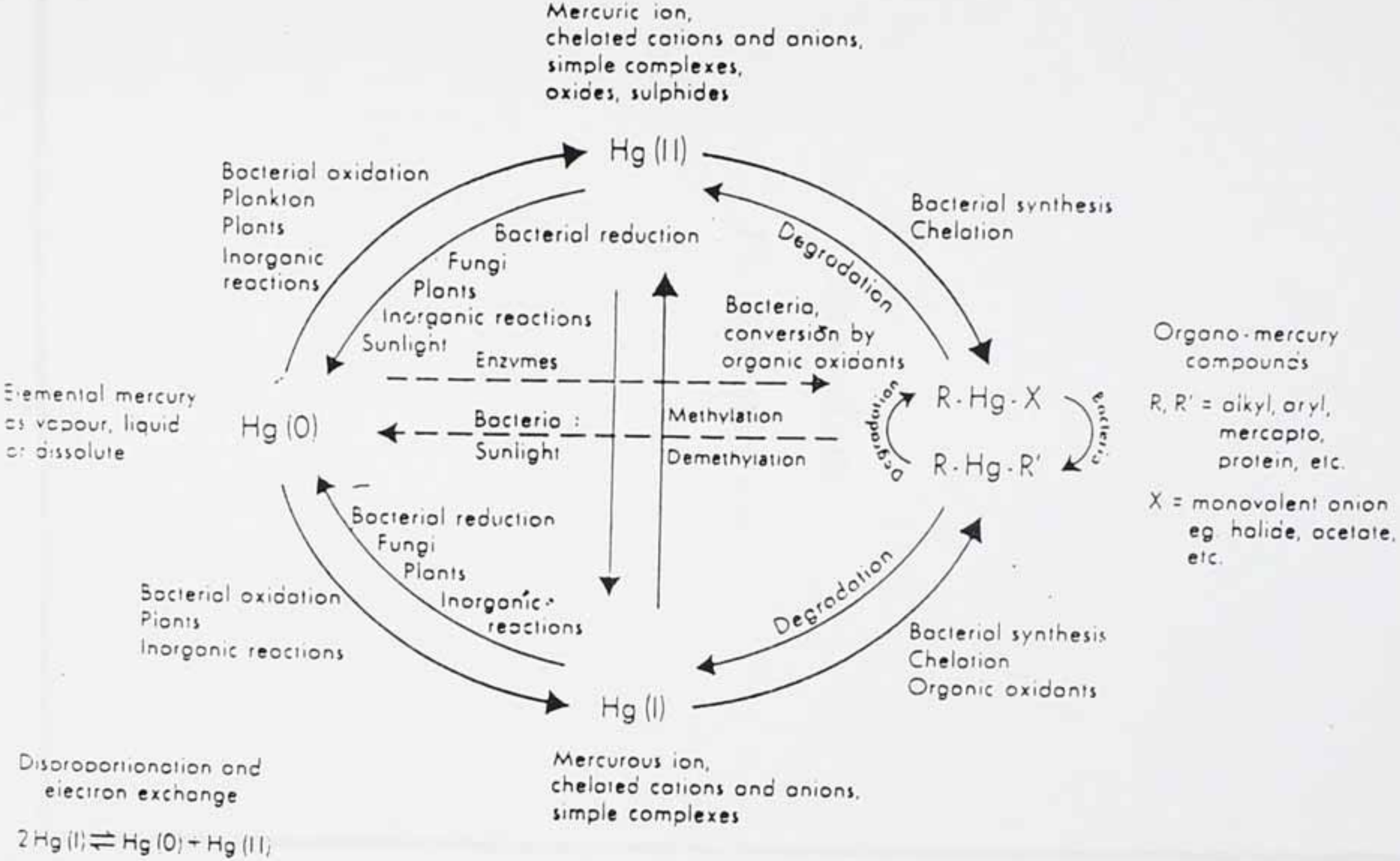
Atomic number	80
Relative atomic mass	200.59
Electronic configuration	[Xe] $4f^{14}5d^{10}6s^2$
Atomic radius	156 pm
Density (273 K)	13 590 kg m^{-3}
Melting point	234.3 K
Boiling point	629.7 K
1st Ionisation Energy	10.437 eV
2nd Ionisation Energy	18.756 eV
3rd Ionisation Energy	33.01 eV
Vapour pressure at 293 K	0.16 Pa

Source: *Science Data Book*, Tennent,R.M. Ed., Oliver and Boyd, Edinburgh, 1986

Appendix ii

Mercury Interconversions in Nature

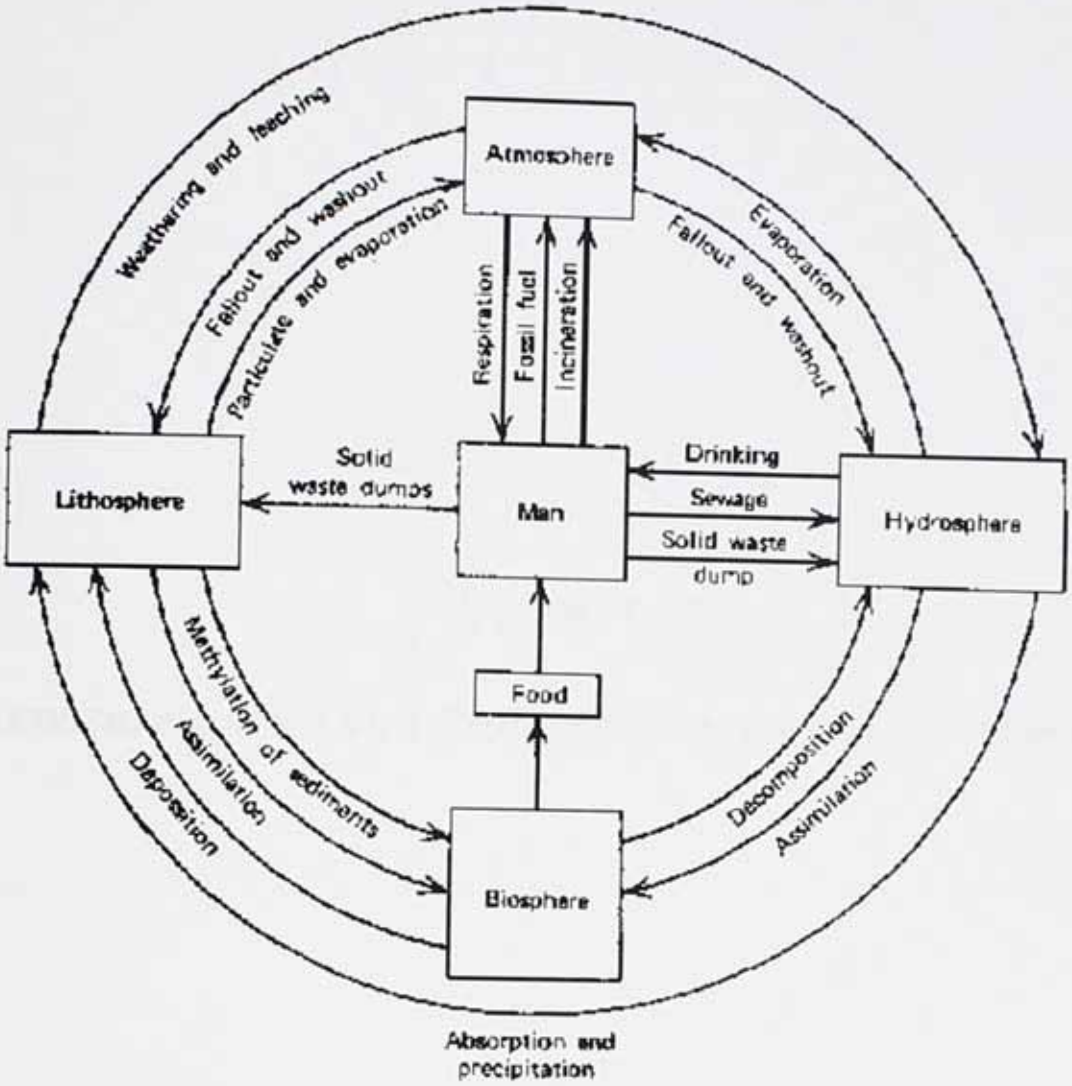
The mercury cycle



Geological Survey of Canada

Appendix iii

The Mercury Cycle



Mercury Cycling in the Total Environment

The boxes represent levels, and the arrows, rates of exchange and transport.

Appendix iv

Exposure Limits and Biological Indicators for Mercury

Exposure Limits and Biological Indicators for Mercury

Mercury Compound	Medium	Value	Comment	Reference
Elemental	Air of working premises	0.025 mg m^{-3}	UK OES 8 hr TWA	HSE, 1995
Elemental and inorganic	..	0.1 mg m^{-3}	Ceiling OEL, OSHA	BOHS, 1992
Alkylmercurials	..	0.01 mg m^{-3}	OES 8 hr TWA, OSHA	BOHS, 1992
Alkylmercurials	..	0.04 mg m^{-3}	Ceiling OEL, OSHA	BOHS, 1992
Elemental	Ambient air	0.7 µg m^{-3}	USSR	MARC, 1980
Elemental and inorganic	Blood	30 µg l^{-1}	UK (advisory)	BOHS, 1992
Elemental and inorganic	Urine	20 µmol/mol creatinine	UK (advisory)	HSE, 1995
Total	Drinking water	1-5 µg l^{-1}	WHO	MARC, 1980
Total	Food	300 µg $week^{-1}$	WHO	MARC, 1980

Abbreviations

OES	Occupational Exposure Standard
OEL	Occupational Exposure Limit
TWA	Time weighted average
HSE	Health and Safety Executive (UK)
OSHA	Occupational Safety and Health Administration (USA)
WHO	World Health Organisation

References

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Appendix v

Crematoria Soil Samples

Crematoria Soil Samples

Kettering Crematorium

Sample 3.	Heavily sheltered
Sample 5.	Appeared to be recent topsoil, very peaty
Sample 7.	Moss
Sample 8.	High organic content

Counties Crematorium, Northampton

Sample 7.	Quite sheltered

Canley Crematorium, Coventry

Sample 1.	Base of tree
Sample 2.	Base of tree, under deep covering of pine needles
Sample 3.	Pine needles
Samples 4,5	Open, clear to stack
Sample 6.	Wood chip, peat(4” deep covering soil) Sheltered by trees and shrubs
Sample 7.	As above, but soil taken from underneath
Sample 8.	Beneath bushes

Milton Keynes Crematorium

Samples 1,8	Very sheltered
Sample 6.	Moss

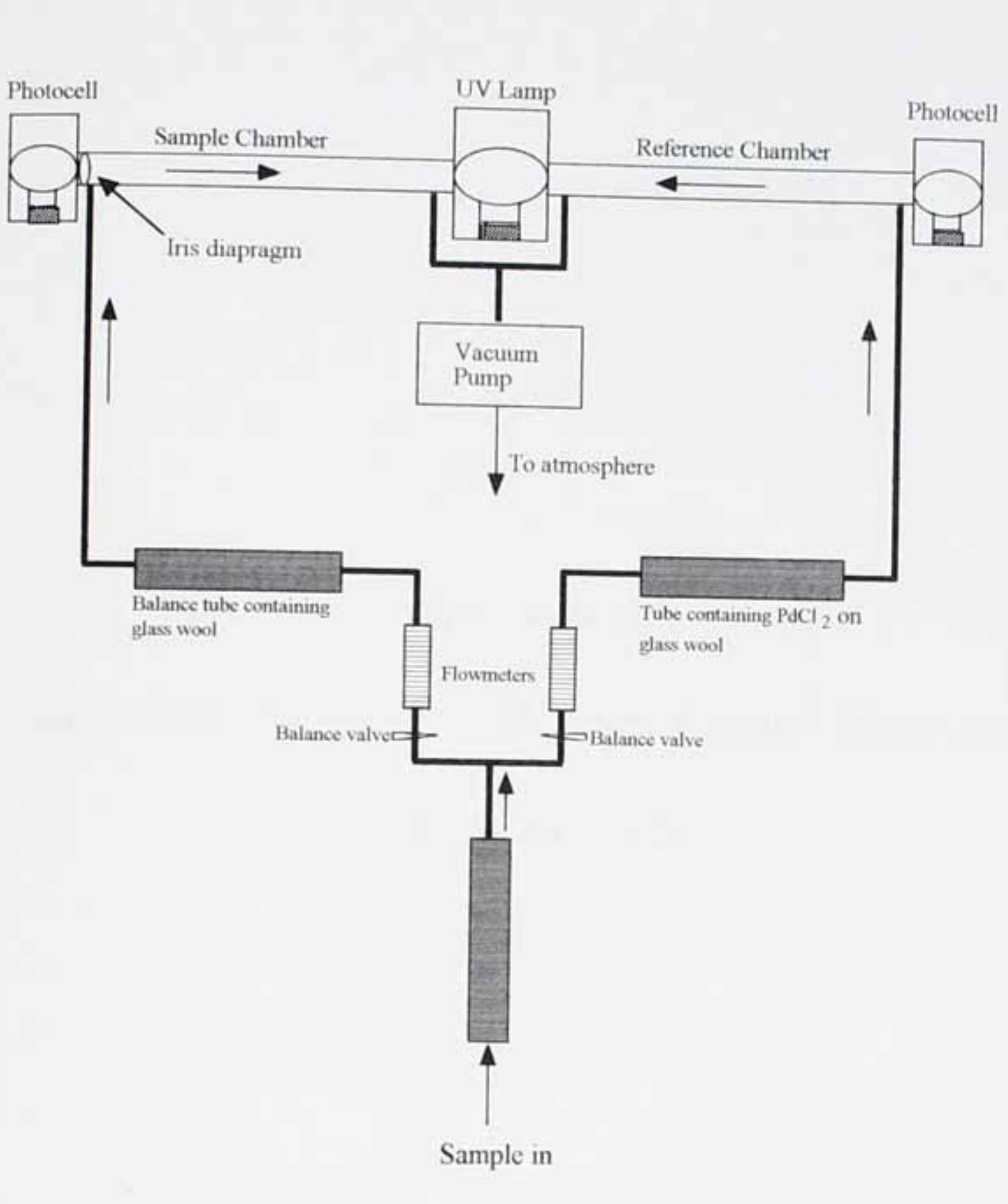
City of London Crematorium

Samples 1,2,6,13	Very sheltered
Samples 3,5,11	Slightly sheltered
Samples 4,8,14	Mossy
Sample 7.	Grave front
Sample 9.	Open, adjacent to old crematorium stack
Sample 10.	Slightly sheltered and adjacent to old crematorium stack
Sample 12.	Soil around ornamental pond. Appearance of ‘make-up’ soil.
Sample 15.	Pine needles

Appendix vi

Schematic Diagram of Mercury Vapour Meter

Schematic Diagram of Mercury Vapour Meter

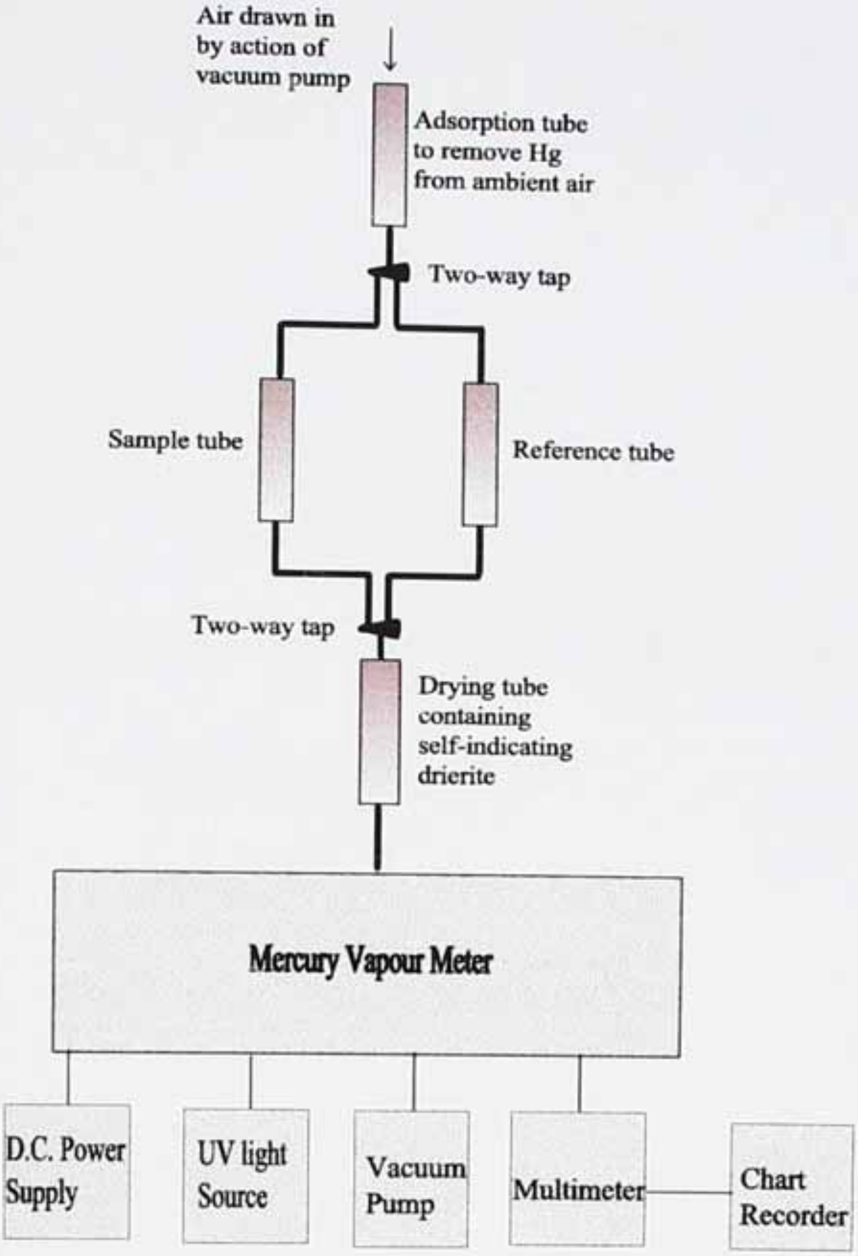


Vapour meter designed and constructed by C.H.James & J.S.Webb, Leicester University [**36**]

Appendix vii

Schematic Diagram of Mercury Vapour Meter and Sampling Train

Schematic Diagram of Mercury Vapour Meter and Sampling Train



Appendix viii

Calculation of Mercury Mass for Calibration of Mercury Vapour Meter

Calculation of Mercury Mass for Calibration of Mercury Vapour Meter

TEMP	VP	MOL	VOL of 1 mol	CONC	CONC	Wt (g) of Hg	Wt (g) ofHg	Wt (g) ofHg	Wt (g) ofHg	Wt (g) ofHg	Wt (g) ofHg
deg C	mm Hg	FRACTION	cm3	Mol Hg cm-3	g Hg cm-3	0.5	1	1.5	2	3	4
20	1.2010E-03	1.580E-06	24056.00	6.5691E-11	1.31382E-08	6.5691E-09	1.31382E-08	1.9707E-08	2.628E-08	3.9415E-08	5.25528E-08
20.2	1.2211E-03	1.607E-06	24072.47	6.67447E-11	1.33489E-08	6.67447E-09	1.33489E-08	2.0023E-08	2.67E-08	4.0047E-08	5.33958E-08
20.4	1.2467E-03	1.640E-06	24088.89	6.80976E-11	1.36195E-08	6.80976E-09	1.36195E-08	2.0429E-08	2.724E-08	4.0859E-08	5.4478E-08
20.6	1.2668E-03	1.667E-06	24105.31	6.91483E-11	1.38297E-08	6.91483E-09	1.38297E-08	2.0744E-08	2.766E-08	4.1489E-08	5.53187E-08
20.8	1.2924E-03	1.701E-06	24121.73	7.04977E-11	1.40995E-08	7.04977E-09	1.40995E-08	2.1149E-08	2.82E-08	4.2299E-08	5.63981E-08
21	1.3235E-03	1.741E-06	24138.15	7.2145E-11	1.4429E-08	7.2145E-09	1.4429E-08	2.1644E-08	2.886E-08	4.3287E-08	5.7716E-08
21.2	1.3309E-03	1.751E-06	24154.57	7.24991E-11	1.44998E-08	7.24991E-09	1.44998E-08	2.175E-08	2.9E-08	4.3499E-08	5.79993E-08
21.4	1.3612E-03	1.791E-06	24170.99	7.40993E-11	1.48199E-08	7.40993E-09	1.48199E-08	2.223E-08	2.964E-08	4.446E-08	5.92794E-08
21.6	1.3852E-03	1.823E-06	24187.42	7.53545E-11	1.50709E-08	7.53545E-09	1.50709E-08	2.2606E-08	3.014E-08	4.5213E-08	6.02836E-08
21.8	1.4072E-03	1.852E-06	24203.84	7.64994E-11	1.52999E-08	7.64994E-09	1.52999E-08	2.295E-08	3.06E-08	4.59E-08	6.11995E-08
22	1.4312E-03	1.883E-06	24220.26	7.775E-11	1.555E-08	7.775E-09	1.555E-08	2.3325E-08	3.11E-08	4.665E-08	6.22E-08
22.2	1.4579E-03	1.918E-06	24236.68	7.91482E-11	1.58296E-08	7.91482E-09	1.58296E-08	2.3744E-08	3.166E-08	4.7489E-08	6.33186E-08
22.4	1.4819E-03	1.950E-06	24253.10	8.03967E-11	1.60793E-08	8.03967E-09	1.60793E-08	2.4119E-08	3.216E-08	4.8238E-08	6.43173E-08
22.6	1.5106E-03	1.988E-06	24269.52	8.18983E-11	1.63797E-08	8.18983E-09	1.63797E-08	2.4569E-08	3.276E-08	4.9139E-08	6.55186E-08
22.8	1.5319E-03	2.016E-06	24285.94	8.29969E-11	1.65994E-08	8.29969E-09	1.65994E-08	2.4899E-08	3.32E-08	4.9798E-08	6.63975E-08
23	1.5606E-03	2.053E-06	24302.36	8.44947E-11	1.68989E-08	8.44947E-09	1.68989E-08	2.5348E-08	3.38E-08	5.0697E-08	6.75958E-08
23.2	1.5848E-03	2.085E-06	24318.78	8.5747E-11	1.71494E-08	8.5747E-09	1.71494E-08	2.5724E-08	3.43E-08	5.1448E-08	6.85976E-08
23.4	1.6182E-03	2.129E-06	24335.20	8.74951E-11	1.7499E-08	8.74951E-09	1.7499E-08	2.6249E-08	3.5E-08	5.2497E-08	6.99961E-08
23.6	1.6471E-03	2.167E-06	24351.62	8.89976E-11	1.77995E-08	8.89976E-09	1.77995E-08	2.6699E-08	3.56E-08	5.3399E-08	7.11981E-08
23.8	1.6667E-03	2.193E-06	24368.04	8.9996E-11	1.79992E-08	8.9996E-09	1.79992E-08	2.6999E-08	3.6E-08	5.3998E-08	7.19968E-08
24	1.6910E-03	2.225E-06	24384.46	9.12466E-11	1.82493E-08	9.12466E-09	1.82493E-08	2.7374E-08	3.65E-08	5.4748E-08	7.29973E-08
24.2	1.7246E-03	2.269E-06	24400.88	9.29971E-11	1.85994E-08	9.29971E-09	1.85994E-08	2.7899E-08	3.72E-08	5.5798E-08	7.43977E-08
24.4	1.7536E-03	2.307E-06	24417.30	9.44973E-11	1.88995E-08	9.44973E-09	1.88995E-08	2.8349E-08	3.78E-08	5.6698E-08	7.55978E-08
24.6	1.7919E-03	2.358E-06	24433.72	9.64963E-11	1.92993E-08	9.64963E-09	1.92993E-08	2.8949E-08	3.86E-08	5.7898E-08	7.7197E-08
24.8	1.8117E-03	2.384E-06	24450.14	9.7497E-11	1.94994E-08	9.7497E-09	1.94994E-08	2.9249E-08	3.9E-08	5.8498E-08	7.79976E-08
25	1.8501E-03	2.434E-06	24466.56	9.94967E-11	1.98993E-08	9.94967E-09	1.98993E-08	2.9849E-08	3.98E-08	5.9698E-08	7.95974E-08
25.2	1.8793E-03	2.473E-06	24482.98	1.00999E-10	2.01999E-08	1.00999E-08	2.01999E-08	3.03E-08	4.04E-08	6.06E-08	8.07994E-08
25.4	1.9084E-03	2.511E-06	24499.41	1.02494E-10	2.04989E-08	1.02494E-08	2.04989E-08	3.0748E-08	4.1E-08	6.1497E-08	8.19955E-08

Calculation of Mercury Mass for Calibration of Mercury Vapour Meter

TEMP	VP	MOL	VOL of 1 mol	CONC	CONC	Wt (g) of Hg	Wt (g) ofHg	Wt (g) ofHg	Wt (g) ofHg	Wt (g) ofHg	Wt (g) ofHg
deg C	mm Hg	FRACTION	cm3	Mol Hg cm-3	g Hg cm-3	0.5	1	1.5	2	3	4
25.6	1.9470E-03	2.562E-06	24515.83	1.04497E-10	2.08995E-08	1.04497E-08	2.08995E-08	3.1349E-08	4.18E-08	6.2698E-08	8.3598E-08
25.8	1.9762E-03	2.600E-06	24532.25	1.05994E-10	2.11987E-08	1.05994E-08	2.11987E-08	3.1798E-08	4.24E-08	6.3596E-08	8.47949E-08
26	2.0056E-03	2.639E-06	24548.67	1.07499E-10	2.14997E-08	1.07499E-08	2.14997E-08	3.225E-08	4.3E-08	6.4499E-08	8.59989E-08
26.2	2.0405E-03	2.685E-06	24565.09	1.09296E-10	2.18592E-08	1.09296E-08	2.18592E-08	3.2789E-08	4.372E-08	6.5578E-08	8.74369E-08
26.4	2.0736E-03	2.728E-06	24581.51	1.10995E-10	2.2199E-08	1.10995E-08	2.2199E-08	3.3298E-08	4.44E-08	6.6597E-08	8.87959E-08
26.6	2.1077E-03	2.773E-06	24597.93	1.12745E-10	2.2549E-08	1.12745E-08	2.2549E-08	3.3823E-08	4.51E-08	6.7647E-08	9.01959E-08
26.8	2.1419E-03	2.818E-06	24614.35	1.14498E-10	2.28996E-08	1.14498E-08	2.28996E-08	3.4349E-08	4.58E-08	6.8699E-08	9.15983E-08
27	2.1770E-03	2.864E-06	24630.77	1.16297E-10	2.32593E-08	1.16297E-08	2.32593E-08	3.4889E-08	4.652E-08	6.9778E-08	9.30372E-08
27.2	2.2122E-03	2.911E-06	24647.19	1.18098E-10	2.36196E-08	1.18098E-08	2.36196E-08	3.5429E-08	4.724E-08	7.0859E-08	9.44786E-08
27.4	2.2483E-03	2.958E-06	24663.61	1.19946E-10	2.39891E-08	1.19946E-08	2.39891E-08	3.5984E-08	4.798E-08	7.1967E-08	9.59564E-08
27.6	2.2836E-03	3.005E-06	24680.03	1.21748E-10	2.43495E-08	1.21748E-08	2.43495E-08	3.6524E-08	4.87E-08	7.3049E-08	9.73982E-08
27.8	2.3208E-03	3.054E-06	24696.45	1.23649E-10	2.47297E-08	1.23649E-08	2.47297E-08	3.7095E-08	4.946E-08	7.4189E-08	9.8919E-08
28	2.3590E-03	3.104E-06	24712.87	1.256E-10	2.51201E-08	1.256E-08	2.51201E-08	3.768E-08	5.024E-08	7.536E-08	1.0048E-07

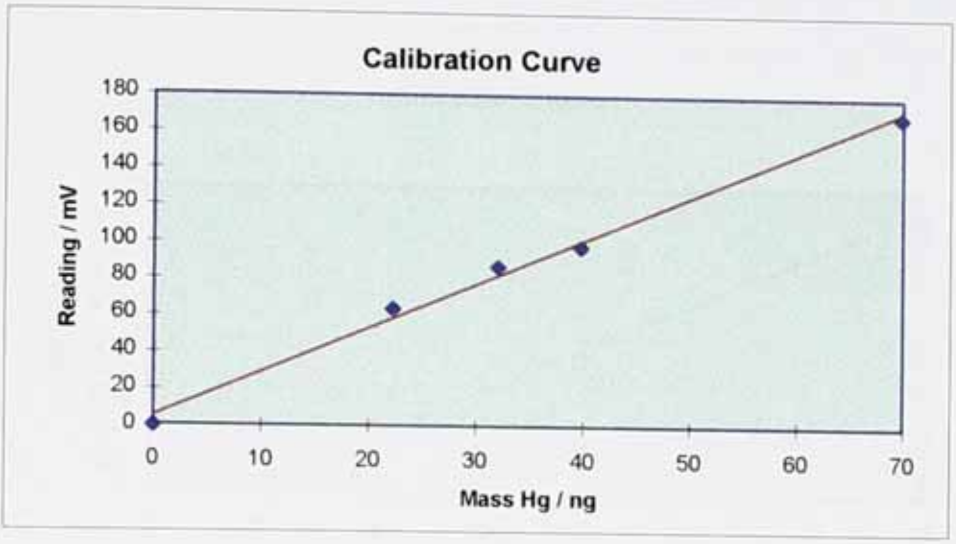
Appendix ix

Mercury Vapour Meter Calibration

Mercury Vapour Meter Calibration

Data

Vol Hg/cm3	Temp/oC	Mass Hg/ng	Reading/mV
0.00	-	0	0
2.00	25	39.8	98
1.50	25.9	32	87
1.00	26.4	22.2	64
3.00	27	69.8	170

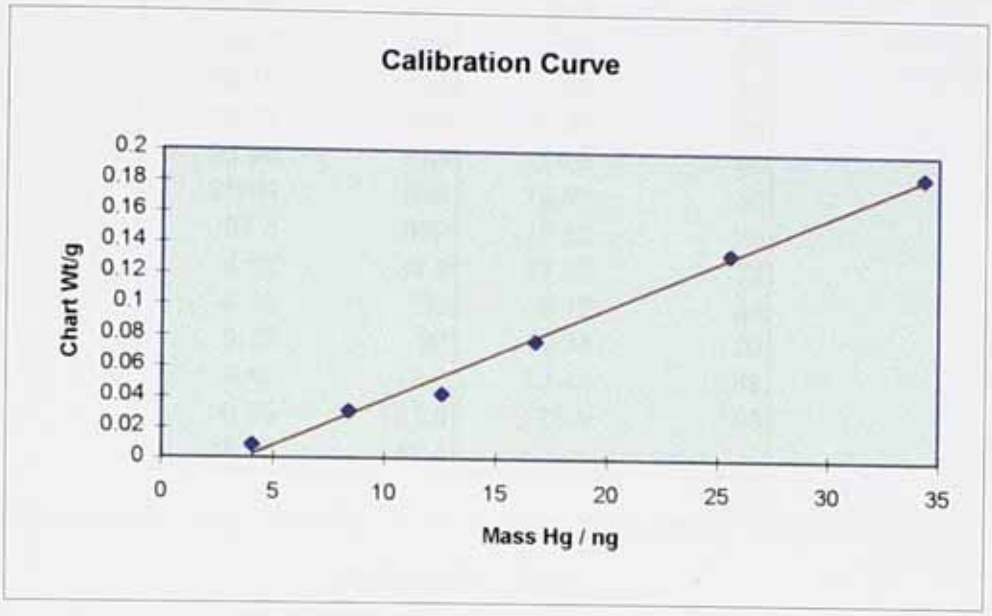


Regression Equation: $y = 2.3955x + 5.3222$ R2 = 0.9935

Mercury Vapour Meter Calibration

Data

Vol Hg/cm3	Temp/oC	Mass Hg/ng	Chart wt/g
0.25	22.5	4.0574	0.0089
0.50	22.9	8.3746	0.0309
0.75	22.9	12.562	0.0426
1.00	22.9	16.749	0.0773
1.50	23.1	25.536	0.1345
2.00	23.2	34.299	0.186

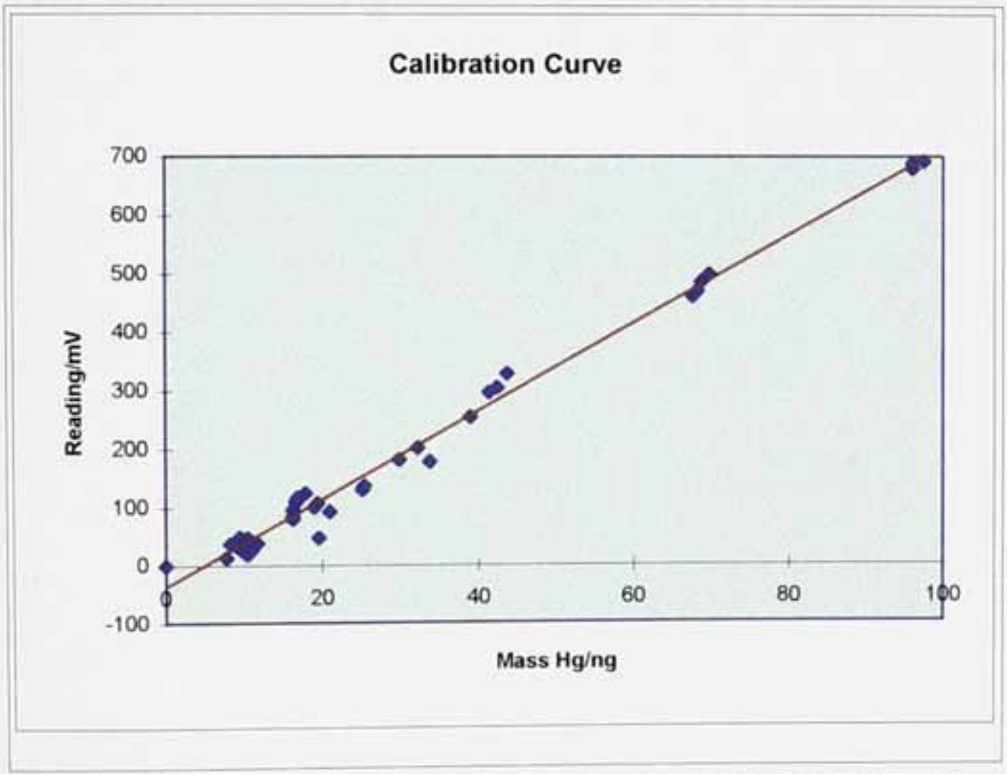


Regression Equation: $y = 0.006x - 0.022$ $R2 = 0.9921$

Mercury Vapour Meter Calibration

Data

Hg/ng	Reading/mV	Hg/ng	Reading/mV
16.23	96	0	0
16.6	110	32.25	202
16.6	111	18.95	100.3
16.9	118	7.72	14
17.8	125	16.23	85
39	254	16.23	80
41.4	297	8.19	38
42.4	305	25.13	130
43.72	328	25.35	137
67.65	461	33.8	178
68.7	486	9.95	39
68.18	470	9.95	24
69.78	498	10.35	26
95.96	689	19.5	48
95.96	680	10.93	36
97.4	692	10.93	28
9.12	34.9	11.63	39
9.12	33	9.12	34
9.12	36	10.34	20
9.45	49.3	10.44	48
19.35	107.5	20.9	93
29.85	181.4		



Regression Equation: y =7.5245x - 37.319 R2 = 0.9904

Appendix x

Control Sample Soil Results - Data and Calculations

Soil Mercury Content - Control Samples

	Moisture Content							Hg Content							
Sample No.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sampl + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	ample no.	Wet Wt grams	Reading Chart wt	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Standard Deviatio	Coef. Var.
1	48.4653	42.1	6.3164	48.1342	5.9853	5.2419	1a	0.056	0.06072	13.787	246.190	259.809			
							b	0.062	0.0744	16.067	259.140	273.475	266.64	9.66	3.62
2	51.0533	45.8	5.2888	50.5928	4.8283	8.7071	2a	0.035	0.01524	6.207	177.333	194.247			
							b	0.041	0.02024	7.040	171.707	188.084	191.17	4.36	2.28
3	44.6834	41.7	3.0089	44.3218	2.6473	12.0177	3a	0.032	0.0101	5.350	167.188	190.024			
							b	0.03	0.01161	5.602	186.722	212.227	201.13	15.70	7.81
4	51.3821	42.2	9.2216	50.5634	8.4029	8.8781	4a	0.035	0.04107	10.512	300.333	329.595			
							b	0.037	0.0503	12.050	325.676	357.406	343.50	19.67	5.73
5	50.8459	44.9	5.9281	50.3745	5.4567	7.9520	5a	0.056	0.05632	13.053	233.095	253.232			
							b	0.056	0.0612	13.867	247.619	269.011	261.12	11.16	4.27

Soil Mercury Content - Control Samples

Sample No.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sampl + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	ample no.	Wet Wt grams	Reading Chart wt	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Standard Deviatio	Coef. Var.
6	46.2943	42.2	4.1187	46.0082	3.8326	6.9464	6a	0.051	0.07834	16.723	327.908	352.387			
							b	0.052	0.07832	16.720	321.538	345.541	348.96	4.84	1.39
7	47.4678	41.9	5.5658	47.1023	5.2003	6.5669	7a	0.056	0.03978	10.297	183.869	196.792			
							b	0.047	0.03856	10.093	214.752	229.845	213.32	23.37	11
8	52.0453	42.2	9.8419	51.3427	9.1393	7.1389	8a	0.047	0.07456	16.093	342.411	368.735			
							b	0.049	0.0832	17.533	357.823	385.331	377.03	11.74	3.11
	Regression Equation: $y = 0.006x - 0.022$										Overall mean		275.36	72.83	26.4

Appendix xi

Northampton Crematorium Soil Results - Data and Calculations

Counties Crematorium, Northampton - Soil Mercury Content

	Moisture Content						Mercury Content								
Sample No.	Wet Sampl +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sampl +tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	Reading mV	Hg content nanograms	Hg Content ng / g wet sample	Hg content ng / g dry sample	Mean Hg content ng / g dry sample	Stand. Dev.	Coef. Var.
1	53.7939	42.7332	11.0607	53.5238	10.7906	2.4420	1a	0.017	24.9	8.269	486.436	498.612			
							b	0.017	35.1	9.625	566.180	580.352			
							c	0.018	28.8	8.788	488.208	500.428			
							d	0.042	91	17.055	406.063	416.227	498.90	67.01	13.43
2	49.0411	42.3291	6.712	48.8898	6.5607	2.2542	2a	0.022	40	10.276	467.105	477.877			
							b	0.022	22	7.884	358.362	366.627			
							c	0.022	37	9.878	448.981	459.336	434.61	59.60	13.71
3	51.7766	42.4151	9.3615	51.5822	9.1671	2.0766	3a	0.018	27	8.549	474.917	484.989			
							b	0.018	26	8.416	467.534	477.448			
							c	0.017	29	8.814	518.490	529.485	497.31	28.12	5.65
4	60.4737	45.9094	14.5643	60.1185	14.2091	2.4388	4a	0.038	38.8	10.117	266.232	272.888			
							b	0.015	28.1	8.695	579.647	594.137			
							c	0.018	23	8.017	445.382	456.516	441.18	161.17	36.53
5	55.0007	45.904	9.0967	54.701	8.797	3.2946	5a	0.015	12	2.788	185.848	192.180			
							b	0.023	18	5.292	230.105	237.945			
							c	0.021	16	4.458	212.263	219.495			
							d	0.052	68	13.998	269.187	278.358	231.99	36.18	15.59

Counties Crematorium, Northampton - Soil Mercury Content

Sample No.	Wet Sampl +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sampl +tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	Reading mV	Hg content nanograms	Hg Content ng / g wet sample	Hg content ng / g dry sample	Mean Hg content ng / g dry sample	Stand. Dev.	Coef. Var.
6	51.657	42.1387	9.5183	51.3904	9.2517	2.8009	6a	0.026	47	11.207	431.026	443.446			
							b	0.033	65	13.599	412.091	423.966			
							c	0.021	45.4	10.994	523.525	538.611	468.67	61.34	13.09
7	55.0385	45.9214	9.1171	54.8038	8.8824	2.5743	7a	0.022	27	9.049	411.339	422.208			
							b	0.02	20	6.127	306.366	314.461			
							c	0.02	22	6.962	348.111	357.309			
							d	0.049	81	15.726	320.929	329.409	355.85	47.67	13.40
8	50.0369	42.7575	7.2794	49.8814	7.1239	2.1362	8a	0.028	28	9.467	338.104	345.484			
							b	0.011	12	2.788	253.430	258.962			
							c	0.025	27	9.049	361.979	369.880			
							d	0.049	38	13.641	278.396	284.473	314.70	51.68	16.42
										Overall mean			405.40	95.68	23.60

Regression Equations

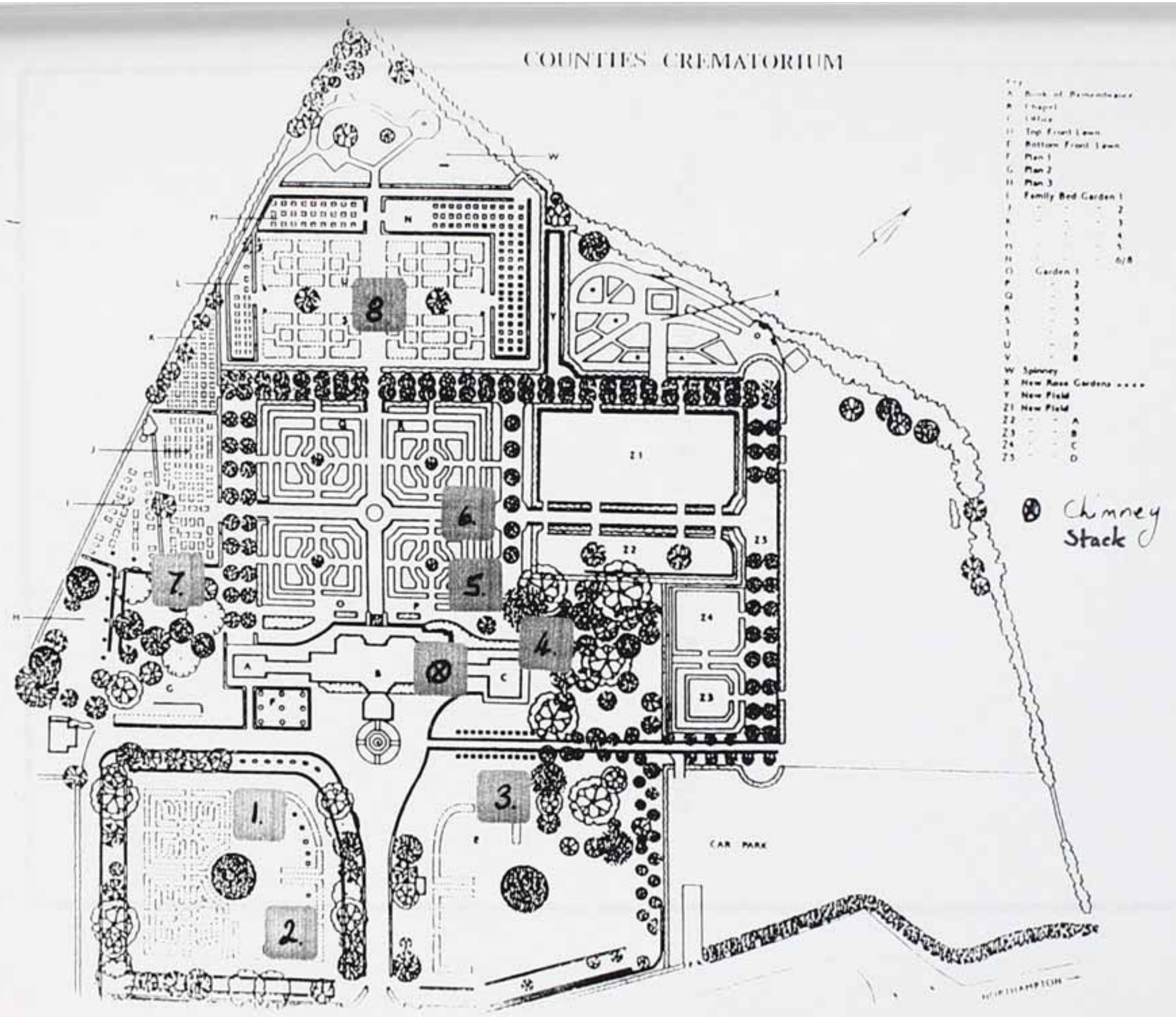
$y = 7.524452x - 37.319476$, $r2 = .990384$

$y = 2.395536x + 5.322239$, $r2 = .993541$

Appendix xii

Northampton Crematorium Plan with Sample Positions

COUNTIES CREMATORIUM

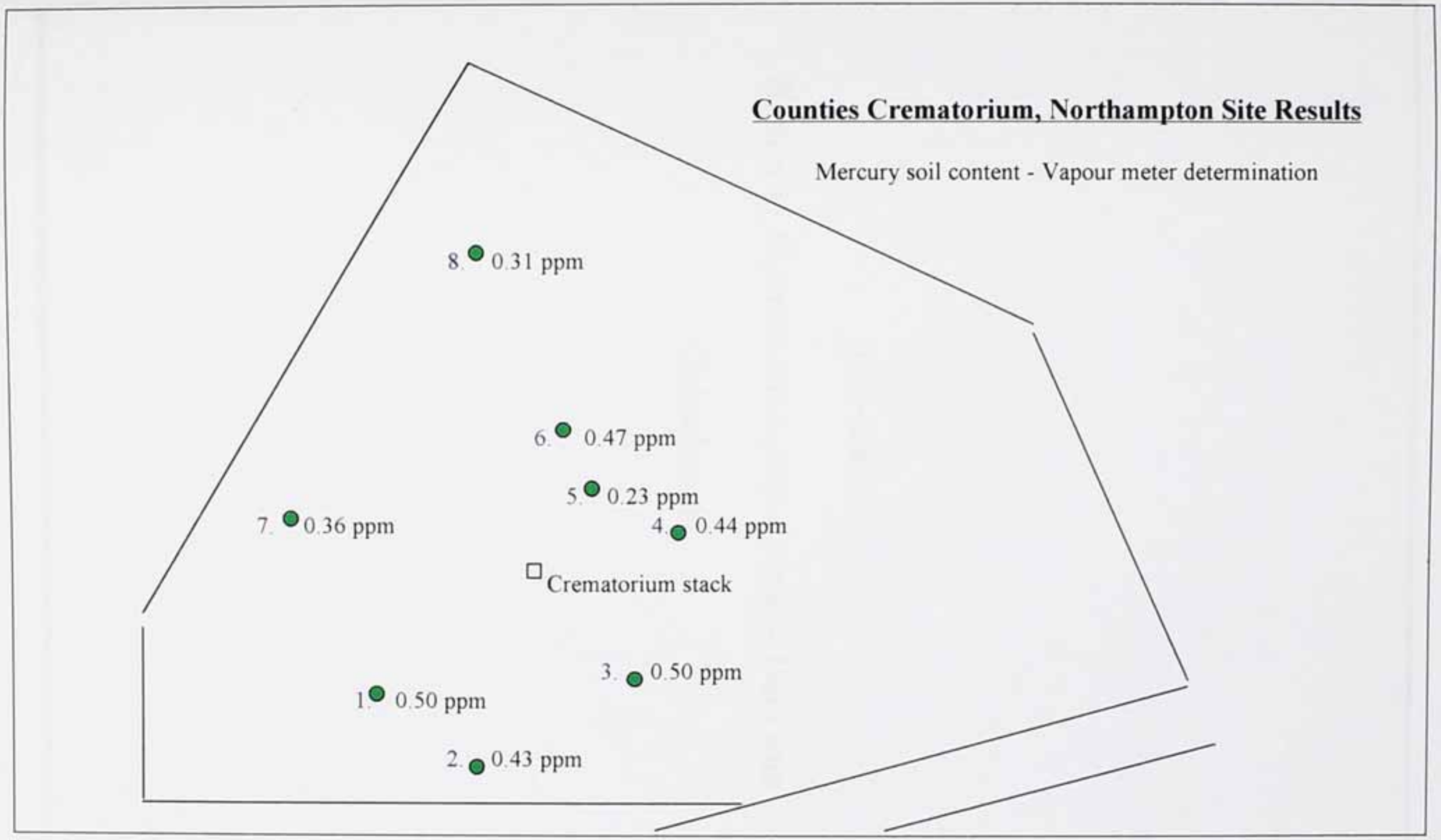


Appendix xiii

Northampton Crematorium Soil Results Plan

Counties Crematorium, Northampton Site Results

Mercury soil content - Vapour meter determination



Appendix xiv

Kettering Crematorium Soil Results - Data and Calculations

Kettering Soil Content

	Moisture Content							Hg Content							
No.	Wet Sample +tin Wt/g	Tin Wt / g	Wet Sample Weight / g	Dry Sample + Tin Wt / g	Dry Sample Weight / g	Percent Moisture	No.	Wet Wt / g	Reading mV	Hg content / ng	Hg Content ng / g wet sample	Hg content ng / g dry sample	Mean Hg content ng/g dry sample	Std Dev	Coef. Var
1	52.0835	45.922	6.1615	51.8371	5.9151	3.9990	1a	0.011	51	11.738	1067.119	1111.571			
							b	0.022	71	14.396	654.385	681.644			
							c	0.034	80	15.593	458.607	477.711	756.98	323.57	42.74
2	54.8465	45.927	8.9198	54.6657	8.739	2.0270	2a	0.017	34	9.479	557.580	569.116			
							b	0.025	49	11.472	458.900	468.394			
							c	0.019	44	10.808	568.839	580.608	539.37	61.73	11.45
3	49.3247	42.417	6.9075	49.0288	6.6116	4.2837	3a	0.022	23	11.823	537.413	561.465			
							b	0.021	23	11.823	563.004	588.201			
							c	0.024	27	13.493	562.203	587.365	579.01	15.20	2.62
4	53.4393	45.911	7.5279	53.1662	7.2548	3.6278	4a	0.016	71	14.396	899.779	933.650			
							b	0.011	41	10.409	946.293	981.915			
							c	0.015	65	13.599	906.601	940.729	952.10	26.06	2.74

Kettering Soil Content

No.	Wet Sample +tin Wt/g	Tin Wt / g	Wet Sample Weight / g	Dry Sample + Tin Wt / g	Dry Sampl Weight / g	Percent Moisture	No.	Wet Wt / g	Reading mV	Hg content / ng	Hg Content ng / g wet sample	Hg content ng / g dry sample	Mean Hg content ng/g dry sample	Std Dev	Coef. Var
5	47.8502	42.345	5.5048	47.3863	5.0409	8.4272	5a	0.013	60	22.825	1755.792	1917.373			
							b	0.024	84	32.844	1368.503	1494.443			
							c	0.02	81	31.592	1579.587	1724.952	1712.26	211.75	12.37
6	48.2765	42.332	5.9445	48.0909	5.7589	3.1222	6a	0.023	50	11.605	504.582	520.844			
							b	0.017	35	9.612	565.399	583.620			
							c	0.019	38	10.010	526.868	543.849	549.44	31.76	5.78
7	44.7363	42.743	1.9931	44.629	1.8858	5.3836	7a	0.02	24	7.797	389.856	412.038			
							b	0.017	22	6.962	409.542	432.845			
							c	0.022	29	9.884	449.289	474.853	439.91	31.99	7.27
8	42.5417	41.91	0.6316	42.4851	0.575	8.9614	8a	0.021	226	34.997	1666.534	1830.579			
							b	0.013	170	27.554	2119.566	2328.205			
		Regression Equations					c	0.017	192	30.478	1792.843	1969.321	2042.7	256.68	12.57
		y = 7.524452x - 37.319476, r2 = .990384													
		y = 2.395536x + 5.322239, r2 = .993541													
											Overall mean		946.47	602.27	63.63

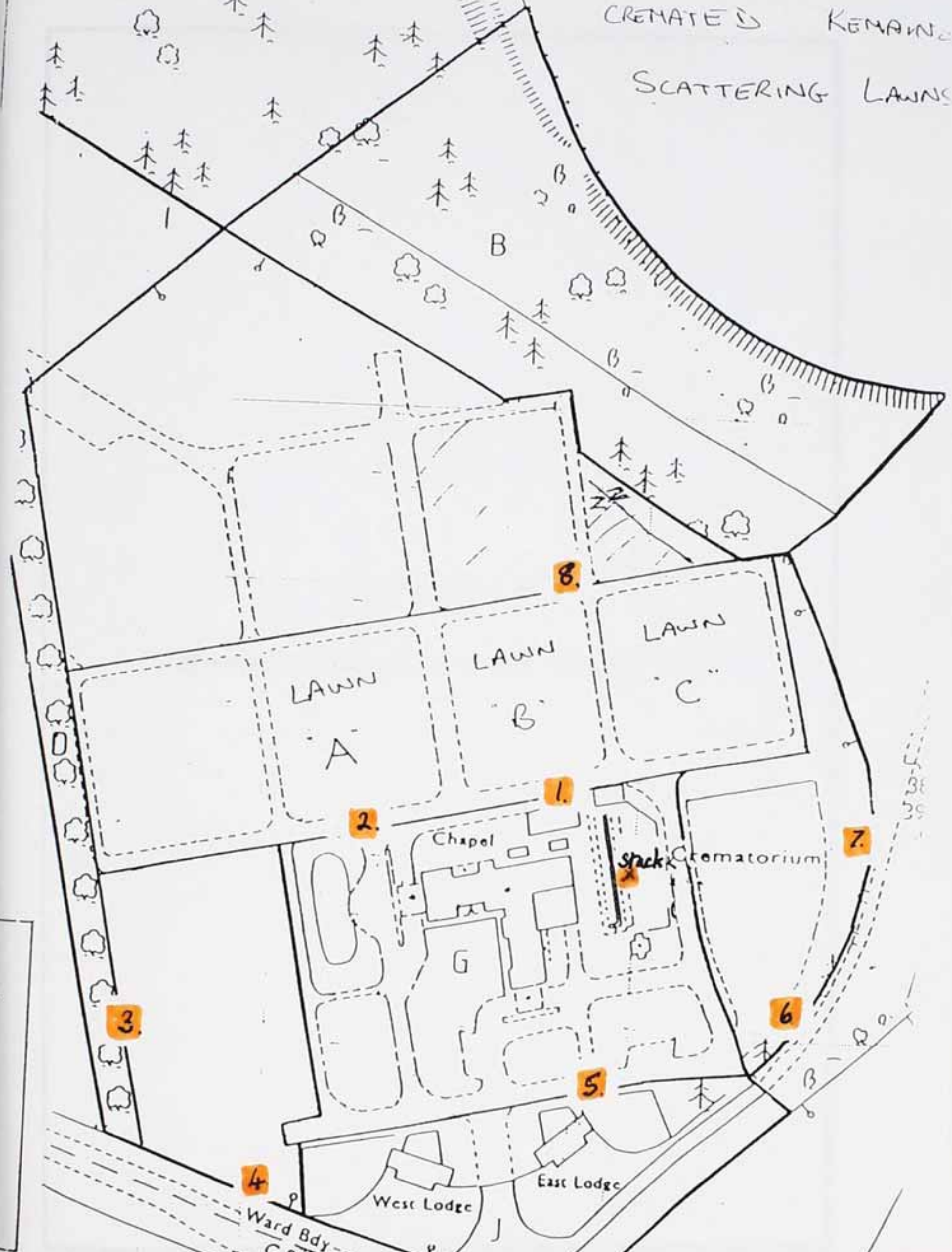
Appendix xv

Kettering Crematorium Plan with Sample Positions

Kettering Crematorium

CREMATED REMAIN

SCATTERING LAWNS

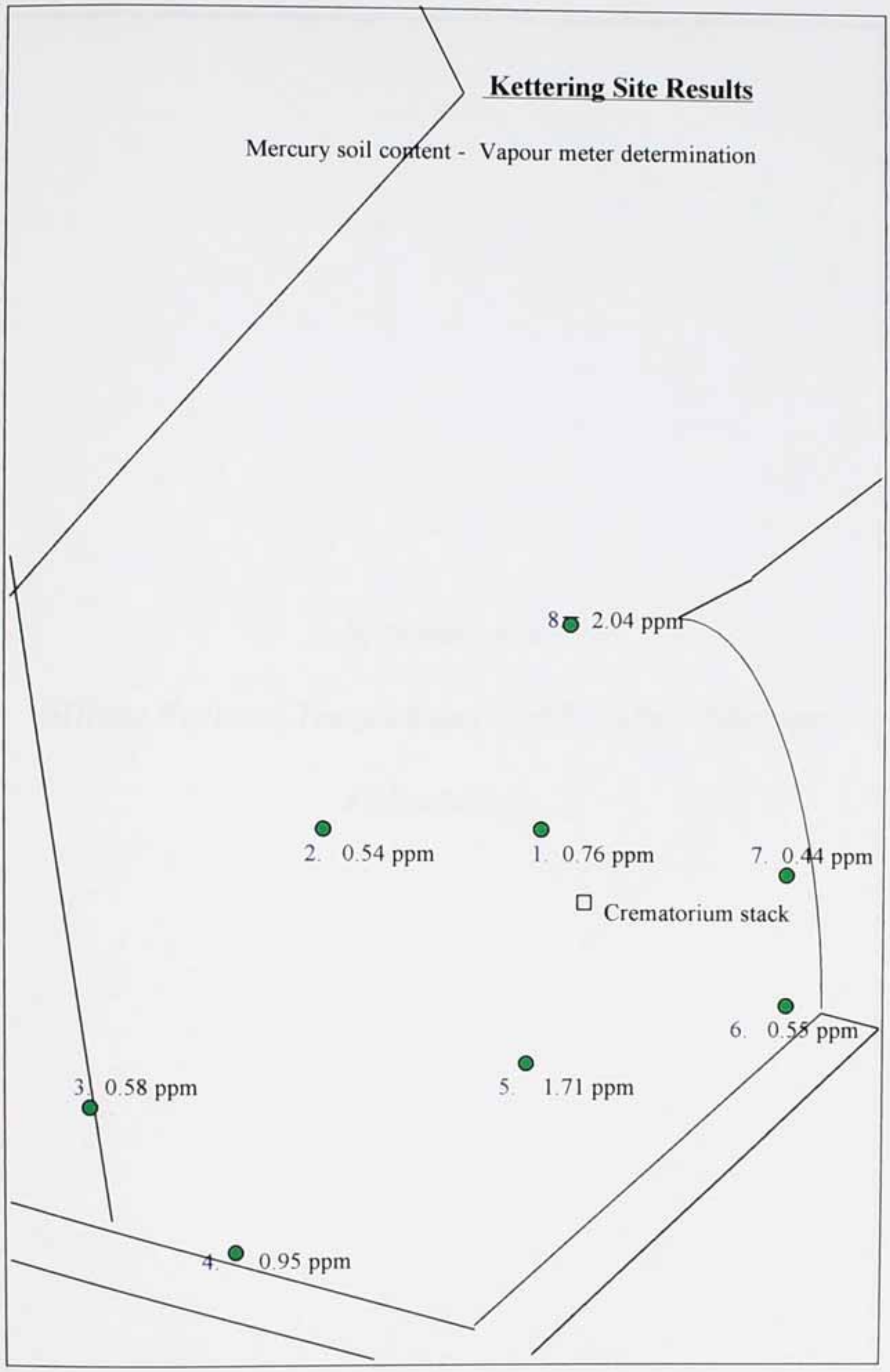


Appendix xvi

Kettering Crematorium Soil Results Plan

Kettering Site Results

Mercury soil content - Vapour meter determination



Appendix xvii

Milton Keynes Crematorium Soil Results - Data and Calculations

Milton Keynes Crematorium - Mercury Soil Content

	Moisture Content						Mercury Content									
Sample No.	Wet Sample + tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sample +tin Wt. / g	Dry Sample Wt / g	Moisture Content Percentage	Sample No.	Wet Wt /g	Chart wt. /g	Hg content /ng	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Std Dev.	Coef. Var.
1	52.0835	45.9	6.1615	51.8371	5.9151	3.9990	1a	0.026	0.088	18.333	705.128	734.501			
							b	0.024	0.1345	26.083	1086.806	1132.078			
							c	0.024	0.1298	25.300	1054.167	1098.079	988.22	220.38	22.3
2	54.8465	45.9	8.9198	54.6657	8.739	2.0269513	2a	0.026	0.0819	17.317	666.026	679.805			
							b	0.026	0.1199	23.650	909.615	928.434			
							c	0.026	0.1058	21.300	819.231	836.180	814.81	125.69	15.4
3	49.3247	42.4	6.9075	49.0288	6.6116	4.2837	3a	0.029	0.1477	28.283	975.287	1018.936			
							b	0.028	0.1356	26.267	938.095	980.079			
							c	0.029	0.1491	28.517	983.333	1027.342	1008.79	25.213	2.5
4	53.4393	45.9	7.5279	53.1662	7.2548	3.6278	4a	0.043	0.1144	22.733	528.682	548.584			
							b	0.033	0.0723	15.717	476.263	494.191			
							c	0.036	0.0963	19.717	547.685	568.302	537.03	38.384	7.1

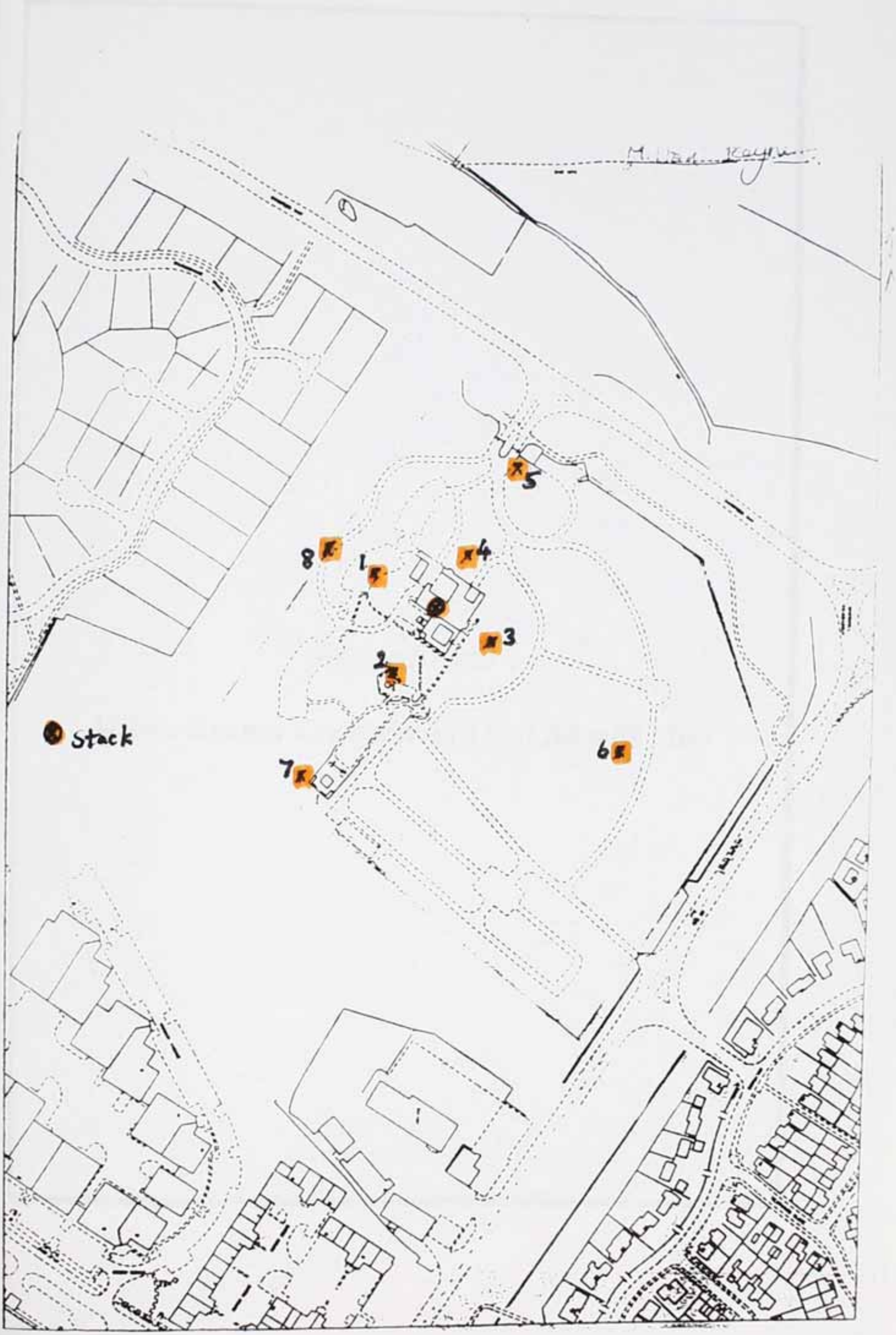
Milton Keynes Crematorium - Mercury Soil Content

Sample No.	Wet Sample + tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sample +tin Wt. / g	Dry Sample Wt / g	Moisture Content Percentage	Sample No.	Wet Wt /g	Chart wt. /g	Hg content /ng	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Std Dev.	Coef. Var.
5	47.8502	42.3	5.5048	47.3863	5.0409	8.4272	5a	0.047	0.1894	35.233	749.645	818.633			
							b	0.026	0.0715	15.583	599.359	654.516			
							c	0.03	0.1055	21.250	708.333	773.519	748.89	84.785	11.3
6	48.2765	42.3	5.9445	48.0909	5.7589	3.1222	6a	0.012	0.6757	116.283	9690.278	10002.580			
							b	0.011	0.8297	141.950	12904.545	13320.438			
							c	0.012	0.7623	130.717	10893.056	11244.121	11522.38	1676.3	14.5
7	44.7363	42.7	1.9931	44.629	1.8858	5.3836	7a	0.03	0.2546	46.100	1536.667	1624.101			
							b	0.03	0.2061	38.017	1267.222	1339.326			
							c	0.03	0.2345	42.750	1425.000	1506.081	1489.84	143.08	9.6
8	42.5417	41.9	0.6316	42.4851	0.575	8.9614	8a	0.029	0.0805	17.083	589.080	647.066			
							b	0.036	0.1824	34.067	946.296	1039.445			
							c	0.03	0.0898	18.633	621.111	682.250	789.59	217.1	27.5
	Regression Equation: y = 0.006x - 0.022, r2 = .99										***Overall mean**		911.02	300.2	33.0
											*Excludes Sample 6				

Appendix xviii

Milton Keynes Crematorium Plan with Sample Positions

Milton Keynes Crematorium

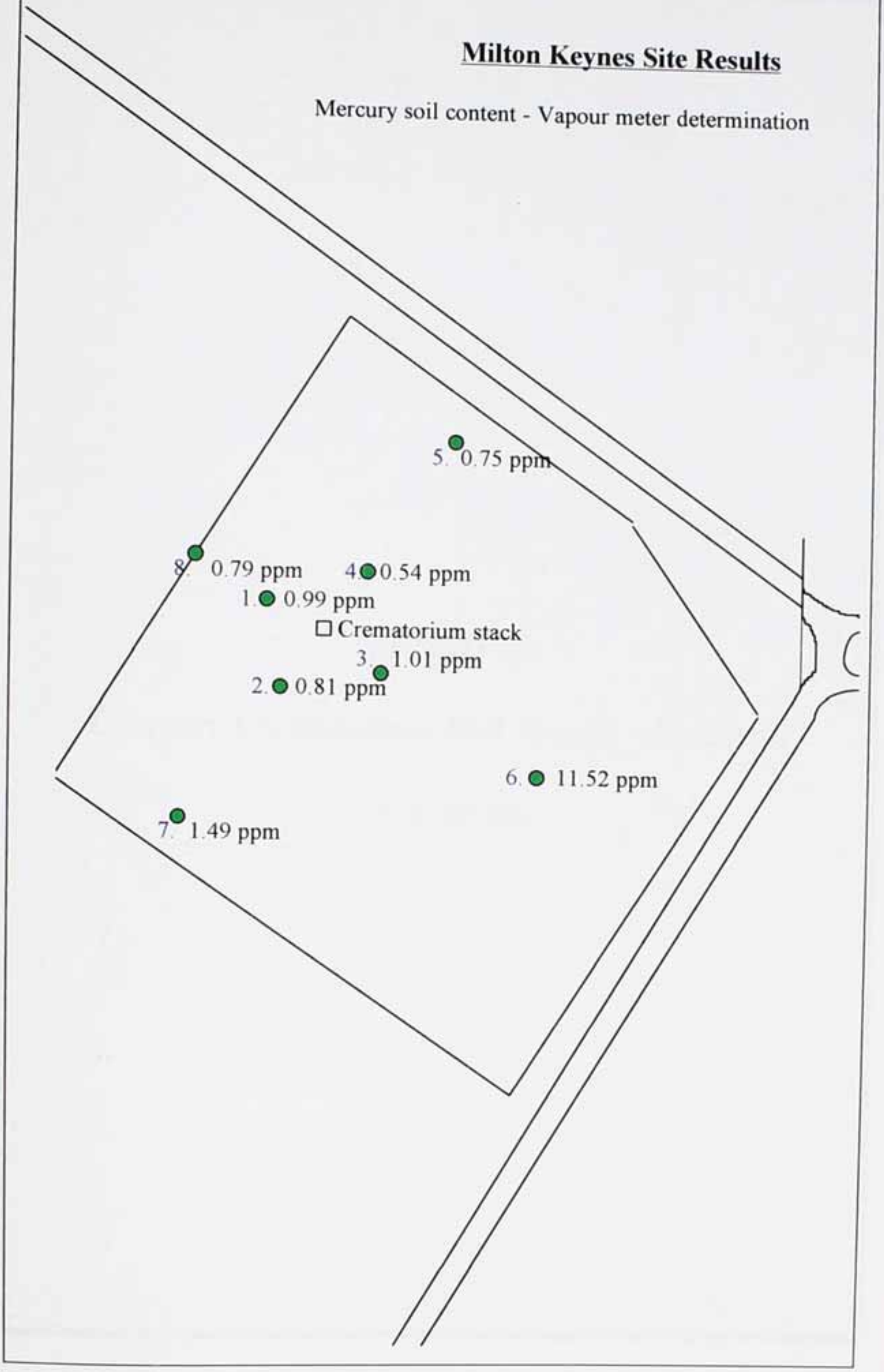


Appendix xix

Milton Keynes Crematorium Soil Results Plan

Milton Keynes Site Results

Mercury soil content - Vapour meter determination



Appendix xx

Coventry Crematorium Soil Results - Data and Calculations

Coventry Soil Results (Vapour Meter)

		Moisture Content							Hg Content						
Sample no.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sample + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	Reading Chart wt	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Standard Deviation	Coef. Var.
1	51.9182	42.1489	9.7693	51.5906	9.4417	3.3534	**1a**	0.018	0.10365	20.942	1163.426	1203.793			
							b	0.018	0.10928	21.880	1215.556	1257.732	1230.76	38.14	3.1
2	51.1066	45.9857	5.1209	50.9508	4.9651	3.0424	**2a**	0.019	0.08029	17.048	897.281	925.436			
							b	0.018	0.07554	16.257	903.148	931.488	928.462	4.28	0.5
3	43.6369	42.2708	1.3661	43.4896	1.2188	10.7825	**3a**	0.005	0.21455	39.425	7885.000	8837.954			
							b	0.004	0.16268	30.780	7695.000	8624.991	8731.473	150.59	1.7
4	50.2921	42.1508	8.1413	50.1207	7.9699	2.1053	**4a**	0.037	0.15203	29.005	783.919	800.778			
							b	0.036	0.13015	25.358	704.398	719.547	760.163	57.44	7.6
5	58.0713	42.3513	15.72	57.8	15.4487	1.7258	**5a**	0.023	0.07605	16.342	710.507	722.985			
							b	0.023	0.06787	14.978	651.232	662.668	692.827	42.650	6.1
6	47.6702	42.1556	5.5146	47.4473	5.2917	4.0420	**6a**	0.023	0.17882	33.470	1455.217	1516.515			
							b	0.024	0.22692	41.487	1728.611	1801.425	1658.97	201.46	12.1

Coventry Soil Results (Vapour Meter)

Sample no.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sample + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	Reading Chart wt	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Standard Deviation	Coef. Var.
7	50.6435	41.9022	8.7413	50.437	8.5348	2.3623	**7a**	0.033	0.16605	31.342	949.747	972.727			
							b	0.028	0.15632	29.720	1061.429	1087.110	1029.919	80.880	7.8
8	50.1011	42.2554	7.8457	49.8372	7.5818	3.3636	**8a**	0.026	0.21192	38.987	1499.487	1551.680			
							b	0.031	0.27699	49.832	1607.473	1663.424	1607.552	79.01	4.9
9	55.3892	43.1908	12.1984	55.1387	11.9479	2.0535	**9a**	0.025	0.2008	37.133	1485.333	1537.033			
							b	0.028	0.2189	40.150	1433.929	1483.839	1510.436	37.61	2.49
10	51.4739	43.7590	7.7149	51.1537	7.3947	4.1504	**10a**	0.026	0.2067	38.117	1466.026	1517.054			
							b	0.027	0.2081	38.350	1420.370	1469.809	1493.431	33.41	2.237
												***Overall mean**	1212.502	372.845	30.75

Regression Equation: $y = 0.006x - 0.22$ $r2 = 0.992$

*Excludes sample 3

Appendix xxi

Coventry Crematorium Soil results - CVAAS - Data and Calculations

Coventry Soil Results (CVAAS)

		Moisture Content								**Hg Content**					
Sample No.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sample + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	AA Units	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Standard Deviation	Coef. Var.
1	54.0863	43.8455	10.2408	53.8609	10.0154	2.2010	1a	3.468	8	1212.12	349.52	357.38			
							b	3.189	12	1818.18	570.14	582.97	470.18	159.52	33.93
2	75.2765	66.157	9.1195	72.9959	6.8389	25.0079	2a	2.6492	8	1212.12	457.54	610.12			
							b	2.6499	17	1647.29	621.64	828.94	719.53	154.73	21.5
3	43.6369	42.2708	1.3661	43.4896	1.2188	10.7825	3a	1.2288	9	1363.64	1109.73	1243.85			
							b	1.22	12	1818.18	1490.31	1670.43	1457.14	301.64	20.7
4	61.8884	45.7452	16.1432	61.4404	15.6952	2.7752	4a	3.4536	19	1841.09	533.09	548.31			
							b	3.4305	12	1818.18	530.00	545.13	546.72	2.24	0.41
5	61.195	48.9237	12.2713	60.6165	11.6928	4.7143	5a	3.6496	25	3063.73	839.47	881.00			
							b	3.5115	24	2941.18	837.58	879.02	880.01	1.40	0.16
6	56.7818	50.0973	6.6845	55.8145	5.7172	14.4708	6a	2.5573	36	4411.76	1725.17	2017.05			
							b	2.5794	37	4534.31	1757.89	2055.32	2036.18	27.06	1.329

Coventry Soil Results (CVAAS)

Sample No.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sample + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	AA Units	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Standard Deviation	Coef. Var.
7	39.7435	32.912	6.8315	37.755	4.843	29.1078	**7a**	1.3137	13	1259.69	958.89	1352.60			
							b	1.2456	12	1162.79	933.52	1316.81	1334.71	25.30	1.896
8	55.3508	46.8548	8.496	54.1445	7.2897	14.1984	**8a**	3.4942	34	4086.54	1169.52	1363.05			
							b	3.4158	29	3485.58	1020.43	1189.29	1276.17	122.87	9.628
9	54.6587	43.376	11.2827	53.389	10.013	11.2535	**9a**	3.2781	36	4326.92	1319.95	1538.37			
							b	3.1452	35	4206.73	1337.51	1558.84	1548.61	14.47	0.93
10	43.0387	32.7945	10.2442	41.3759	8.5814	16.2316	**10a**	2.9482	31	3725.96	1263.81	1472.94			
							b	2.8471	30	3605.77	1266.47	1476.05	1474.50	2.19	0.15
											Overall Mean		1174.37	502.464	42.79

Appendix xxii

Air Samples - Results, Calculations, Calibration Data and Graphs

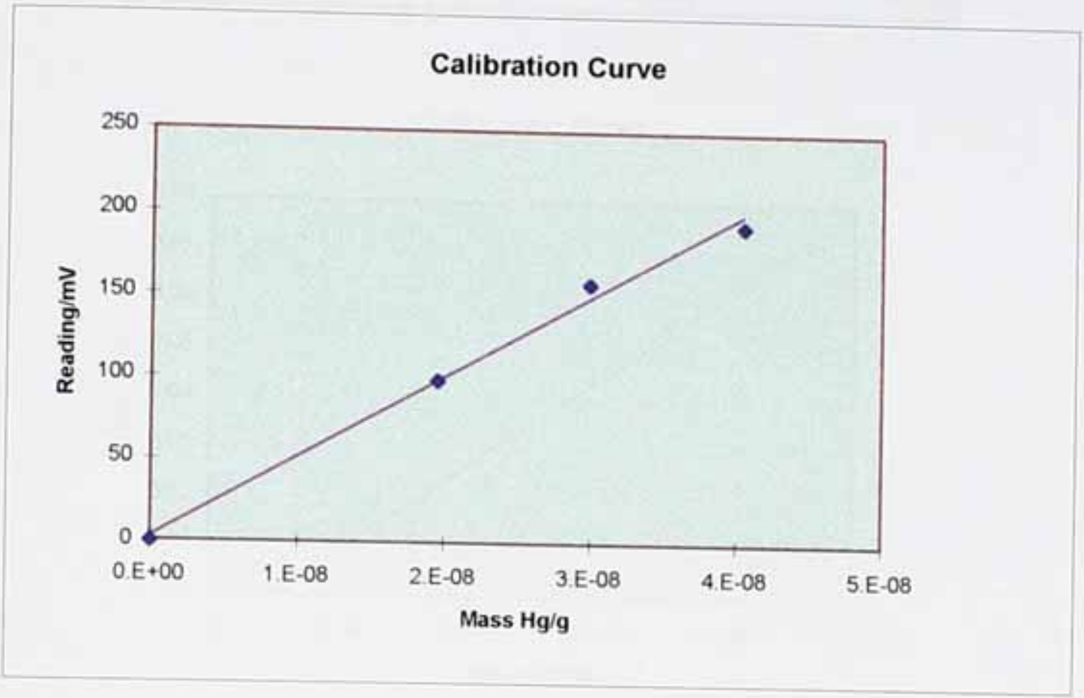
Air samples - Results

Sample no	Flow rate/	Start time	Time/	Volume/	Chart wt/g	Reading/	Calibrati	Hg content/	Conc Hg	Mean Hg
	l/min	min	min	m3		mV	curve	ng	ng/m3	concs
London 1	2		30	0.06		859	iii	147	2458	
London 2	2		15	0.03		2500	iii *	415	13844	
London 3	2		10	0.02		1256	iii	212	10613	
London 4	2		15	0.03		1458	iii	245	8174	
London 5	2		10	0.02	0.5329		ii	313	15665	
London 6c	2	0	15	0.03		1250	iii	211	7043	
London 7c	2	15	15	0.03		1130	iii	192	6390	
London 8c	2	30	15	0.03		2500	iii *	415	13844	
London 9c	2	45	15	0.03		1486	iii	250	8327	
London 10c	2	60	15	0.03		1301	iii	220	7320	9368
Coventry 1	1.5		10	0.015	0.1733		ii	105	7003	
Coventry 2	2		5	0.01	0.6549		ii	384	38395	
Coventry 3	1.5		10	0.015	0.7561		ii	443	29504	
Coventry 4	1.5		5	0.0075	0.6798		ii	398	53116	
Coventry 5	1.5		10	0.015		2500	iii *	415	27689	31141
Coventry 6c	2	0	13	0.026		238	i	48	1849	
Coventry 7c	2	13	10	0.02		324	i	66	3281	
Coventry 8c	2	23	12	0.024		301	i	61	2538	
Coventry 9c	2	35	8	0.016		367	i	74	4649	
Coventry 10c	2	47	9	0.018		369	i	75	4155	
Coventry 11c	2	56	15	0.03		326	i	66	2201	3112
Control 1	2		15	0.03	0.03242		ii	23	782	
Control 2	2		15	0.03	0.0295		ii	22	725	
Control 3	2		15	0.03	0.0283		ii	21	702	
Control 4	2		15	0.03	0.0312		ii	23	758	742

* Readings of 2500 indicate >2500 - exact measurement off scale

Air Samples - Calibration (i)

Temp/Deg C	Hg Vol/cm3	Mass Hg/g	Reading/mV
		0.E+00	0
24.8E+0	1	1.95E-08	98.3
25.0E+0	1.5	2.98E-08	157.6
25.2E+0	2	4.04E-08	193.6



SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	0.99
Adjusted R Squ	0.99
Standard Error	8.11
Observations	4

RESIDUAL OUTPUT

Observation	*Predicted Reading/mV*	*Residuals*
1	2.5	-2.5
2	98.0	0.3
3	148.7	8.9
4	200.3	-6.7

ANOVA

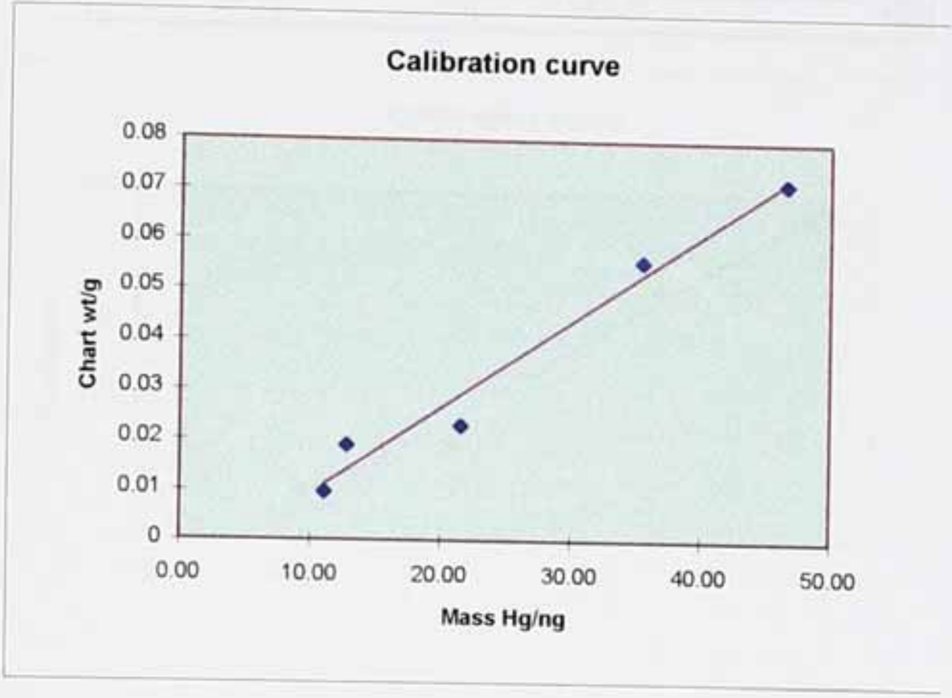
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	21337.6	21337.6	324.6	0.003
Residual	2	131.5	65.7		
Total	3	21469.0			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2.49	7.32	0.34	0.766
Mass Hg/g	4.9E+9	2.72E+08	18.02	0.003

Regression Equation: y = 4.9E9x + 2.49

Air samples - Calibration (ii)

Temp/Deg C	Hg Vol/cm3	Mass Hg/ng	Chart wt/g
26	1	21.50	0.02303
26.5	0.5	12.75	0.0189
27	2	11.10	0.00972
27.2	1.5	46.52	0.0718
28.2	0.5	35.43	0.056



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99
R Square	0.97
Adjusted R Sq	0.97
Standard Error	0.005
Observations	5

RESIDUAL OUTPUT

Observation	*Predicted Chart wt/g*
1	0.0291
2	0.0139
3	0.0111
4	0.0723
5	0.0531

ANOVA

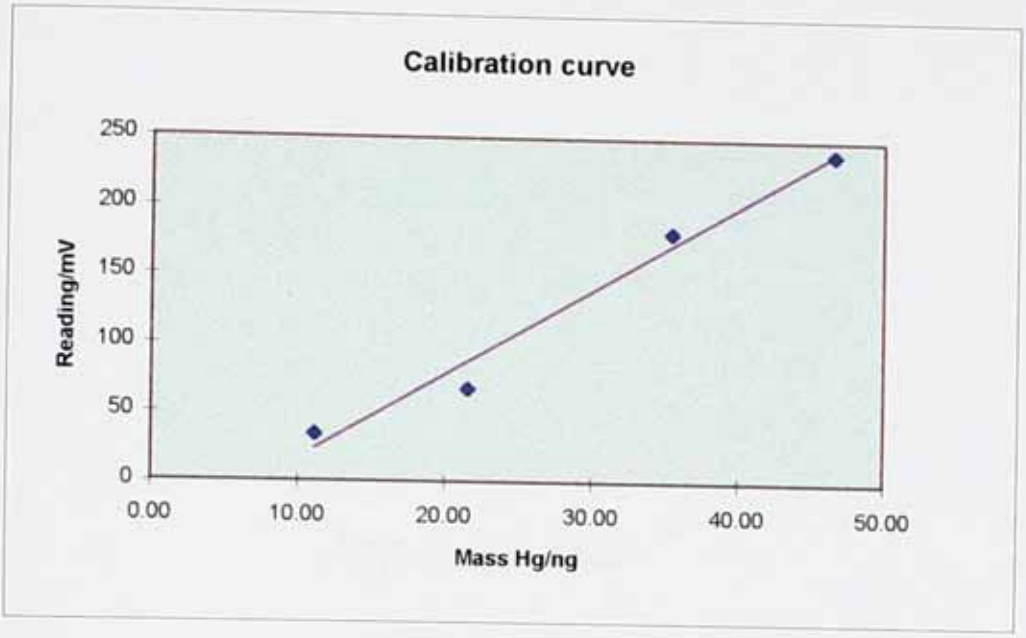
	df	*SS*	*MS*	*F*
Regression	1	0.0028	0.0028	116.1678
Residual	3	7.13E-05	2.38E-05	
Total	4	0.0028		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-8.07E-03	4.62E-03	-1.74	0.18
Mass Hg/ng	1.73E-03	1.6E-04	10.78	1.71E-03

Regression equation: y = 0.0017x - 0.0081

Air samples - calibration (iii)

Temp/Deg C	Hg Vol/cm3	Mass Hg/ng	Reading/mV
26	1	21.50	68
26.5	0.5	11.10	34.5
27	2	46.52	240
27.2	1.5	35.43	182



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99
R Square	0.98
Adjusted R Sq	0.97
Standard Error	17.02
Observations	4

RESIDUAL OUTPUT

Observation	*Predicted Reading/mV*	*Residuals*
1	87	-19
2	24	11
3	241	-1
4	173	9

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	27184	27184	94	0.01
Residual	2	580	290		
Total	3	27763			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-44.31	20.01	-2.21	0.16
Mass Hg/ng	6.13	0.63	9.69	0.01

Regression Equation: $y = 6.13x - 44.31$

Appendix xxiii

Coventry Crematorium Plan with Sample Positions

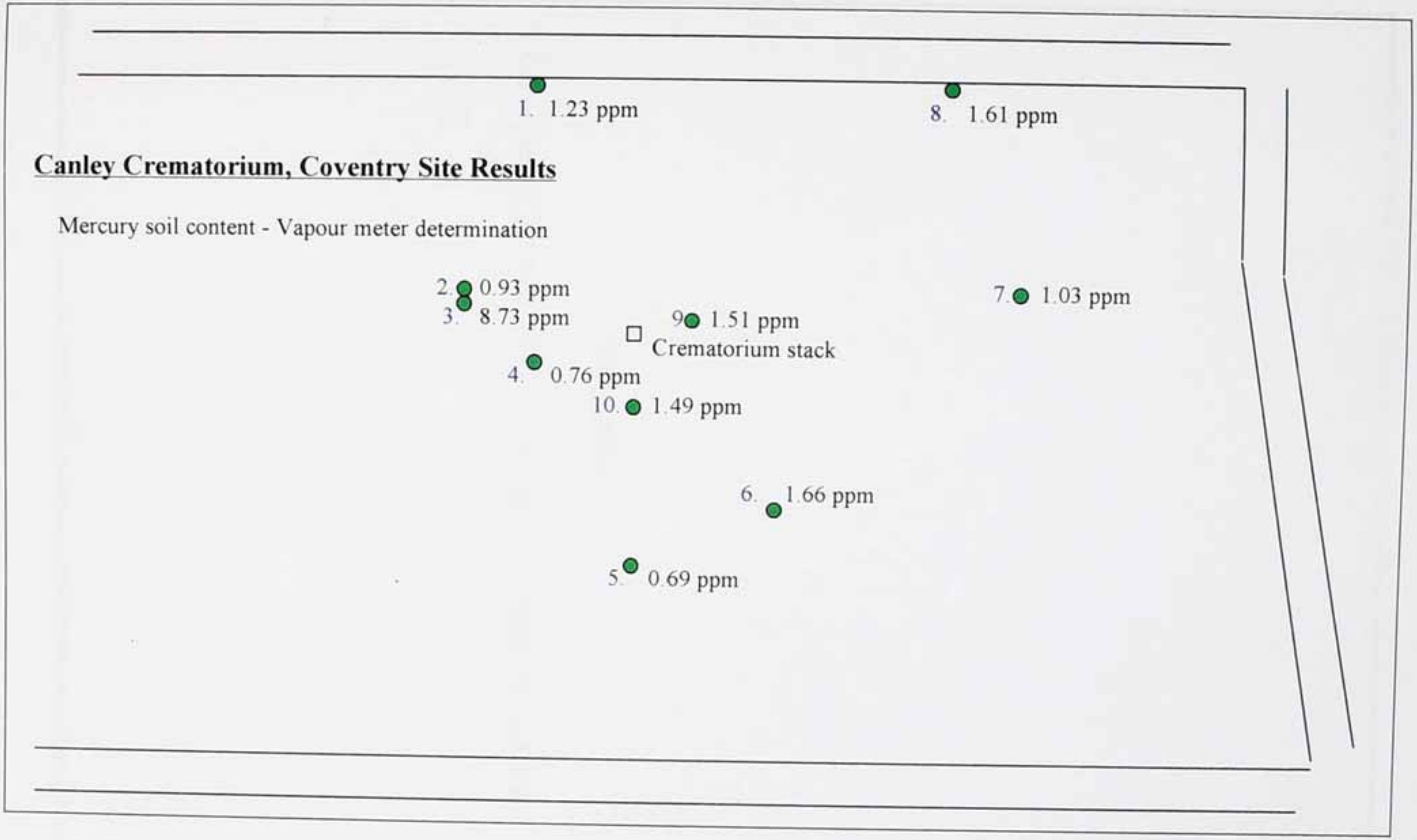
Coventry Crematorium

Appendix xxiv

Coventry Crematorium Soil Results Plan

Canley Crematorium, Coventry Site Results

Mercury soil content - Vapour meter determination

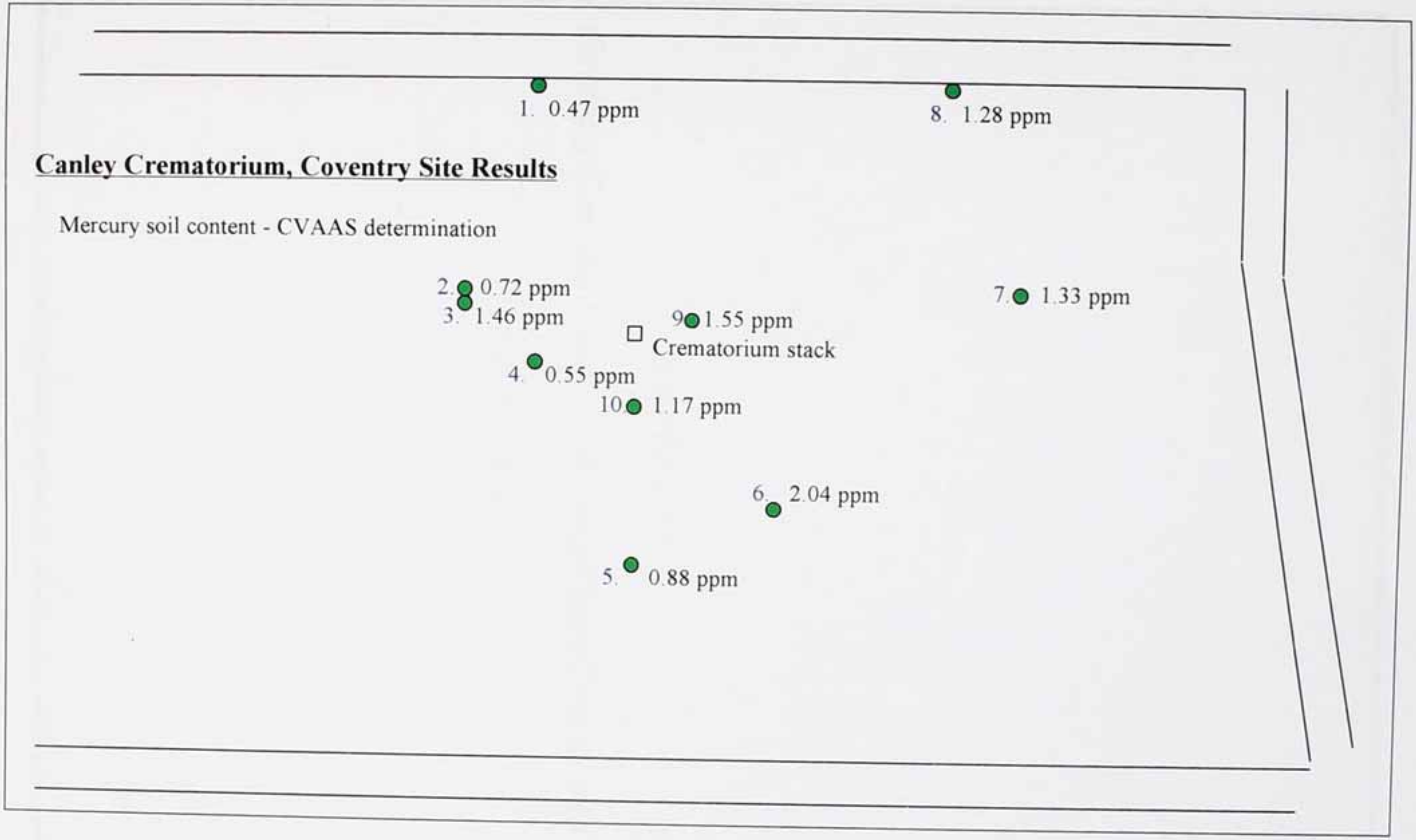


Appendix xxv

Coventry Crematorium Soil Results Plan (CVAAS)

Canley Crematorium, Coventry Site Results

Mercury soil content - CVAAS determination

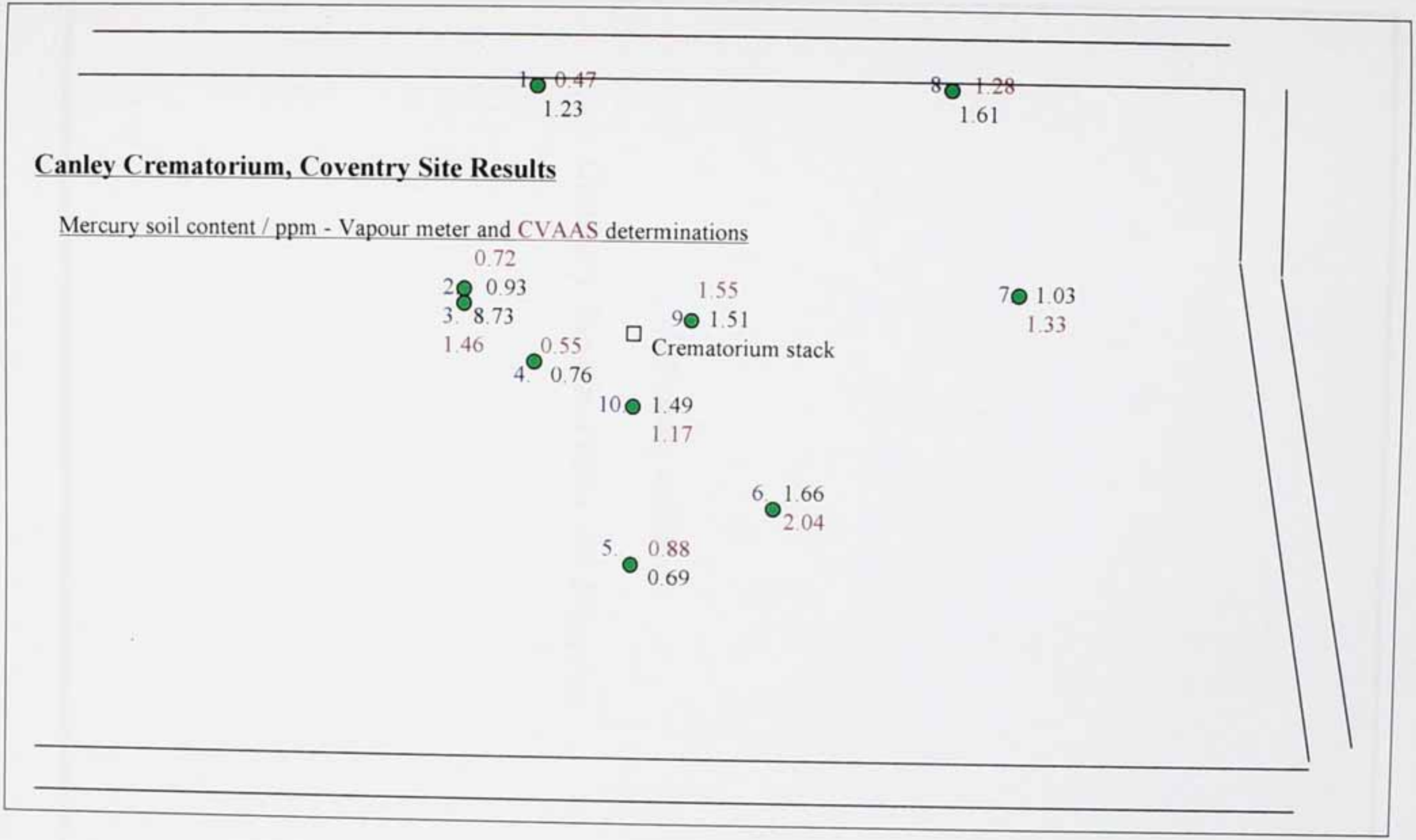


Appendix xxvi

Coventry Crematorium Soil Results Plan (CVAAS and Vapour Meter)

Canley Crematorium, Coventry Site Results

Mercury soil content / ppm - Vapour meter and CVAAS determinations

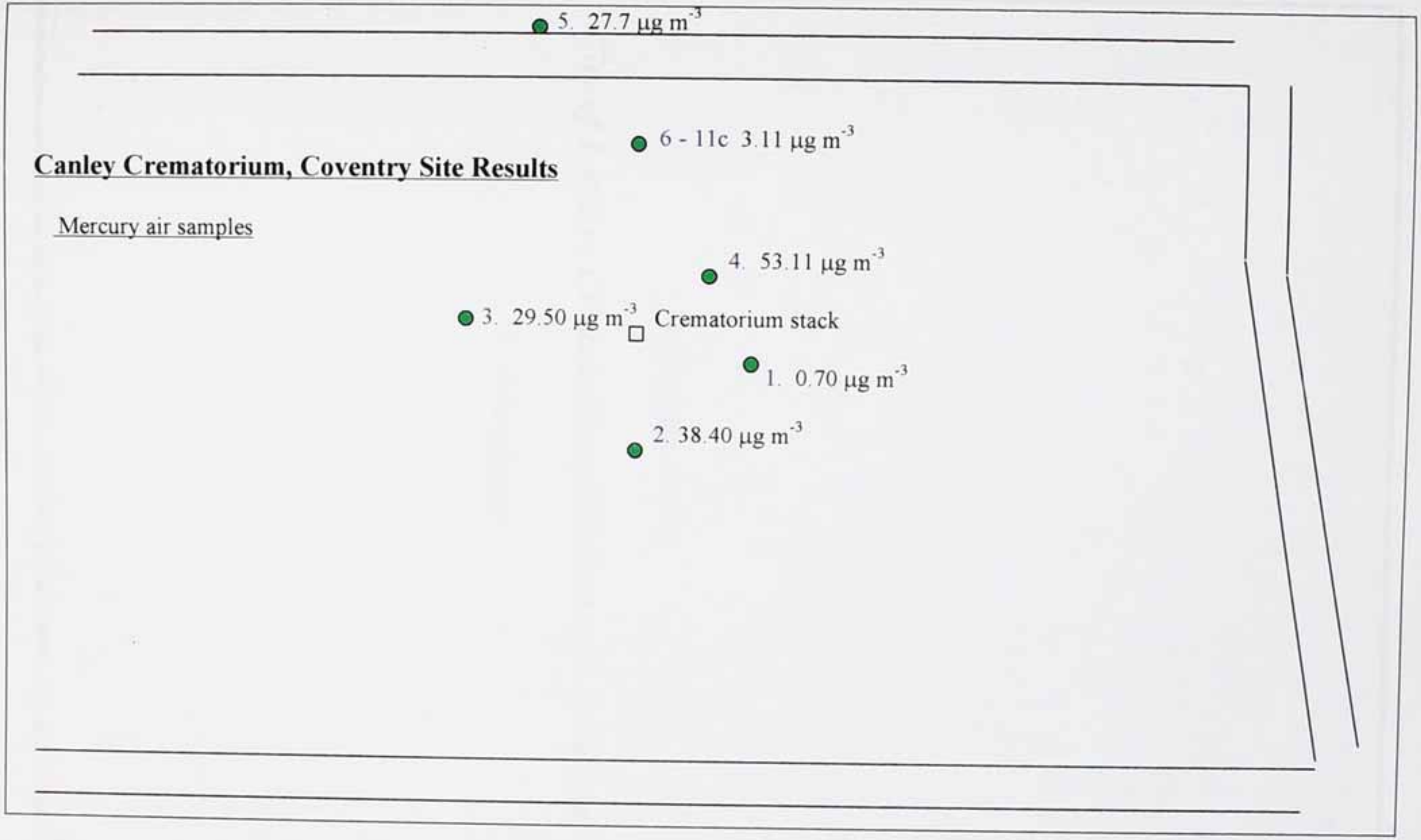


Appendix xxvii

Coventry Results Plan - Air Samples

Canley Crematorium, Coventry Site Results

Mercury air samples



Appendix xxviii

City of London Crematorium Soil Results - Data and Calculations

London Soil Results (Vapour Meter)

		Moisture Content								Mercury Content						
Sample No.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sampl + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	Reading Chart wt.	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	S.D.	Coeff Var.
1	50.0262	45.8907	4.1355	49.9359	4.0452	2.1835	**1a**	0.027	0.2802	50.367	1865.432	1907.074			
							b	0.031	0.2839	50.983	1644.624	1681.336	1794.20	159.62	8.90
2	51.7093	45.8871	5.8222	51.5597	5.6726	2.5695	**2a**	0.023	0.2679	48.317	2100.725	2156.126			
							b	0.028	0.2878	51.633	1844.048	1892.680	2024.40	186.28	9.20
3	48.6965	42.1177	6.5788	48.561	6.4433	2.0596	**3a**	0.030	0.3588	63.467	2115.556	2160.045			
							b	0.024	0.1995	36.917	1538.194	1570.542	1865.29	416.84	22.35
4	42.3483	42.1345	0.2138	42.3279	0.1934	9.5416	**4a**	0.019	0.843	144.167	7587.719	8388.079			
							b	0.018	0.779	133.500	7416.667	8198.983	8293.53	133.71	1.61
5	49.5691	42.3025	7.2666	49.3912	7.0887	2.4482	**5a**	0.039	0.3116	55.600	1425.641	1461.419			
							b	0.024	0.2101	38.683	1611.806	1652.256	1556.84	134.94	8.67
6	48.7414	41.8877	6.8537	48.4844	6.5967	3.7498	**6a**	0.024	0.1873	34.883	1453.472	1510.098			
							b	0.030	0.2123	39.050	1301.667	1352.378	1431.24	111.52	7.79
7	48.1789	42.3866	5.7923	47.926	5.5394	4.3661	**7a**	0.021	0.181	33.833	1611.111	1684.666			
							b	0.021	0.176	33.000	1571.429	1643.172	1663.92	29.34	1.76

London Soil Results (Vapour Meter)

Sample No.	Wet Sample +tin	Tin	Wet Sample	Dry Sampl + tin	Dry Sample	Moisture Content	Sample no.	Wet Wt grams	Reading Chart wt.	Hg content nanograms	Hg Content ng/g	Hg content ng/g	Mean Hg content ng/g	S.D.	Coeff Var.
	Wt / g	Wt / g	Wt / g	Wt / g	Wt / g	Percentage					wet sample	dry sample	dry sample		
8	42.564	42.1334	0.4306	42.5141	0.3807	11.5885	**8a**	0.014	0.691	118.833	8488.095	9600.667			
							b	0.016	0.8074	138.233	8639.583	9772.011	9686.34	121.16	1.25
9	51.6022	45.8842	5.718	51.4405	5.5563	2.8279	**9a**	0.033	0.2666	48.100	1457.576	1499.994			
							b	0.019	0.1413	27.217	1432.456	1474.144	1487.07	18.28	1.23
10	50.9244	42.326	8.5984	50.7225	8.3965	2.3481	**10a**	0.022	0.1427	27.450	1247.727	1277.730			
							b	0.038	0.298	53.333	1403.509	1437.257	1357.49	112.80	8.31
11	53.6467	45.958	7.6887	53.3989	7.4409	3.2229	**11a**	0.028	0.2946	52.767	1884.524	1947.283			
							b	0.028	0.3233	57.550	2055.357	2123.806	2035.54	124.82	6.13
12	46.2901	42.7218	3.5683	46.1213	3.3995	4.7305	**12a**	0.018	0.1287	25.117	1395.370	1464.657			
							b	0.022	0.1471	28.183	1281.061	1344.671	1404.66	84.84	6.04
13	48.4036	42.2473	6.1563	48.2396	5.9923	2.6639	**13a**	0.016	0.0817	17.283	1080.208	1109.772			
							b	0.017	0.1385	26.750	1573.529	1616.594			
							c	0.028	0.3578	63.300	2260.714	2322.587	1682.98	609.13	36.19
14	43.0824	42.3395	0.7429	43.0256	0.6861	7.6457	**14a**	0.018	0.126	24.667	1370.370	1483.819			
							b	0.025	0.16	30.333	1213.333	1313.781			
							c	0.012	0.074	16.000	1333.333	1443.716	1413.77	88.89	6.29

London Soil Results (Vapour Meter)

Sample No.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sampl + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	Reading Chart wt.	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	S.D.	Coeff Var.
15	43.2934	42.7407	0.5527	43.2309	0.4902	11.3081	**15a**	0.011	0.581	100.500	9136.364	10301.241			
							b	0.014	0.627	108.167	7726.190	8711.272	9506.26	1124.28	11.83
16	45.3794	42.1056	3.2738	45.1455	3.0399	7.1446	**16a**	0.04	0.413	72.500	1812.500	1951.960			
							b	0.032	0.35	62.000	1937.500	2086.578	2019.27	95.19	4.71
17	50.5279	42.1271	8.4008	50.3999	8.2728	1.5237	**17a**	0.024	0.18506	34.510	1437.917	1460.165			
							b	0.039	0.29742	53.237	1365.043	1386.163	1423.16	52.33	3.68
											Overall mean		2979.18	2971.07	99.73

Appendix xxix

City of London soil results - CVAAS

London Soil Results (CVAAS)

		Moisture Content								**Hg Content**					
Sample No.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sample + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	AA Units	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Standard Deviation	Coef. Var.
1	24.2963	15.9496	8.3467	23.9357	7.9861	4.3203	**1a**	1.9901	29	4393.94	2207.90	2307.59			
							b	2.0621	40	6060.61	2939.05	3071.75	2689.67	540.34	20.09
2	28.42498	18.0159	10.4091	28.1268	10.1109	2.8646	**2a**	2.1305	23	3484.85	1635.70	1683.93			
							b	1.9207	25	3787.88	1972.13	2030.29	1857.11	244.91	13.19
3	39.5838	32.9066	6.67718	39.3002	6.39358	4.2473	**3a**	2.0263	35	5303.03	2617.10	2733.19			
							b	1.9207	44	6666.67	3470.96	3624.92	3179.05	630.55	19.83
4	61.8884	45.7452	16.1432	61.4404	15.6952	2.7752	**4a**	3.4536	19	2878.79	833.56	857.35			
							b	3.4305	12	1818.18	530.00	545.13	701.24	220.77	31.48
5	23.74	14.553	9.187	23.3042	8.7512	4.7437	**5a**	2.6219	25	3787.88	1444.71	1516.65			
							b	2.6247	14	2121.21	808.17	848.42	1182.54	472.51	39.96
6	60.479	50.0914	10.3876	59.9164	9.825	5.4161	**6a**	2.7873	11	1666.67	597.95	632.19			
							b	2.7648	11	1666.67	602.82	637.33	634.76	3.64	0.57
7	27.0612	18.1929	8.8683	26.4109	8.218	7.3329	**7a**	0.9719	13	1969.70	2026.65	2187.02			
							b	0.8241	11	1666.67	2022.41	2182.44			
							c	0.6291	17	2575.76	4094.35	4418.34			
							d	0.4985	23	3484.85	6990.67	7543.85	4082.91	2536.19	62.12

London Soil Results (CVAAS)

Sample No.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sample + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	AA Units	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Standard Deviation	Coef. Var.
8	55.3508	46.8548	8.496	54.1445	7.2897	14.1984	**8a**	3.4942	34	5151.52	1474.30	1718.27			
							b	3.4158	29	4393.94	1286.36	1499.22	1608.75	154.89	9.63
9	20.78	12.5362	8.2438	20.2498	7.7136	6.4315	**9a**	2.7807	16	2424.24	871.81	931.73			
							b	2.9794	22	3333.33	1118.79	1195.69	1063.71	186.65	17.55
10	54.587	45.746	8.841	54.2445	8.4985	3.8740	**10a**	3.189	16	2424.24	760.19	790.83			
							b	3.3192	14	2121.21	639.07	664.83	727.83	89.09	12.24
11	56.0674	46.8225	9.2449	55.573	8.7505	5.3478	**11a**	3.4227	22	3333.33	973.89	1028.91			
							b	2.9614	20	3030.30	1023.27	1081.08	1055.00	36.89	3.50
12	27.0915	19.387	7.7045	25.8768	6.4898	15.7661	**12a**	3.1034	10	1515.15	488.22	579.60			
							b	3.3715	12	1818.18	539.28	640.22	609.91	42.86	7.03
13	57.0474	48.9181	8.1293	56.4893	7.5712	6.8653	**13a**	3.1451	13	1969.70	626.27	672.44			
							b	3.0762	9	1363.64	443.29	475.96	574.20	138.93	24.20
14	55.3508	46.8548	8.496	54.1445	7.2897	14.1984	**14a**	3.4942	34	5151.52	1474.30	1718.27			
							b	3.4158	29	4393.94	1286.36	1499.22	1608.75	154.89	9.63

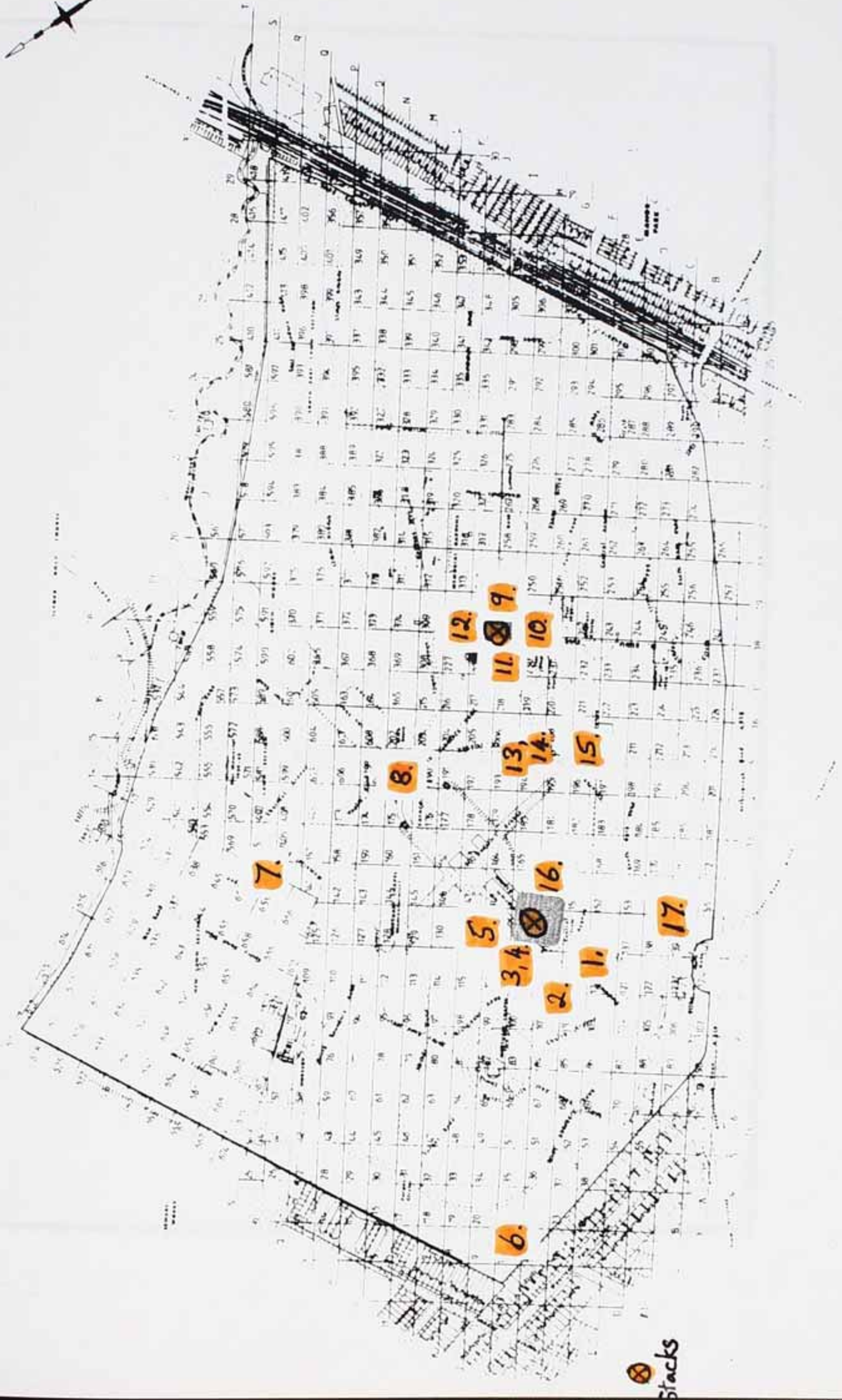
London Soil Results (CVAAS)

Sample No.	Wet Sample +tin Wt / g	Tin Wt / g	Wet Sample Wt / g	Dry Sample + tin Wt / g	Dry Sample Wt / g	Moisture Content Percentage	Sample no.	Wet Wt grams	AA Units	Hg content nanograms	Hg Content ng/g wet sample	Hg content ng/g dry sample	Mean Hg content ng/g dry sample	Standard Deviation	Coef. Var.
15	22.1134	19.1943	2.9191	21.5126	2.3183	20.5817	**15a**	0.3153	12	1818.18	5766.51	7260.94			
							b	0.3078	22	2619.05	8508.93	10714.06			
							c	0.5015	17	2575.76	5136.11	6467.16			
							d	0.4904	16	2424.24	4943.40	6224.51	7666.67	2079.25	27.12
16	30.1784	19.1943	10.9841	28.4756	9.2813	15.5024	**16a**	2.2428	14	2121.21	945.79	1119.31			
							b	2.4125	14	2121.21	879.26	1040.57	1079.94	55.67	5.16
17	18.0522	11.342	6.7102	17.8406	6.4986	3.1534	**17a**	2.3738	18	2727.27	1148.91	1186.32			
							b	2.4911	17	2575.76	1033.98	1067.65	1126.98	83.91	7.45
											Overall Mean		1849.94	2365.93	127.89

Appendix xxx

City of London Crematorium Plan with Sample Positions

City of London Crematorium

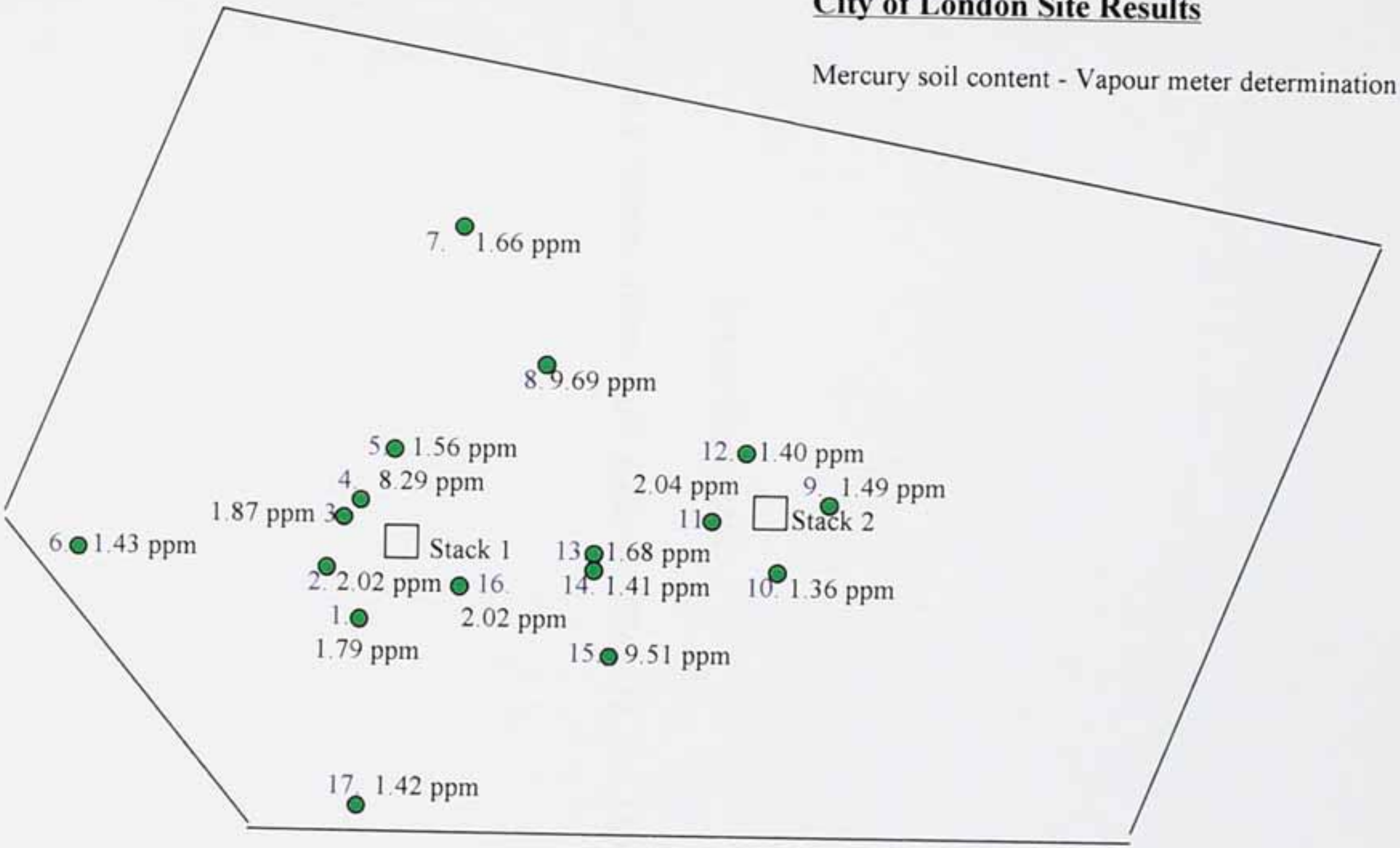


Appendix xxxi

City of London Crematorium Soil Results Plan

City of London Site Results

Mercury soil content - Vapour meter determination

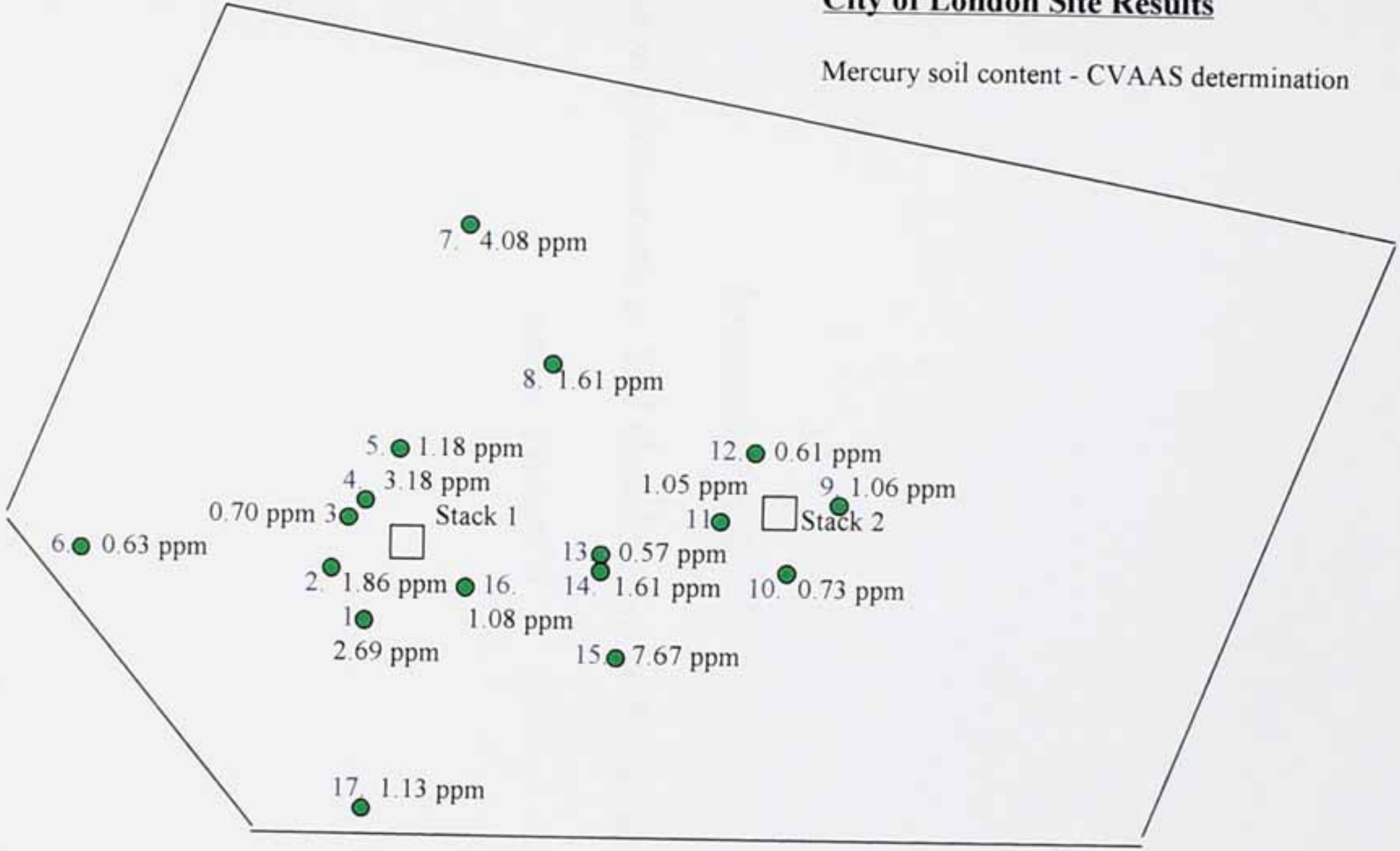


Appendix xxxii

London Crematorium Soil Results Plan (CVAAS)

City of London Site Results

Mercury soil content - CVAAS determination

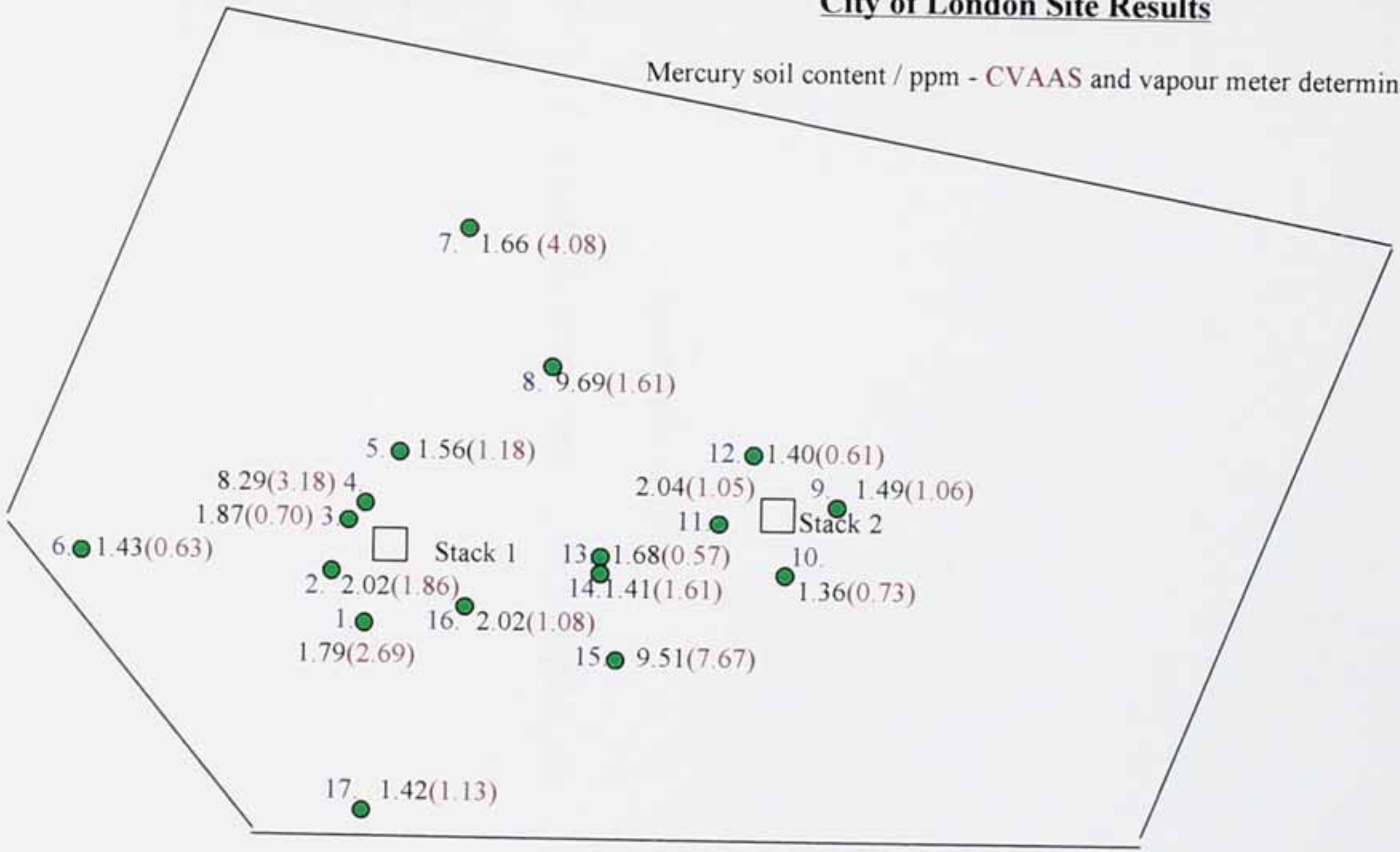


Appendix xxxiii

London Crematorium Soil Results Plan (CVAAS and Vapour Meter)

City of London Site Results

Mercury soil content / ppm - CVAAS and vapour meter determinations

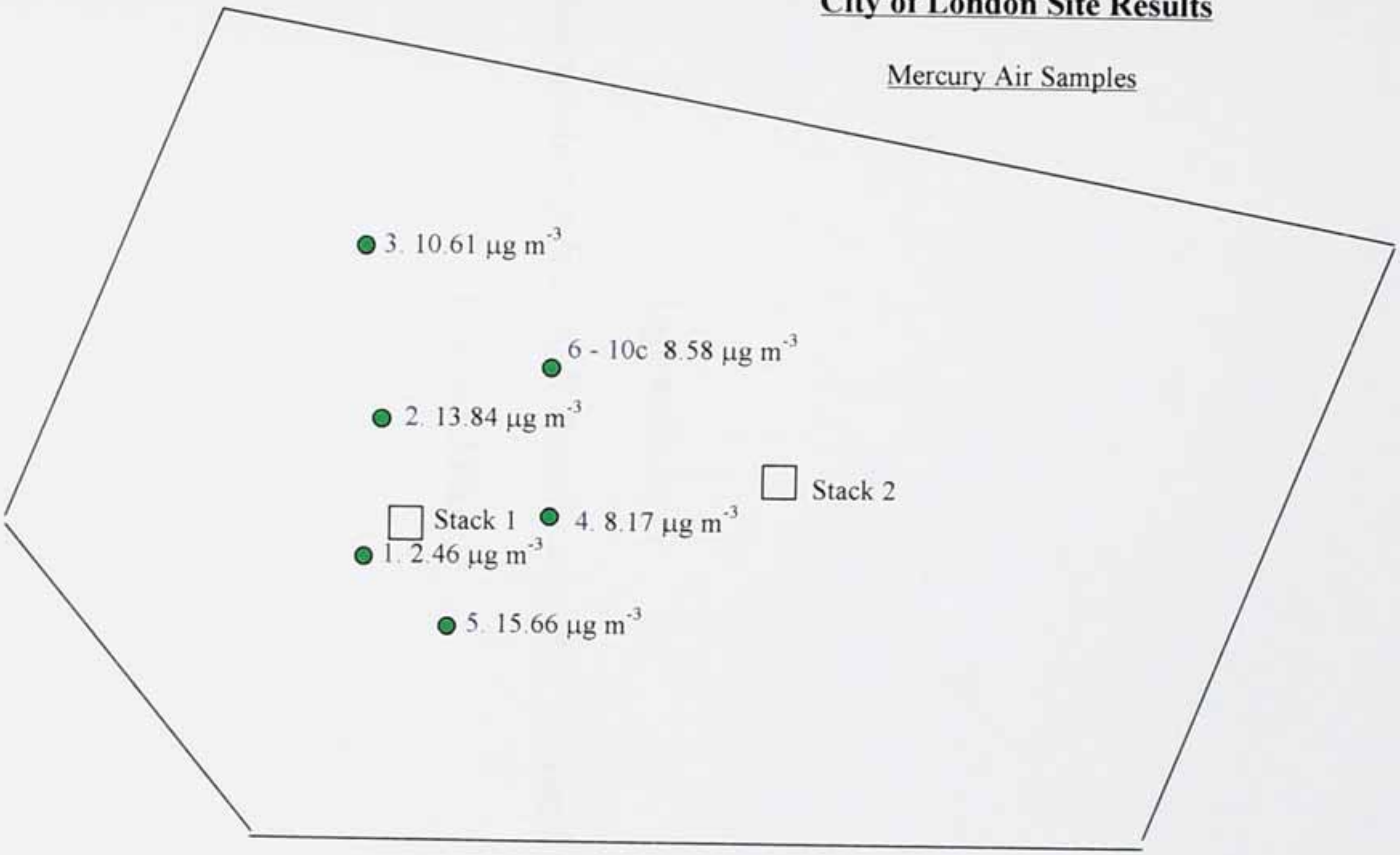


Appendix xxxiv

London Results Plan - Air Samples

City of London Site Results

Mercury Air Samples



Appendix xxxv

Statistical Analysis of Soil Results between Crematoria

(Vapour Meter)

Soil Analysis (Vapour Meter) Statistical Analysis of Results

Analysis using Minitab Statistical Package.

ANALYSIS OF VARIANCE

```
SOURCE   DF        SS         MS        F      p
FACTOR    5    64037148   12807430   4.49   0.002
ERROR    51   145528144    2853493
TOTAL    56   209565280


LEVEL         N    MEAN    STDEV
Controls      8    275      73
Northampton   8    405      96
M.Keynes      7    911     300
Kettering     8    947     602
London       17   2979    2971
Coventry      9   1213     373
POOLED ST DEV =   1689
```

TWO SAMPLE T FOR Controls VS Northampton

```
              N    MEAN     ST DEV    SE MEAN
Controls      8    275.4    72.8      26
Northampton   8    405.4    95.7      34


95 PCT CI FOR μ Controls - μ  Northampton: (-222, -38)

TTEST μ Controls = μ Northamp (VS N.E.): T= -3.06  P=0.0091  DF=  13
```

Appendix xxxvi

Statistical Analysis of Soil Results within Crematoria

(Vapour Meter)

Statistical analysis of soil results within crematoria

Output from `minitab` statistical package

```
MTB > Oneway 'kETTERIN' 'c2'.

ANALYSIS OF VARIANCE ON kETTERIN
SOURCE     DF        SS        MS
c2          7   7617248   1088178      39.17    0.000
ERROR      16    444480     27780
TOTAL      23   8061728
                                     INDIVIDUAL 95 PCT CI'S FOR MEAN
                                     BASED ON POOLED STDEV
  LEVEL     N      MEAN     STDEV    -------+----------------------------
      1     3     757.0     323.6          (---*--)
      2     3     539.4      61.7       (--*--)
      3     3     579.0      15.2       (---*--)
      4     3     952.1      26.1             (---*--)
      5     3    1712.3     211.8                          (---*--)
      6     3     549.4      31.8       (--*---)
      7     3     439.9      32.0     (--*---)
      8     3    2042.7     256.8                                (--*--)
                                     -------+-------------------+--------
POOLED STDEV =    166.7                     600      1200      1800
MTB > Oneway 'NORTHAMP' C4.

ANALYSIS OF VARIANCE ON NORTHAMP
SOURCE     DF        SS        MS
C4          7    240002     34286       6.83    0.000
ERROR      20    100395      5020
TOTAL      27    340397
                                     INDIVIDUAL 95 PCT CI'S FOR MEAN
                                     BASED ON POOLED STDEV
  LEVEL     N      MEAN     STDEV    -------+----------------------------
      1     4    498.90     67.01                           (------*-----)
      2     3    434.61     59.60                     (------*------)
      3     3    497.31     28.12                         (------*-------
      4     3    441.18    161.17                      (------*------)
      5     4    231.99     36.18    (-----*-----)
      6     3    468.67     61.34                         (------*------
      7     4    355.85     47.67              (------*-----)
      8     4    314.70     51.68           (-----*-----)
                                     ------------------------------------
POOLED STDEV =    70.85                    240       360       480
MTB > Oneway 'MKEYNES' 'c2'.
```

Statistical analysis of soil results within crematoria

Output from 'minitab' statistical package

```
ANALYSIS OF VARIANCE ON MKEYNES
SOURCE      DF          SS          MS          F          p
c2           7   297199584    42457084    115.08     0.000
ERROR       16     5902775      368923
TOTAL       23   303102336
                                            INDIVIDUAL 95 PCT CI'S FOR MEAN
                                            BASED ON POOLED STDEV
 LEVEL       N        MEAN       STDEV     --+---------+---------+---------+---------
     1       3         988         220        (-*-)
     2       3         815         126      (-*-)
     3       3        1009          25        (-*-)
     4       3         537          38     (--*-)
     5       3         749          85      (-*-)
     6       3       11522        1676                                              -*-)
     7       3        1490         143         (-*-)
     8       3         790         217      (-*-)
                                           --+---------+---------+---------+---------
POOLED STDEV =         607                   0        3500      7000      10500
MTB > Oneway 'COVENTRY' C7.

ANALYSIS OF VARIANCE ON COVENTRY
SOURCE      DF          SS          MS          F          p
C7           9   103987056    11554117   1356.58     0.000
ERROR       10       85171        8517
TOTAL       19   104072232
                                            INDIVIDUAL 95 PCT CI'S FOR MEAN
                                            BASED ON POOLED STDEV
 LEVEL       N        MEAN       STDEV     --------+---------+---------+---------
     1       2      1230.8        38.1        (*)
     2       2       928.5         4.3       (*
     3       2      8731.5       150.6                                          (*
     4       2       760.2        57.4     (*)
     5       2       692.8        42.7     (*
     6       2      1659.0       201.5          (*
     7       2      1029.9        80.9       *)
     8       2      1607.6        79.0          *)
     9       2      1510.4        37.6         (*)
    10       2      1493.4        33.4         (*)
                                           --------+---------+---------+---------
POOLED STDEV =        92.3                       2500      5000      7500
MTB > Oneway 'LONDON' C9.
```

Statistical analysis of soil results within crematoria

Output from 'minitab' statistical package

```
ANALYSIS OF VARIANCE ON LONDON
SOURCE     DF         SS         MS         F        P
C9         16  286374528   17898408    143.64    0.000
ERROR      19    2367512     124606
TOTAL      35  288742016
                                        INDIVIDUAL 95 PCT CI'S FOR MEAN
                                        BASED ON POOLED STDEV
LEVEL       N       MEAN      STDEV    ----------------------------------------
    1       2       1794        160      (-*-)
    2       2       2024        186       (-*)
    3       2       1865        417      (-*-)
    4       2       8294        134                               (-*)
    5       2       1557        135     (-*-)
    6       2       1431        112     (-*-)
    7       2       1664         29      (-*)
    8       2       9686        121                                    (*-)
    9       2       1487         18     (-*-)
   10       2       1357        113     (-*)
   11       2       2036        125       (-*-)
   12       2       1405         85     (-*)
   13       3       1683        609      (-*)
   14       2       1414         89     (-*)
   15       2       9506       1124                                   (-*)
   16       2       2019         95       (-*)
   17       2       1423         52     (-*)
                                       --------+-------------------------------
POOLED STDEV =       353                   3000      6000      9000
MTB > NOPAPER
```

Statistical analysis of soil results within crematoria

Output from `minitab' statistical package

```
MTB > Oneway 'KETT2' C11.

ANALYSIS OF VARIANCE ON KETT2
SOURCE     DF        SS        MS        F        P
C11         5    519238    103848     5.59    0.007
ERROR      12    222911     18576
TOTAL      17    742149
                                     INDIVIDUAL 95 PCT CI'S FOR MEAN
                                     BASED ON POOLED STDEV
 LEVEL      N      MEAN     STDEV    ------------------------------------
     1      3     757.0     323.6                (------*------)
     2      3     539.4      61.7        (------*-----)
     3      3     579.0      15.2         (------*------)
     4      3     952.1      26.1                          ------*------
     6      3     549.4      31.8        (------*------)
     7      3     439.9      32.0    (------*-----)
                                     ------------------------------------
POOLED STDEV =    136.3                        500       750      1000
MTB > Oneway 'MKEYNES2' C12.

ANALYSIS OF VARIANCE ON MKEYNES2
SOURCE     DF        SS        MS        F        P
C12         6   1622106    270351    13.40    0.000
ERROR      14    282497     20178
TOTAL      20   1904603
                                     INDIVIDUAL 95 PCT CI'S FOR MEAN
                                     BASED ON POOLED STDEV
 LEVEL      N      MEAN     STDEV    -+---------------+------------------
     1      3     988.2     220.4              (----*---)
     2      3     814.8     125.7          (---*----)
     3      3    1008.8      25.2               (---*----)
     4      3     537.0      38.4    (---*----)
     5      3     748.9      84.8         (----*---)
     7      3    1489.8     143.1                          (---*----)
     8      3     789.6     217.0          (----*---)
                                     -+---------+---------+---------+----
POOLED STDEV =    142.1             400       800      1200      1600
MTB > Oneway 'COVENT2' C15.

ANALYSIS OF VARIANCE ON COVENT2
SOURCE     DF        SS        MS        F        P
C15         8   2224210    278026    40.04    0.000
ERROR       9     62492      6944
TOTAL      17   2286703
                                     INDIVIDUAL 95 PCT CI'S FOR MEAN
                                     BASED ON POOLED STDEV
 LEVEL      N      MEAN     STDEV    -----+------------------------------
     1      2    1230.8      38.1                   (---*---)
     2      2     928.5       4.3            (---*--)
     4      2     760.2      57.4       (---*---)
     5      2     692.8      42.6     (---*---)
     6      2    1659.0     201.5                                (--*---)
     7      2    1029.9      80.9               (--*---)
     8      2    1607.6      79.0                             (---*---)
     9      2    1510.4      37.6                           (---*---)
    10      2    1493.4      33.4                           (---*--)
                                     -----+---------+---------+---------+
POOLED STDEV =     83.3                 700      1050      1400      1750
```

Statistical analysis of soil results within crematoria

Output from 'minitab' statistical package

```
MTB > Oneway 'KETT2' C11.

ANALYSIS OF VARIANCE ON KETT2
SOURCE     DF        SS        MS         F        p
C11         5    519238    103848      5.59    0.007
ERROR      12    222911     18576
TOTAL      17    742149
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
 LEVEL      N      MEAN     STDEV  ----------------------+-----------------
     1      3     757.0     323.6            (------*------)
     2      3     539.4      61.7      (------*-----)
     3      3     579.0      15.2       (------*------)
     4      3     952.1      26.1                        ------*------
     6      3     549.4      31.8      (------*------)
     7      3     439.9      32.0  (------*-----)
                                   ----------------------+---------------+-----
POOLED STDEV =    136.3                      500         750         1000
MTB > Oneway 'MKEYNES2' C12.

ANALYSIS OF VARIANCE ON MKEYNES2
SOURCE     DF        SS        MS         F        p
C12         6   1380180    230030      6.14    0.002
ERROR      14    524423     37459
TOTAL      20   1904603
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
 LEVEL      N      MEAN     STDEV  -+----------+---------+-----------------
     1      4     911.1     237.0          (----*----)
     2      3     927.8      91.4         (-----*-----)
     3      3     852.0     263.8       (-----*-----)
     4      3     627.0     170.0  (-----*-----)
     5      2     714.0      84.1   (------*------)
     7      3    1489.8     143.1                          (-----*-----
     8      3     789.6     217.0       (-----*-----)
                                   ----------------------------------------
POOLED STDEV =    193.5           400        800        1200        1600
NOTE * The Data Screen was used to change the worksheet
MTB > NOPAPER
```

Statistical analysis of soil results within crematoria

Output from 'minitab' statistical package

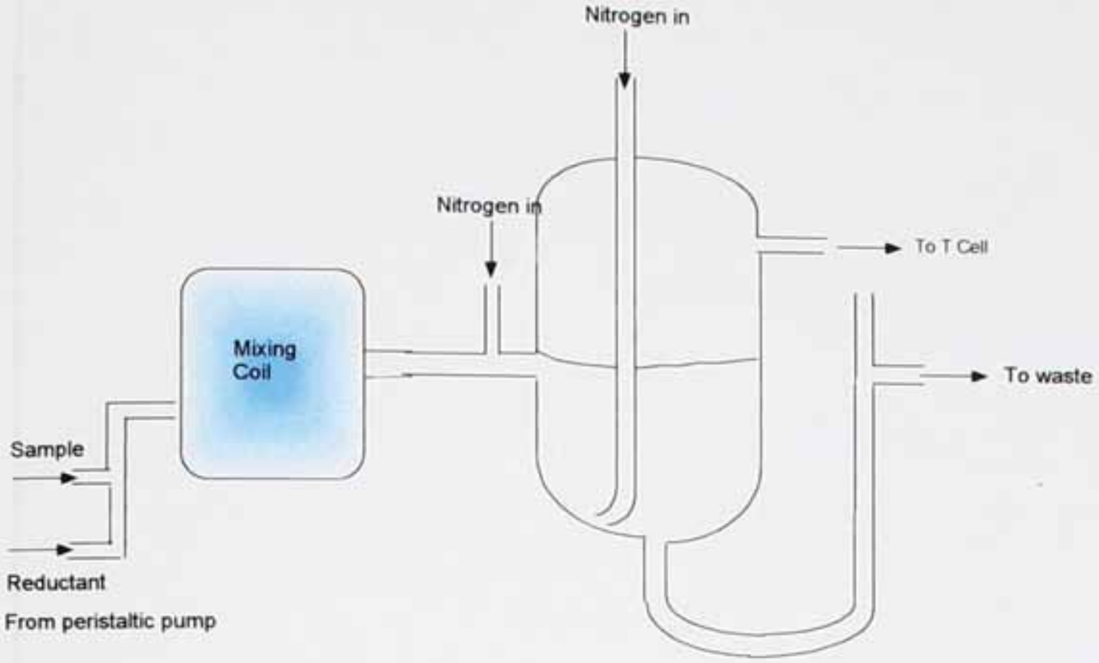
```
MTB > Oneway 'LONDON2' C17.

ANALYSIS OF VARIANCE ON LONDON2
SOURCE     DF         SS        MS        F        P
C17        13    1716005    132000     1.97    0.099
ERROR      16    1070949     66934
TOTAL      29    2786954
                                     INDIVIDUAL 95 PCT CI'S FOR MEAN
                                     BASED ON POOLED STDEV
  LEVEL      N       MEAN     STDEV  --------------------------------------
      1      2     1794.2     159.7              (---------*---------)
      2      2     2024.4     186.3                    (---------*---------)
      3      2     1865.2     416.8                (---------*---------)
      5      2     1556.9     135.0        (---------*---------)
      6      2     1431.2     111.5     (---------*---------)
      7      2     1663.9      29.3           (---------*---------)
      9      2     1487.1      18.3      (---------*---------)
     10      2     1357.5     112.9   (---------*---------)
     11      2     2035.6     124.8                    (---------*---------)
     12      2     1404.7      84.9    (---------*---------)
     13      3     1683.0     609.1             (-------*-------)
     14      3     1413.8      88.9      (-------*-------)
     16      2     2019.3      95.2                   (---------*---------)
     17      2     1423.2      52.3    (---------*---------)
                                     ------+-------------------+-----------
POOLED STDEV =      258.7               1200      1600      2000      2400
MTB >
```

Appendix xxxvii

Mercury Vapour Generator

Mercury Vapour Generator

Constructed by Geochemistry Dept, Leicester University

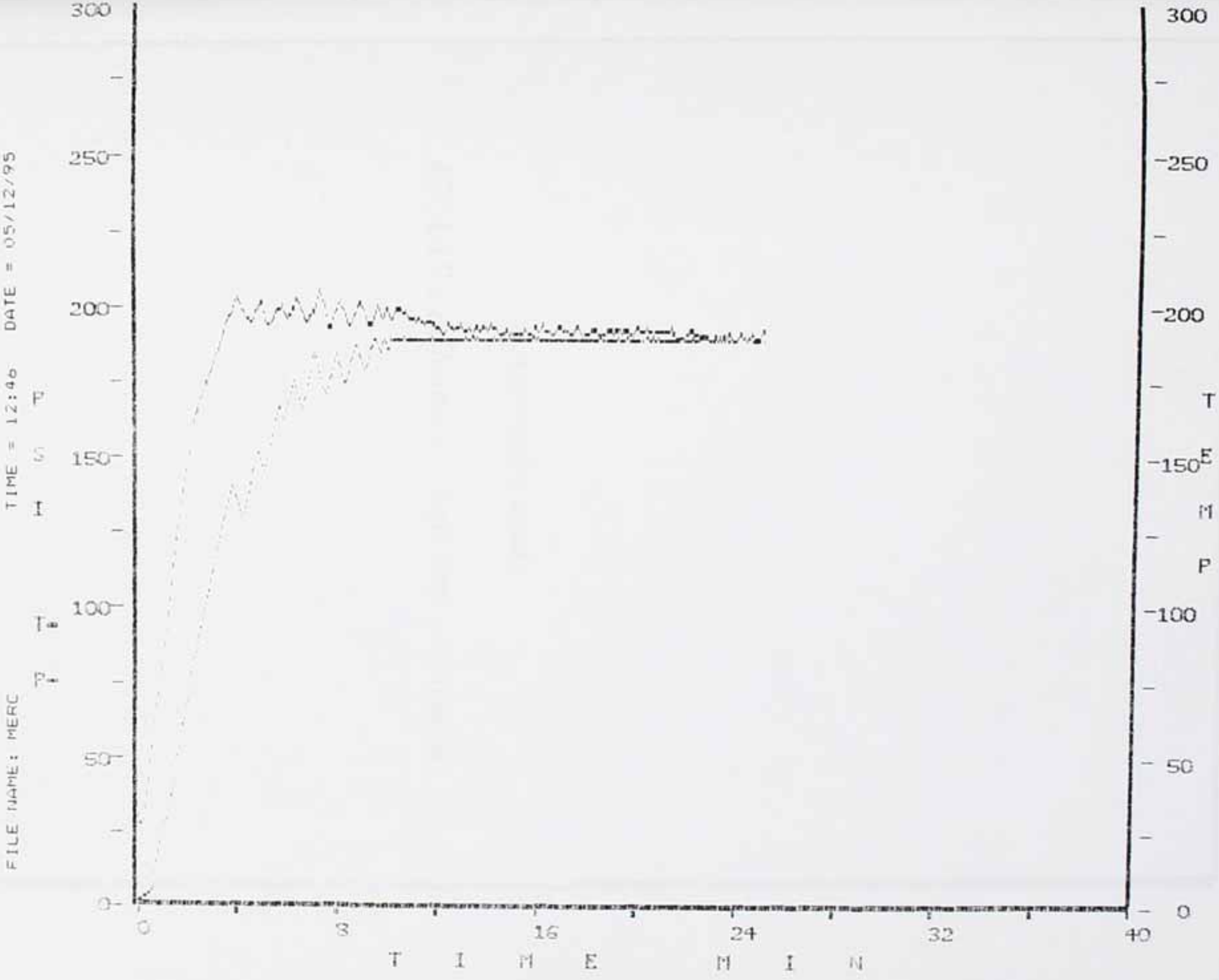


Gas Liquid Separator

Appendix xxxviii

Microwave Digestion Program

```
                           MDS 2100
                        CEM CORPORATION
                       05/04/95    14:48


PROGRAM VARIABLES
        FILE NAME = MERC
        TIME TO PRESSURE DIGESTION
        stage         (1)      (2)      (3)      (4)      (5)
        POWER         40%       0%       0%       0%       0%
        PRESSURE     0190     0020     0020     0020     0020
        RAMP TIME   05:00    00:00    00:00    00:00    00:00
        HOLD TIME   10:00    00:00    00:00    00:00    00:00
        Tmax
        200C     20C      20C      20C      20C
        FAN SPEED    100%     100%     100%     100%     100%
        NUMBER OF VESSELS:  4
        VOLUME PER VESSEL:  10ml
        SAMPLE WEIGHT:  0.5g
        ACID: NIT SUL
```


FILE NAME: MERC
TIME = 12:46
DATE = 05/12/95
P
S
I
T
P
300
250
200
150
100
50
0
0
8
16
24
32
40
T I M E
M I N
300
250
200
150
100
50
0
T
E
M
P

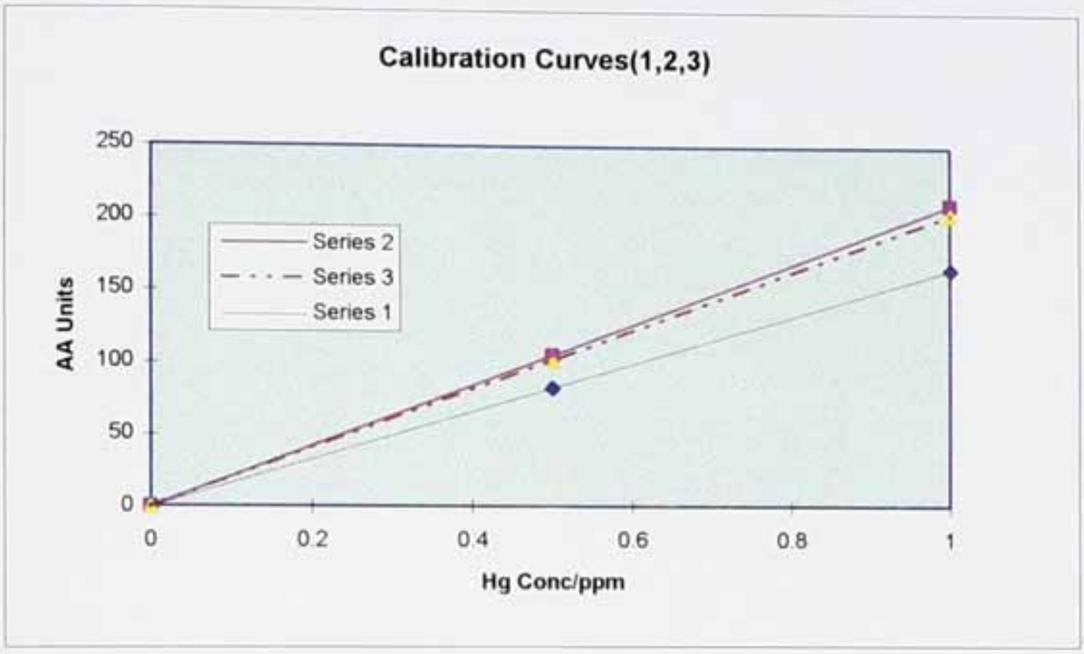
Appendix xxxix

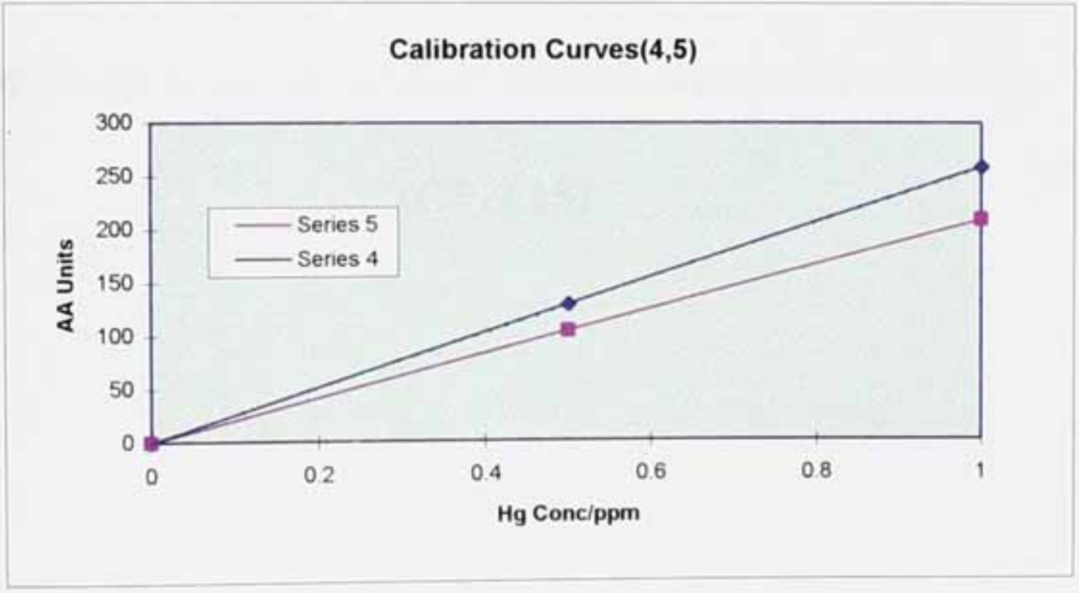
CVAAS Calibration - Soil Determination

CVAAS Calibration - Soil Determination

Data

Hg conc/ppm	AA Units(1)	AA Units(2)	AA Units(3)	AA Units(4)	AA Units(5)
0	0	0	0	0	0
0.5	82.5	105	102	129	104
1	165	210	204	258	208





Regression Equations:	1. y = 165x, 2. y = 210x, 3. y = 204x, 4. y = 258x, 5. y = 208x

Appendix XL

Statistical analysis of Soil Results within Crematoria

(CVAAS)

Statistical Analysis of Soil Results (CVAAS) within Crematoria

Output from 'Minitab' statistical analysis package:

```
MTB > Oneway 'London' C2.

ANALYSIS OF VARIANCE ON London
SOURCE     DF        SS        MS         F        p
C2         16 173700272  10856267      6.82    0.000
ERROR      21  33411642   1591031
TOTAL      37 207111904
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
LEVEL       N      MEAN     STDEV  -----+---------+---------+---------+-
    1       2      2690       540          (-----*-----)
    2       2      1857       245       (-----*------)
    3       2      3179       631           (------*-----)
    4       2       701       221   (-----*------)
    5       2      1183       473     (-----*-----)
    6       2       635         4   (-----*-----)
    7       4      4083      2536                (----*---)
    8       2      1609       155      (-----*------)
    9       2      1064       187    (------*-----)
   10       2       728        89   (-----*------)
   11       2      1055        37    (------*-----)
   12       2       610        43   (-----*-----)
   13       2       574       139   (-----*-----)
   14       2      1609       155      (-----*------)
   15       4      7667      2079                            (----*---)
   16       2      1080        56    (------*-----)
   17       2      1127        84     (-----*-----)
                                   -----+---------+---------+---------+-
POOLED STDEV =     1261                 0      3000      6000      9000


MTB > Oneway 'coventry' C2.

ANALYSIS OF VARIANCE ON coventry
SOURCE     DF        SS        MS         F        p
C2          9   4544462    504940     32.15    0.000
ERROR      10    157063     15706
TOTAL      19   4701525
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
LEVEL       N      MEAN     STDEV  ------+---------+---------+---------+
    1       2     470.2     159.5   (--*--)
    2       2     719.5     154.7       (--*--)
    3       2    1457.1     301.6                   (--*---)
    4       2     546.7       2.2    (--*--)
    5       2     880.0       1.4         (---*--)
    6       2    2036.2      27.1                             (--*--)
    7       2    1334.7      25.3                 (--*---)
    8       2    1276.2     122.9                (--*---)
    9       2    1548.6      14.5                     (--*--)
   10       2    1474.5       2.2                   (---*--)
                                   ------+---------+---------+---------+
POOLED STDEV =    125.3               600      1200      1800      2400
MTB > nopaper
```

Appendix XLi

Statistical analysis of CVAAS and Vapour Meter Determinations

Statistical analysis of CVAAS and vapour meter determinations.

Difference between vapour meter and CVAAS results for Coventry

```
TWOSAMPLE T-Test for cov_cv VS cov_vm

            N    MEAN        STDEV      SE MEAN

cov_cv      20   1174        497        111

cov_vm      20   1964        2340       523


95 PCT CI FOR MU cov_cv - MU cov_vm: (-1906, 326)

T-TEST MU cov_cv = MU cov_vm (VS NE): T= -1.48  P=0.16  DF=  20
```

No significant difference at 95% confidence level

Coventry - Differences between vapour meter and CVAAS results at individual positions.

1. Mann-Whitney Confidence Interval and Test

cov1cv N = 2 Median = 470.2

cov1vm N = 2 Median = 1230.8

Point estimate for ETA1-ETA2 is -760.6

75.5 pct c.i. for ETA1-ETA2 is (-900.4,-620.8)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

2. Mann-Whitney Confidence Interval and Test

cov2cv N = 2 Median = 719.5

cov2vm N = 2 Median = 928.5

Point estimate for ETA1-ETA2 is -208.9

75.5 pct c.i. for ETA1-ETA2 is (-321.3,-96.5)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

3. Mann-Whitney Confidence Interval and Test

cov3cv N = 2 Median = 1457.1

cov3vm N = 2 Median = 8731.5

Point estimate for ETA1-ETA2 is -7274.3

75.5 pct c.i. for ETA1-ETA2 is (-7594.1,-6954.6)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

4. Mann-Whitney Confidence Interval and Test

cov4cv N = 2 Median = 546.7

cov4vm N = 2 Median = 760.2

Point estimate for ETA1-ETA2 is -213.4

75.5 pct c.i. for ETA1-ETA2 is (-255.6,-171.3)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

5. Mann-Whitney Confidence Interval and Test

cov5cv N = 2 Median = 880.01

cov5vm N = 2 Median = 692.82

Point estimate for ETA1-ETA2 is 187.19

75.5 pct c.i. for ETA1-ETA2 is (156.06,218.31)

W = 7.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

6. Mann-Whitney Confidence Interval and Test

cov6cv N = 2 Median = 2036.2

cov6vm N = 2 Median = 1659.0

Point estimate for ETA1-ETA2 is 377.2

75.5 pct c.i. for ETA1-ETA2 is (215.6,538.8)

W = 7.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

7. Mann-Whitney Confidence Interval and Test

cov7cv N = 2 Median = 1334.7

cov7vm N = 2 Median = 1029.9

Point estimate for ETA1-ETA2 is 304.8

75.5 pct c.i. for ETA1-ETA2 is (229.6,379.9)

W = 7.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

8. Mann-Whitney Confidence Interval and Test

cov8cv N = 2 Median = 1276.2

cov8vm N = 2 Median = 1607.6

Point estimate for ETA1-ETA2 is -331.4

75.5 pct c.i. for ETA1-ETA2 is (-474.1,-188.7)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

9. Mann-Whitney Confidence Interval and Test

cov9cv N = 2 Median = 1548.6

cov9vm N = 2 Median = 1510.4

Point estimate for ETA1-ETA2 is 38.2

75.5 pct c.i. for ETA1-ETA2 is (1.3,75.0)

W = 7.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

10. Mann-Whitney Confidence Interval and Test

cov10cv N = 2 Median = 1474.5

cov10vm N = 2 Median = 1493.4

Point estimate for ETA1-ETA2 is -18.9

75.5 pct c.i. for ETA1-ETA2 is (-44.1,6.3)

W = 5.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 1.0000

Cannot reject at alpha = 0.05

Correlation of Coventry CVAAS and Vapour meter determinations

	Coventry CVAAS	*Coventry Vap Met*
Coventry CVAAS	1	
Coventry Vap Met	0.734629127	1

Correlation coefficient = 0.73

Difference between London results, vapour meter and CVAAS

t-Test: Two-Sample Assuming Unequal Variances

	London CV	*London VM*
Mean	2273.611065	2899.68661
Variance	5597618.933	8249771.948
Observations	38	36
Hypothesized Mean Difference	0	
df	68	
t Stat	-1.020384391	
P(T<=t) one-tail	0.155581406	
t Critical one-tail	1.667572178	
P(T<=t) two-tail	0.311162811	
t Critical two-tail	1.995467755	

Correlation of London CVAAS and Vapour meter determinations

	London VM	London CV
London VM	1	
London CV	0.436969682	1

Correlation coefficient = 0.44

London - Differences between vapour meter and CVAAS results at individual positions.

1. Mann-Whitney Confidence Interval and Test

Lon1VM N = 2 Median = 1794.2

Lond1CV N = 2 Median = 2689.7

Point estimate for ETA1-ETA2 is -895.5

75.5 pct c.i. for ETA1-ETA2 is (-1390.2,-400.7)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

2. Mann-Whitney Confidence Interval and Test

Lon2CV N = 2 Median = 1857.1

Lon2VM N = 2 Median = 2024.4

Point estimate for ETA1-ETA2 is -167.3

75.5 pct c.i. for ETA1-ETA2 is (-472.3,137.7)

W = 4.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.6985

Cannot reject at alpha = 0.05

3. Mann-Whitney Confidence Interval and Test

Lon3CV N = 2 Median = 3179.1

Lon3VM N = 2 Median = 1865.3

Point estimate for ETA1-ETA2 is 1313.7

75.5 pct c.i. for ETA1-ETA2 is (573.1,2054.4)

W = 7.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

4. Mann-Whitney Confidence Interval and Test

Lon4CV N = 2 Median = 701.2

Lon4VM N = 2 Median = 8293.5

Point estimate for ETA1-ETA2 is -7592.3

75.5 pct c.i. for ETA1-ETA2 is (-7843.1,-7341.5)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

5. Mann-Whitney Confidence Interval and Test

Lon5CV N = 2 Median = 1182.5

Lon5VM N = 2 Median = 1556.8

Point estimate for ETA1-ETA2 is -374.3

75.5 pct c.i. for ETA1-ETA2 is (-803.8,55.2)

W = 4.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.6985

Cannot reject at alpha = 0.05

6. Mann-Whitney Confidence Interval and Test

Lon6CV N = 2 Median = 634.8

Lon6VM N = 2 Median = 1431.2

Point estimate for ETA1-ETA2 is -796.5

75.5 pct c.i. for ETA1-ETA2 is (-877.9,-715.1)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

7. Mann-Whitney Confidence Interval and Test

Lon7CV N = 4 Median = 3302.7

Lon7VM N = 2 Median = 1663.9

Point estimate for ETA1-ETA2 is 1638.8

89.5 pct c.i. for ETA1-ETA2 is (497.7,5900.7)

W = 18.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.1052

Cannot reject at alpha = 0.05

8. Mann-Whitney Confidence Interval and Test

Lon8CV N = 2 Median = 1608.7

Lon8VM N = 2 Median = 9686.3

Point estimate for ETA1-ETA2 is -8077.6

75.5 pct c.i. for ETA1-ETA2 is (-8272.9,-7882.3)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

9. Mann-Whitney Confidence Interval and Test

Lon9CV N = 2 Median = 1063.7

Lon9VM N = 2 Median = 1487.1

Point estimate for ETA1-ETA2 is -423.3

75.5 pct c.i. for ETA1-ETA2 is (-568.1,-278.6)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

10. Mann-Whitney Confidence Interval and Test

Lon10CV N = 2 Median = 727.8

Lon10VM N = 2 Median = 1357.5

Point estimate for ETA1-ETA2 is -629.7

75.5 pct c.i. for ETA1-ETA2 is (-772.4,-486.9)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

11. Mann-Whitney Confidence Interval and Test

Lon11CV N = 2 Median = 1055.0

Lon11VM N = 2 Median = 2035.5

Point estimate for ETA1-ETA2 is -980.5

75.5 pct c.i. for ETA1-ETA2 is (-1094.9,-866.2)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

12. Mann-Whitney Confidence Interval and Test

Lon12CV N = 2 Median = 609.9

Lon12VM N = 2 Median = 1404.7

Point estimate for ETA1-ETA2 is -794.8

75.5 pct c.i. for ETA1-ETA2 is (-885.1,-704.4)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

13. Mann-Whitney Confidence Interval and Test

Lon13CV N = 2 Median = 574.2

Lon13VM N = 3 Median = 1616.6

Point estimate for ETA1-ETA2 is -1042.4

85.1 pct c.i. for ETA1-ETA2 is (-1846.7,-437.4)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.1489

Cannot reject at alpha = 0.05

14. Mann-Whitney Confidence Interval and Test

Lon14CV N = 2 Median = 1608.7

Lon14VM N = 3 Median = 1443.7

Point estimate for ETA1-ETA2 is 209.9

85.1 pct c.i. for ETA1-ETA2 is (15.4,404.4)

W = 9.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.1489

Cannot reject at alpha = 0.05

15. Mann-Whitney Confidence Interval and Test

Lon15CV N = 4 Median = 6864.0

Lon15VM N = 2 Median = 9506.3

Point estimate for ETA1-ETA2 is -2365.5

89.5 pct c.i. for ETA1-ETA2 is (-4076.9,2002.7)

W = 12.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.4875

Cannot reject at alpha = 0.05

16. Mann-Whitney Confidence Interval and Test

Lon16CV N = 2 Median = 1079.9

Lon16VM N = 2 Median = 2019.3

Point estimate for ETA1-ETA2 is -939.3

75.5 pct c.i. for ETA1-ETA2 is (-1046.0,-832.7)

W = 3.0

Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

17. Mann-Whitney Confidence Interval and Test

Lon17CV N = 2 Median = 1127.0

Lon17VM N = 2 Median = 1423.2

Point estimate for ETA1-ETA2 is -296.2

75.5 pct c.i. for ETA1-ETA2 is (-392.4,-199.9)

W = 3.0

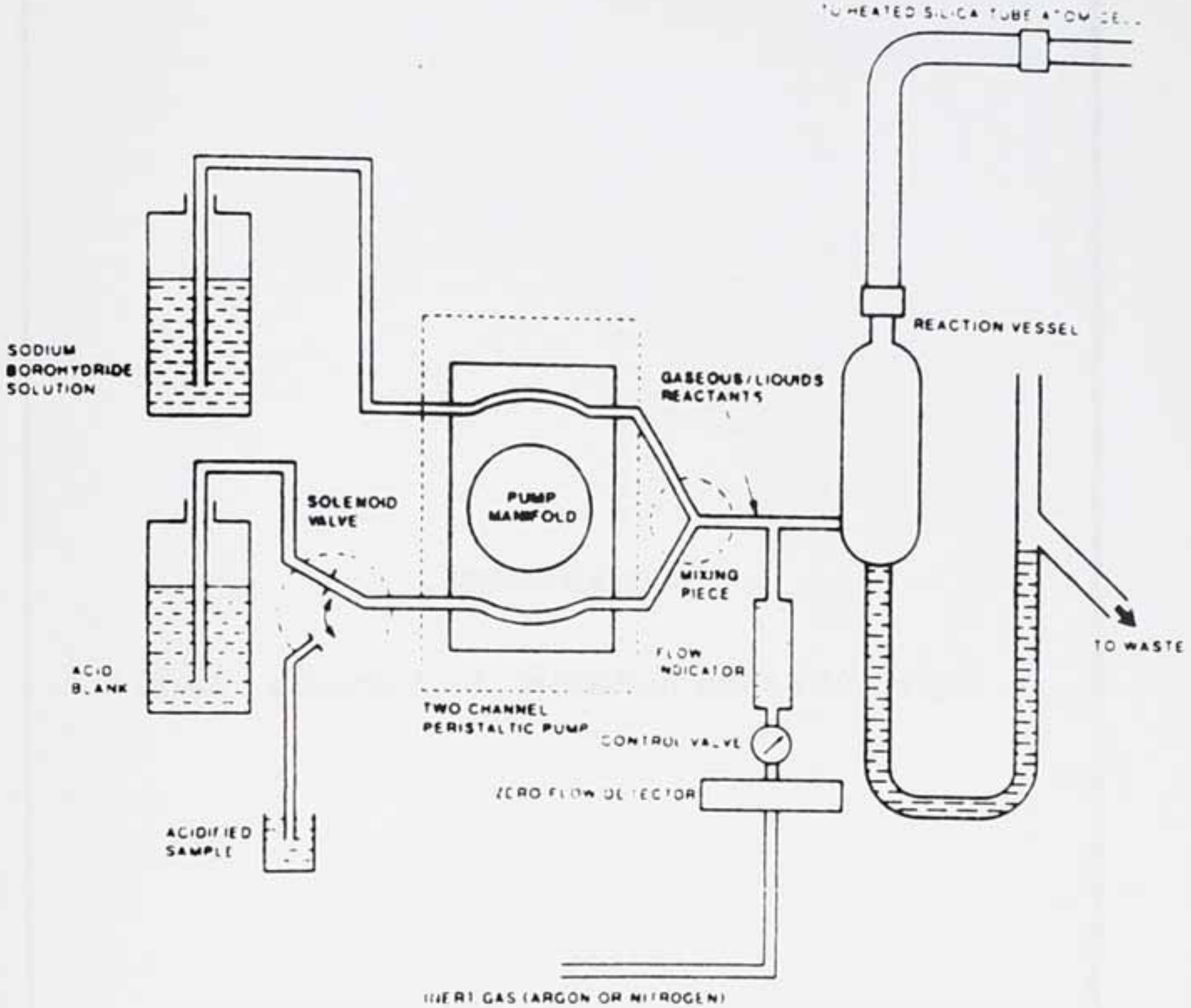
Test of ETA1 = ETA2 vs. ETA1 n.e. ETA2 is significant at 0.2453

Cannot reject at alpha = 0.05

Appendix xlii

Phillips Continuous Flow Vapour System - Schematic Diagram

Continuous Flow Vapour System
Phillips PU9360 - Schematic Diagram



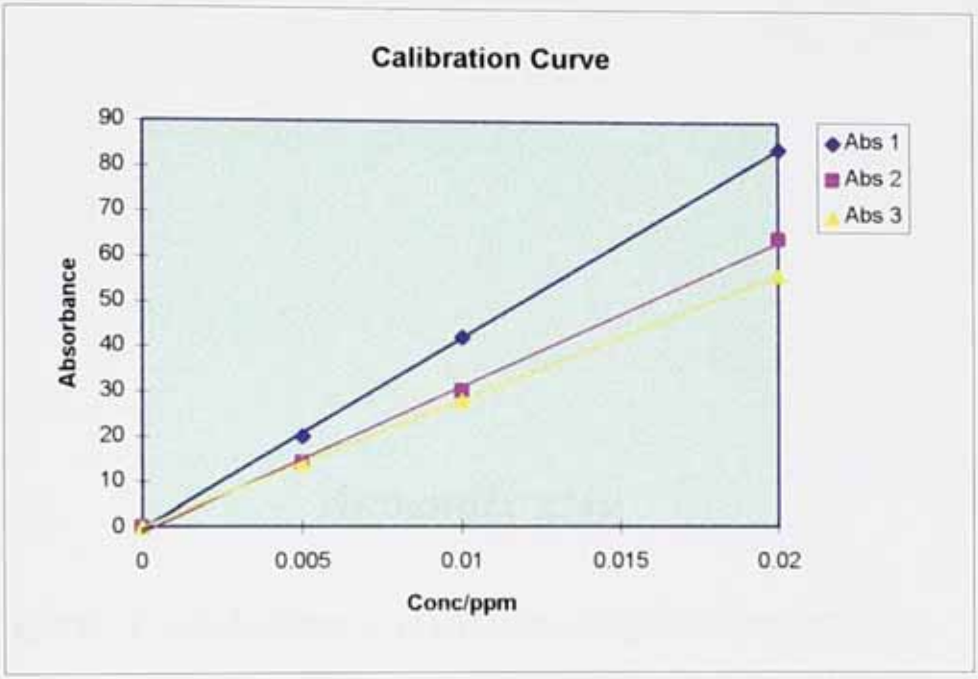
Appendix XLiii

Hair Validation - Calibration data and Graph

Hair Validation - Calibration

Data

Conc/ppm	Abs 1	Abs 2	Abs 3
0	0	0	0
0.005	20	14	14
0.01	42	30	28
0.02	84	64	56



Regression Equations

1. $y = 4217x - 0.4$
2. $y = 3222.9x - 1.2$
3. $y = 2800x$

Appendix xliv

Hair Validation - Results and Calculations

CVAAS Hair Results - Method Validation

Sample	Wt / g	Std Additio	Abs.	Calib.	Conc/ppm	Sample Con	Calculation of Percentage Recovery					Std Dev
No.		/ug		Ref.		/ppm	Means(x)	Mass Hg(y)	Exp.Hg(x*z)	Recovery	% Recovery	sample conc
1a	0.0502		-ve									
1b	0.0241		-ve									
1c	0.0508	0.25	0								0.00	
1d	0.0534		-ve									
1e	0.0561		-ve									
2a	0.0398		9	1	2.23E-03	0.560						
2b	0.1777		36	2	1.15E-02	0.650						
2c	0.0532	0.25	79	3	2.82E-02		0.643	0.282	0.034	0.248	99.18	0.058
2d	0.0456		9	2	3.16E-03	0.694						
2e	0.0381		7	2	2.54E-03	0.668						
3a	0.0561		13	1	3.18E-03	0.566						
3b	0.0495	0.25	93	1	2.21E-02		0.535	0.221	0.026	0.195	78.00	0.100
3c	0.0456	0.25	86	1	2.05E-02		0.535	0.205	0.024	0.180	72.20	0.100
3d	0.0748		9	2	3.16E-03	0.423						
3e	0.0615		11	2	3.79E-03	0.616						
4a	0.0482		8	3	2.86E-03	0.593						
4b	0.0427	0.25	93	1	2.34E-02		0.499	0.234	0.021	0.213	85.14	0.069
4c	0.0228		3	3	1.07E-03	0.470						
4d	0.0248		3	3	1.07E-03	0.432						
4e	0.0572		8	3	2.86E-03	0.500						

Linear Regression

1. $y = -0.40 + 4217x$
2. $y = -1.20 + 3222.9x$
3. $y = 2800\,x$

Calculation of Percentage Recovery	
Mean conc. of samples without Std Addn	x ug g-1
Mass Hg in sample with Std Addn	y ug
Mass sample	z g
Exp. mass Hg from smple(excl. std addn)	x * z ug
Recovery of std add	y - (x*y) ug
Percentage recovery	(y-(x*z))*100/0.25

Appendix XLV

Hair Key

Key to Hair Results

NO	CREMATORIUM	GROUP	AGE	SEX	HOURS	OCCUPATION	FILLINGS	CREM'N NO.	EPA	COMMENTS	HAIR
1	c	C	40	F	0	CONTROL	10				1.210
2	c	C	40	F	0	CONTROL	11				3.980
3	Chesterfield	T	48	M	39	ADMIN	0	2100	N	upgrade complete '98	5.280
4	Stafford	T	39	M	39	CREMATOR	6	1400	Y		1.450
5	Stafford	T	23	M	39	CREMATOR	12	1400	Y		1.510
6	Isle of Wt	T	46	F	25	ADMIN	2	1475	N	New crems installed	1.520
7	Isle of Wt	T	61	M	39	GROUNDS	0	1475	N	in 1997	0.700
8	Isle of Wt	T	39	M	39	CREMATOR	1	1475	N		0.880
9	Isle of Wt	T	53	M	39	ADMIN	6	1475	N		1.330
10	Tameside	T	28	M	35	CREMATOR	2	2307	N	3 cremators	3.220
11	Tameside	T	60	M	35	ADMIN	0	2307	N	replacement 1998	3.100
12	SW Middles	T	40	M	37	ADMIN	6	2781	Y	comply most of time?	2.070
13	Rawdon	T	40	F	37	ADMIN	6				1.360
14	Rawdon	T	32	M	39	CREMATOR	11				1.450
15	Rawdon	T	47	M	39	CREMATOR	10				0.840
16	Colchester	T	43	M	37	CREMATOR	0	1669	N	New crems 1997	2.340
17	Colchester	T	37	M	37	ADMIN	8	1669	N		1.460
18	c	C	26	M	0	CONTROL	5				0.770
19	c	C	26	M	0	CONTROL	5				0.900
20	c	C	40	M	0	CONTROL	10				0.900
21	Llwydcoed	T	57	M	39	CREMATOR	10	1296	Y	Cremators replaced	1.960
22	Llwydcoed	T	45	M	39	GROUNDS	4	1296	Y	stack height increased	2.150
23	Llwydcoed	T	47	M	39	GROUNDS	0	1296	Y		2.640
24	Bretby	T	49	F	16	ADMIN	6	1270	Y	New crems, 1994/5	4.340
25	Bretby	T	38	M	37	ADMIN	8	1270	Y		3.870
26	Bretby	T	45	F	25	ADMIN	5	1270	Y		2.980
27	Bretby	T	59	M	39	CREMATOR	3	1270	Y		6.290
28	c	C	12	F	0	CONTROL	1				0.310
29	c	C	13	M	0	CONTROL	0				0.660
30	c	C	44	F	0	CONTROL	7				1.300
31	c	C	10	M	0	CONTROL	0				1.290
32	d	D	40	F	7	DENTIST	0				6.970

Key to Hair Results

NO	CREMATORIUM	GROUP	AGE	SEX	HOURS	OCCUPATION	FILLINGS	CREM'N NO.	EPA	COMMENTS	HAIR
33	d	D	36	M	35	DENTIST	0				0.330
34	Poole	T	54	M	39	CREMATOR	5	2400	Y	Furnaces operate	1.470
35	Poole	T	36	M	39	GROUNDS	10	2400	Y	under BS 6000	0.470
36	Poole	T	39	M	39	CREMATOR	5	2400	Y	(Formerly BS 3000)	1.870
37	Havering	T	59	M	16	ADMIN	10	3426	N	7 cremators, 1	
38	Havering	T	59	M	36	ADMIN	10	3426	N	compliant,installed '96	2.090
39	Havering	T	36	M	2	GROUNDS	16	3426	N	Others due in '98	
40	Havering	T	32	M	32	GROUNDS	0	3426	N		
41	Havering	T	34	M	36	GROUNDS	4	3426	N		
42	Havering	T	50	F	36	ADMIN	8	3426	N		3.470
43	Havering	T	62	M	36	GROUNDS	12	3426	N		1.090
44	Havering	T	40	M	36	GROUNDS	3	3426	N		6.890
45	Havering	T	50	F	36	ADMIN	11	3426	N		1.890
46	Havering	T	52	F	36	ADMIN	9	3426	N		2.810
47	Havering	T	54	F	36	ADMIN	9	3426	N		4.970
48	Havering	T	45	F	35	ADMIN	11	3426	N		1.770
49	Havering	T	44	F	36	ADMIN	12	3426	N		1.000
50	Havering	T	45	F	36	ADMIN	10	3426	N		1.000
51	Hyndburn	T	21	M	3	CREMATOR	8	1030	N	2 new cremators	0.860
52	Hyndburn	T	45	M	4	CREMATOR	9	1030	N	installed 1997	1.170
53	Hyndburn	T	33	M	38	ADMIN	5	1030	N		0.910
54	Hyndburn	T	36	M	3	CREMATOR	3	1030	N		2.160
55	Southport	T	49	M	37	CREMATOR	10	1871	N	1 in 3 in '93	0.880
56	Southport	T	53	M	37	CREMATOR	2	1871	N	2 in '97/8	1.520
57	Southport	T	49	M	37	CREMATOR	6	1871	N		4.810
58	Southport	T	33	M	37	CREMATOR	6	1871	N		
59	Southport	T	54	M	35	ADMIN	7	1871	N		1.470
60	Southport	T	41	M	35	ADMIN	6	1871	N		1.170
61	c	C	30	M	0	CONTROL	6				0.350
62	c	C	50	M	0	CONTROL	0				1.730
63	c	C	30	M	0	CONTROL	4				0.000
64	c	C	49	M	0	CONTROL	10				0.560

Key to Hair Results

NO	CREMATORIUM	GROUP	AGE	SEX	HOURS	OCCUPATION	FILLINGS	CREM'N NO.	EPA	COMMENTS	HAIR
65	c	C	32	M	0	CONTROL	2				1.960
66	Douglasmuir	T	37	M	37	CREMATOR	8	543	Y		0.940
67	Douglasmuir	T	31	M	37	ADMIN	6	543	Y		0.000
68	Douglasmuir	T	42	F	37	ADMIN	12	543	Y		0.000
69	Douglasmuir	T	29	M	37	ADMIN	6	543	Y		0.000
70	Douglasmuir	T	28	M	37	CREMATOR	2	543	Y		0.000
71	Blackley	T	49	M	40	ADMIN	5				1.270
72	Stockport	T	49	M	50	CREMATOR	4				1.240
73	Stockport	T	46	M	50	CREMATOR	12				0.650
74	Stockport	T	42	M	37	ADMIN	10				1.370
75	Stockport	T	31	F	37	ADMIN	10				0.590
76	Harlow	T	43	M	38	GROUNDS	8	966	N		0.000
77	Harlow	T	64	M	42	CREMATOR	0	966	N		0.530
78	Harlow	T	49	M	42	CREMATOR	5	966	N		9.380
79	Harlow	T	32	M	42	CREMATOR	8	966	N		
80	Harlow	T	47	F	37	ADMIN	9	966	N		
81	Paisley	T	53	M	44	CREMATOR	7	1612	Y	2 cremators	2.160
82	Paisley	T	50	M	44	ADMIN	0	1612	Y		1.230
83	Guildford	T	47	M	45	CREMATOR	10	1724	N	1 in 3 (96) Complete 98	1.390
84	Walsall	T	46	M	40	CREMATOR	9	1941	N		0.590
85	Walsall	T	44	M	39	CREMATOR	9	1941	N		1.330
86	Dudley	T	31	M	37	CREMATOR	7	1788	Y		6.590
87	Dudley	T	49	M	37	CREMATOR	3	1788	Y		1.070
88	S Essex	T	48	F	6	ADMIN	12	3426	N		1.310
89	Burnley	T	56	M	39	CREMATOR	1	1738	Y	3 new replaced 4,'95	0.760
90	Fylde	T	64	M	39	CREMATOR	6	1367	Y	installed 1994	1.030
91	Perth	T	35	M	38	ADMIN	11	1134	N	Replaced '97	0.910
92	Perth	T	56	M	39	CREMATOR	7	1134	N		0.520
93	Perth	T	48	M	39	CREMATOR	2	1134	N		
94	IBCA	T	43	F	40	ADMIN	11				2.320
95	c	C	45	F	0	CONTROL	8				0.390
96	c	C	45	F	0	CONTROL	8				1.880

Key to Hair Results

NO	CREMATORIUM	GROUP	AGE	SEX	HOURS	OCCUPATION	FILLINGS	CREM'N NO.	EPA	COMMENTS	HAIR
97	c	C	40	M	0	CONTROL	10				2.150
98	c	C	40	M	0	CONTROL	0				2.570
99	c	C	35	F	0	CONTROL	8				1.210
100	c	C	40	F	0	CONTROL	0				1.550
101	c	C	40	F	0	CONTROL	8				0.340
102	c	C	40	F	0	CONTROL	11				1.060
103	c	C	35	M	0	CONTROL	5				0.510
104	Coventry	T	41	F	37	ADMIN	10				1.230
105	Coventry	T	36	M	36	ADMIN	5				0.340
106	Coventry	T	29	M	39	GROUNDS	3				0.31
107	Coventry	T	39	M	39	GROUNDS	0				0.24
108	Coventry	T	51	M	37	ADMIN	10				1.61
109	Coventry	T	44	M	44	GROUNDS	7				0.42
110	c	C	59	F	0	CONTROL	0				0.37
111	c	C	16	M	0	CONTROL	4				0.77
112	c	C	73	F	0	CONTROL	0				0.24
113	c	C	71	F	0	CONTROL	0				0.48
114	c	C	80	F	0	CONTROL	0				2.44
115	c	C	69	F	0	CONTROL	12				0.54
116	c	C	73	M	0	CONTROL	0				0
117	c	C	69	F	0	CONTROL	14				0.68
118	c	C	75	M	0	CONTROL	1				0.96
119	c	C	39	F	0	CONTROL	12				0.71
120	c	C	70	F	0	CONTROL	0				0.53
121	c	C	70	F	0	CONTROL	1				0.13
122	Crewe	T	52	M	39	CREMATOR	2				2.1
123	Crewe	T	26	M	39	CREMATOR	8				0.61
124	Crewe	T	50	M	39	ADMIN	0				2.71
125	Bedford	T	50	M	40	CREMATOR	11	1463	Y	New crem - 1995	1.18
126	Cornwall	T	37	M	37	GROUNDS	14	2735	Y	3 compliant in '95	0.76
127	S Essex	T	40	M	39	CREMATOR	10	3426	N		0.960
128	Glasgow	T	49	M	40	CREMATOR	0				0.470

Key to Hair Results

NO	CREMATORIUM	GROUP	AGE	SEX	HOURS	OCCUPATION	FILLINGS	CREM'N NO.	EPA	COMMENTS	HAIR
129	Glasgow	T	40	M	46	CREMATOR	4				0.280
130	Glasgow	T	42	M	40	CREMATOR	8				0.000
131	Bath	T	58	F	30	ADMIN	0				1.320
132	Bath	T	48	F	22	ADMIN	7				0.710
133	Bath	T	50	F	22	ADMIN	17				0.910
134	Bath	T	64	M	37	CREMATOR	0				0.600
135	Bath	T	37	M	37	CREMATOR	10				0.800
136	Bath	T	54	M	37	CREMATOR	2				2.380
137	Bath	T	53	M	37	CREMATOR	2				0.000
138	Bath	T	49	M	37	ADMIN	0				0.480
139	Bath	T	58	M	37	ADMIN	7				1.040
140	Bath	T	17	F	24	ADMIN	0				
141	Darlington	T	55	M	39	CREMATOR	0	2000	N	3 new crems 1997	0.850
142	Darlington	T	34	M	39	CREMATOR	7	2000	N		0.640
143	Darlington	T	63	M	39	GROUNDS	0	2000	N		0.440
144	Gwent	T	29	M	45	CREMATOR	7	2855	Y	Evans universal installed 1993	0.760
145	Gwent	T	37	M	45	CREMATOR	10	2855	Y		0.760
146	Gwent	T	53	M	20	ADMIN	0	2855	Y		0.640
147	c	C	59	F	0	CONTROL	21				0.800
148	c	C	32	M	0	CONTROL	4				0.4
149	c	C	43	F	0	CONTROL	10				1.35
150	c	C	36	F	0	CONTROL	0				0.22
151	c	C	36	M	0	CONTROL	6				0.93
152	c	C	45	M	0	CONTROL	0				0.73
153	c	C	49	F	0	CONTROL	10				0.54
154	c	C	41	F	0	CONTROL	10				0.94
155	c	C	49	M	10	CONTROL	10				1.1
156	c	C	29	M	0	CONTROL	6				1.15
157	Yeovil	T	36	M	37	CREMATOR	5	1600	Y		0.86
158	Yeovil	T	27	M	37	CREMATOR	4	1600	Y		0.61
159	c	C	48	F	0	CONTROL	10				1.08

Appendix XLVI

Hair Samples - Results, Calculations, Calibration Data and Graphs

Hair Analyses - Data and Calculations

Sample no	Id No	Hair wt/g	Abs Unit	Calib	Conc/ug ml-	Total Hg/ug	Conc/ug g-1	Mean Conc
1	105	0.1777	6	a	0.0024	0.0602	0.34	0.34
2	121	0.347	5	a	0.0018	0.0453	0.13	
2b	121	0.2295	4	a	0.0012	0.0304	0.13	0.13
3	111	0.4059	25	a	0.0138	0.3439	0.85	
3b	111	0.2172	12	a	0.0060	0.1498	0.69	0.77
4	112	0.3125	6	a	0.0024	0.0602	0.19	
4b	112	0.2564	7	a	0.0030	0.0752	0.29	0.24
5	120	0.3956	17	a	0.0090	0.2244	0.57	
5b	120	0.2998	12	a	0.0060	0.1498	0.50	0.53
6	119	0.1681	10	a	0.0048	0.1199	0.71	0.71
7	118	0.2506	18	a	0.0096	0.2394	0.96	
7a	118	0.1539	12	a	0.0060	0.1498	0.97	0.96
8	117	0.3936	20	a	0.0108	0.2692	0.68	
8a	117	0.3542	18	a	0.0096	0.2394	0.68	0.68
9	116	0.3639	0	a	0.0000	0.0000	0.00	0.00
9a	116	0.2316	0	a	0.0000	0.0000	0.00	0.00
10	115	0.3029	13	a	0.0066	0.1647	0.54	
10a	115	0.2232	10	a	0.0048	0.1199	0.54	0.54
11	107	0.2518	6	a	0.0024	0.0602	0.24	
11a	107	0.1852	5	a	0.0018	0.0453	0.24	0.24
12	106	0.2344	7	a	0.0030	0.0752	0.32	
12a	106	0.1551	5	a	0.0018	0.0453	0.29	0.31
13	151	0.1926	14	a	0.0072	0.1797	0.93	0.93
14	114	0.2086	36	a	0.0203	0.5081	2.44	
14a	114	0.1889	33	a	0.0185	0.4633	2.45	2.44
15	113	0.3516	14	a	0.0072	0.1797	0.51	
15a	113	0.1704	7	a	0.0030	0.0752	0.44	0.48
16	110	0.2325	8	a	0.0036	0.0901	0.39	
16a	110	0.1703	6	a	0.0024	0.0602	0.35	0.37
17	109	0.3240	11	a	0.0054	0.1349	0.42	
17a	109	0.1406	6	a	0.0024	0.0602	0.43	0.42
18	108	0.2224	27	a	0.0149	0.3737	1.68	
18a	108	0.223	25	a	0.0138	0.3439	1.54	1.61
19	104	0.1220	12	a	0.0060	0.1498	1.23	1.23
20	137	0.0266	2	a			0.00	0.00
21	136	0.0190	5	a	0.0018	0.0453	2.38	2.38
22	135	0.0285	3.5	a	0.0009	0.0229	0.80	0.80
23	134	0.0379	3.5	a	0.0009	0.0229	0.60	0.60
24	133	0.2377	17	a	0.0090	0.2244	0.94	
24a	133	0.1899	13	a	0.0066	0.1647	0.87	0.91
25	152	0.2445	14	a	0.0072	0.1797	0.73	
25a	152	0.1851	11	a	0.0054	0.1349	0.73	0.73
26	132	0.1477	9	a	0.0042	0.1050	0.71	0.71

Hair Analyses - Data and Calculations

Sample no	Id No	Hair wt/g	Abs Unit	Calib	Conc/ug ml-	Total Hg/ug	Conc/ug g-1	Mean Conc
27	131	0.0173	3.5	a	0.0009	0.0229	1.32	1.32
28	153	0.1960	9	a	0.0042	0.1050	0.54	
28a	153	0.2714	12	a	0.0060	0.1498	0.55	0.54
29	155	0.2035	17	a	0.0090	0.2244	1.10	
29a	155	0.1925	16	a	0.0084	0.2095	1.09	1.10
30	156	0.1172	11	a	0.0054	0.1349	1.15	1.15
31	149	0.1665	17	a	0.0090	0.2244	1.35	1.35
32	154	0.1752	13	a	0.0066	0.1647	0.94	0.94
33	130	0.0100	1	a	-0.0006		0.00	0.00
34	129	0.1647	5	a	0.0018	0.0453	0.28	0.28
35	128	0.0641	4	a	0.0012	0.0304	0.47	0.47
36	125	0.0194	3.5	a	0.0009	0.0229	1.18	1.18
37	150	0.2044	5	a	0.0018	0.0453	0.22	
37a	150	0.1358	4	a	0.0012	0.0304	0.22	0.22
38	148	0.1874	7	a	0.0030	0.0752	0.40	
38a	148	0.1154	5	a	0.0018	0.0453	0.39	0.40
39	146	0.1402	8	a	0.0036	0.0901	0.64	
39a	146	0.1904	10	a	0.0048	0.1199	0.63	0.64
40	144	0.0600	5	a	0.0018	0.0453	0.76	0.76
41	145	0.0600	5	a	0.0018	0.0453	0.76	0.76
42	141	0.0710	6	a	0.0024	0.0602	0.85	0.85
43	142	0.2101	11	a	0.0054	0.1349	0.64	
43a	142	0.1859	10	a	0.0048	0.1199	0.65	0.64
44	143	0.1372	6	a	0.0024	0.0602	0.44	0.44
45	140	Insufficient						
46	139	0.0436	5	a	0.0018	0.0453	1.04	1.04
47	138	0.0944	5	a	0.0018	0.0453	0.48	0.48
48	127	0.2179	16	a	0.0084	0.2095	0.96	
48a	127	0.2475	18	a	0.0096	0.2394	0.97	0.96
49	126	0.4537	25	a	0.0138	0.3439	0.76	
49a	126	0.1951	12	a	0.0060	0.1498	0.77	0.76
50	159	0.1806	15	a	0.0078	0.1946	1.08	
50a	159	0.1512	13	a	0.0066	0.1647	1.09	1.08
51	147	0.3177	19	a	0.0102	0.2543	0.80	
51a	147	0.2412	15	a	0.0078	0.1946	0.81	0.80
52	122	0.0145	4	a	0.0012	0.0304	2.10	2.10
53	123	0.2535	13	a	0.0066	0.1647	0.65	
53a	123	0.1145	7	a	0.0030	0.0752	0.66	0.65
54	124	0.1102	22	a	0.0120	0.2991	2.71	2.71
55	157	0.1575	11	a	0.0054	0.1349	0.86	
55a	157	0.2064	14	a	0.0072	0.1797	0.87	0.86
56	158	0.0500	4	a	0.0012	0.0304	0.61	0.61
57	13	0.0626	8	b	0.0034	0.0853	1.36	1.36
58	12	0.0211	5	b	0.0018	0.0438	2.07	2.08

Hair Analyses - Data and Calculations

Sample no	Id No	Hair wt/g	Abs Unit	Calib	Conc/ug ml-	Total Hg/ug	Conc/ug g-1	Mean Conc
59	14	0.0458	7	c	0.0027	0.0664	1.45	1.45
60	5	0.0506	8	c	0.0031	0.0765	1.51	1.51
61	2	0.0932	37	c	0.0148	0.3708	3.98	3.98
62	9	0.0330	5	b	0.0018	0.0438	1.33	1.33
63	8	0.0809	7	b	0.0029	0.0714	0.88	0.88
64	6	0.0436	7	c	0.0027	0.0664	1.52	1.52
65	7	0.0231	3	b	0.0006	0.0161	0.70	0.70
66	10	0.0179	6	b	0.0023	0.0576	3.22	3.22
67	11	0.0410	13	c	0.0051	0.1272	3.10	3.10
68	16	0.0588	14	c	0.0055	0.1374	2.34	2.34
69	17	0.0678	9	b	0.0040	0.0991	1.46	1.46
70	18	0.1465	10	b	0.0045	0.1129	0.77	0.77
71	4	0.0875	11	b	0.0051	0.1268	1.45	1.45
72	3	0.0633	26	b	0.0134	0.3342	5.28	5.28
73	94	0.0903	17	b	0.0084	0.2097	2.32	2.32
74	21	0.0436	8	b	0.0034	0.0853	1.96	1.96
75	22	0.0350	7	a	0.0030	0.0752	2.15	2.15
76	23	0.0481	11	b	0.0051	0.1268	2.64	2.64
77	24	0.0173	7	a	0.0030	0.0752	4.34	4.34
78	25	0.0310	10	a	0.0048	0.1199	3.87	3.87
79	26	0.0325	10	c	0.0039	0.0968	2.98	2.98
80	27	0.0167	9	a	0.0042	0.1050	6.29	6.29
81	28	0.2295	7	b	0.0029	0.0714	0.31	
81a	28	0.1823	6	a	0.0023	0.0576	0.32	0.31
82	31	0.1197	13	b	0.0062	0.1544	1.29	1.29
83	29	0.1154	8	c	0.0031	0.0765	0.66	0.66
84	30	0.1272	13	a	0.0066	0.1647	1.30	1.30
85	34	0.0157	3.5	b	0.0009	0.0230	1.47	1.47
86	32	0.0279	15	a	0.0078	0.1946	6.97	6.97
87	33	0.0070	2	b	0.0001	0.0023	0.33	0.33
88	36	0.0603	10	b	0.0045	0.1129	1.87	1.87
89	19	0.0851	8	c	0.0031	0.0765	0.90	0.90
90	35	0.0218	2	d	0.0004	0.0103	0.47	0.47
91	15	0.0307	3	d	0.0010	0.0259	0.84	0.84
92	38	0.0341	7	b	0.0029	0.0714	2.09	2.09
93	1	0.1505	13	d	0.0073	0.1814	1.21	1.21
94	48	0.0247	5	b	0.0018	0.0438	1.77	1.77
95	20	0.1095	9	b	0.0040	0.0991	0.90	0.90
96	49	0.0571	5	d	0.0023	0.0570	1.00	1.00
97	39	0.0096	1	d	0.0000	0.0000	0.00	0.00
98	42	0.0191	7	c	0.0027	0.0664	3.47	3.47
99	37	insuff						
100	40	insuff						
101	41	insuff						

Hair Analyses - Data and Calculations

Sample no	Id No	Hair wt/g	Abs Unit	Calib	Conc/ug ml-	Total Hg/ug	Conc/ug g-1	Mean Conc
102	43	0.1257	14	c	0.0055	0.1374	1.09	1.09
103	44	0.0184	11	b	0.0051	0.1268	6.89	6.89
104	45	0.0301	5	d	0.0023	0.0570	1.89	1.89
105	46	0.1103	31	c	0.0124	0.3099	2.81	2.81
106	47	0.0338	17	c	0.0067	0.1678	4.97	4.97
107	50	0.0258	3	c	0.0010	0.0258	1.00	1.00
108	51	0.1132	10	c	0.0039	0.0968	0.86	0.86
109	52	0.0481	6	c	0.0022	0.0562	1.17	1.17
110	53	0.1545	12	b	0.0056	0.1406	0.91	0.91
111	54	0.0354	8	c	0.0031	0.0765	2.16	2.16
112	55	0.1794	16	c	0.0063	0.1577	0.88	
112a	55	0.1436	13	c	0.0051	0.1272	0.89	0.88
113	56	0.0273	4	d	0.0017	0.0414	1.52	1.52
114	57	0.0180	9	c	0.0035	0.0867	4.81	4.81
115	58	insuff						
116	59	0.0601	7	d	0.0035	0.0881	1.47	1.47
117	60	0.0488	5	d	0.0023	0.0570	1.17	1.17
118	61	0.0517	2.5	d	0.0007	0.0181	0.35	0.35
119	62	0.1085	19	c	0.0075	0.1881	1.73	1.73
120	63	0.1292	1	d	0.0000	0.0000	0.00	0.00
121	64	0.1725	10	c	0.0039	0.0968	0.56	
121a	64	0.1351	8	c	0.0031	0.0765	0.57	0.56
122	65	0.1533	30	c	0.0120	0.2998	1.96	1.96
123	66	0.0384	4	c	0.0014	0.0359	0.94	0.94
124	67	insuff						
125	68	insuff						
126	69	insuff						
127	70	insuff						
128	71	0.0762	10	c	0.0039	0.0968	1.27	1.27
129	72	0.0335	4	d	0.0017	0.0414	1.24	1.24
130	73	0.1349	7	d	0.0035	0.0881	0.65	0.65
131	74	0.0705	10	c	0.0039	0.0968	1.37	1.37
132	75	0.2315	14	c	0.0055	0.1374	0.59	0.59
133	76	insuff						
134	77	0.0785	4	d	0.0017	0.0414	0.53	0.53
135	78	0.0114	11	c	0.0043	0.1070	9.38	9.38
136	79	insuff						
137	80	insuff						
138	81	0.0120	3	d	0.0010	0.0259	2.16	2.16
139	82	0.0375	5	c	0.0018	0.0461	1.23	1.23
140	83	0.0185	3	c	0.0010	0.0258	1.39	1.39
141	84	0.0952	6	c	0.0022	0.0562	0.59	0.59
142	85	0.0882	12	c	0.0047	0.1171	1.33	1.33
143	89	0.1672	13	c	0.0051	0.1272	0.76	

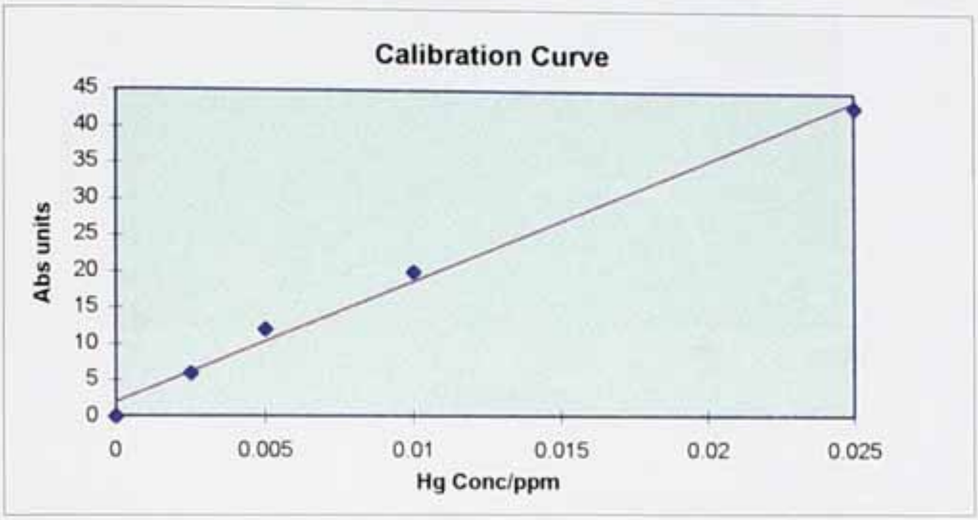
Hair Analyses - Data and Calculations

Sample no	Id No	Hair wt/g	Abs Unit	Calib	Conc/ug ml-	Total Hg/ug	Conc/ug g-1	Mean Conc
143a	89	0.1426	11	c	0.0043	0.1070	0.75	0.76
144	90	0.0545	6	c	0.0022	0.0562	1.03	1.03
145	91	0.1175	11	c	0.0043	0.1070	0.91	0.91
146	92	0.1473	8	c	0.0031	0.0765	0.52	
146a	92	0.1295	7	c	0.0027	0.0664	0.51	0.52
147	93	insuff						
148	88	0.0741	10	c	0.0039	0.0968	1.31	1.31
149	87	0.0526	6	c	0.0022	0.0562	1.07	1.07
150	86	insuff						
151	95	0.1959	8	c	0.0031	0.0765	0.39	
151a	95	0.3066	12	c	0.0047	0.1171	0.38	0.39
152	96	0.1002	19	c	0.0075	0.1881	1.88	1.88
153	97	0.1253	27	c	0.0108	0.2693	2.15	2.15
154	98	0.1327	34	c	0.0136	0.3404	2.57	2.57
155	99	0.0964	12	c	0.0047	0.1171	1.21	1.22
156	100	0.1737	27	c	0.0108	0.2693	1.55	
156a	100	0.1681	26	c	0.0104	0.2592	1.54	1.55
157	101	0.2264	8	c	0.0031	0.0765	0.34	
157a	101	0.3351	12	c	0.0047	0.1171	0.35	0.34
158	102	0.1489	16	c	0.0063	0.1577	1.06	1.06
159	103	0.1886	11	c	0.0043	0.1070	0.57	
159a	103	0.2538	12	c	0.0047	0.1171	0.46	0.51

Hair Calibration Curve and Data - a

Hair Calibration Data

Hg Conc/ppm	Abs units
0	0
0.0025	6
0.005	12
0.01	20
0.025	43



SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	0.99
Adjusted R Square	0.99
Standard Error	1.73
Observations	5

RESIDUAL OUTPUT

Observation	*Predicted Abs*	*Residuals*
1	2.0	-2.0
2	6.2	-0.2
3	10.3	1.7
4	18.7	1.3
5	43.8	-0.8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1107.8	1107.8	369.4	0.0003
Residual	3	9.0	3.0		
Total	4	1116.8			

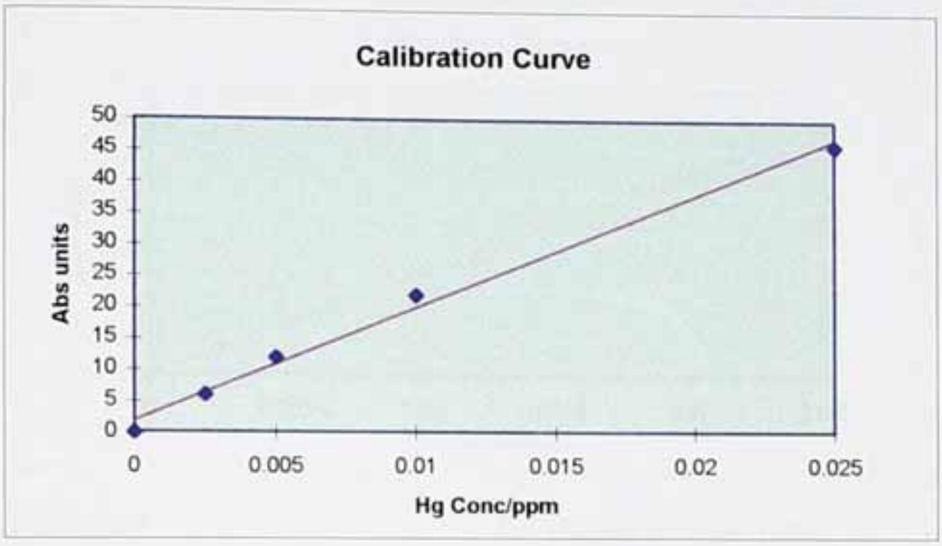
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.97	1.07	1.83	0.16
Hg Conc/ppm	1674.68	87.13	19.22	0.0003

Regression Equation: $y = 1674.68x + 1.96$

Hair Calibration Curve and Data - b

Hair Calibration Data

Hg Conc/ppm	Abs units
0	0
0.0025	6
0.005	12
0.01	22
0.025	46



SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	0.99
Adjusted R Square	0.99
Standard Error	1.84
Observations	5

RESIDUAL OUTPUT

Observation	*Predicted Abs*	*Residuals*
1	1.84	-1.84
2	6.35	-0.35
3	10.87	1.13
4	19.91	2.09
5	47.03	-1.03

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1290.62	1290.62	380.44	0.0003
Residual	3	10.18	3.39		
Total	4	1300.80			

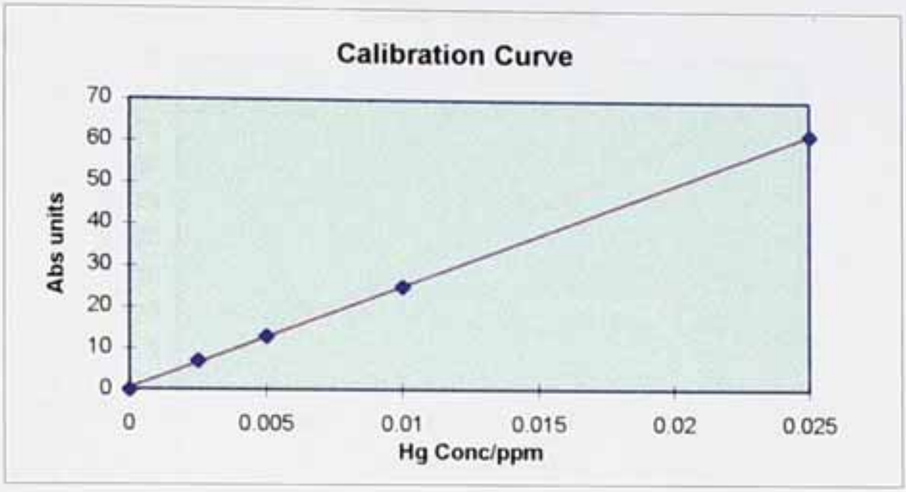
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.84	1.14	1.61	0.21
Hg Conc/ppm	1807.59	92.67	19.50	0.0003

Regression Equation: $y = 1807.59x + 1.83$

Hair Calibration Curve and Data - c

Hair Calibration Data

Hg Conc/ppm	Abs units
0	0
0.0025	7
0.005	13
0.01	25
0.025	62



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999912869
R Square	0.999825746
Adjusted R Square	0.999767661
Standard Error	0.373149442
Observations	5

RESIDUAL OUTPUT

Observation	*Predicted Abs*	*Residuals*
1	0.46	-0.46
2	6.62	0.38
3	12.78	0.22
4	25.09	-0.09
5	62.04	-0.04

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2396.78	2396.78	17213.25	9.76E-07
Residual	3	0.42	0.14		
Total	4	2397.20			

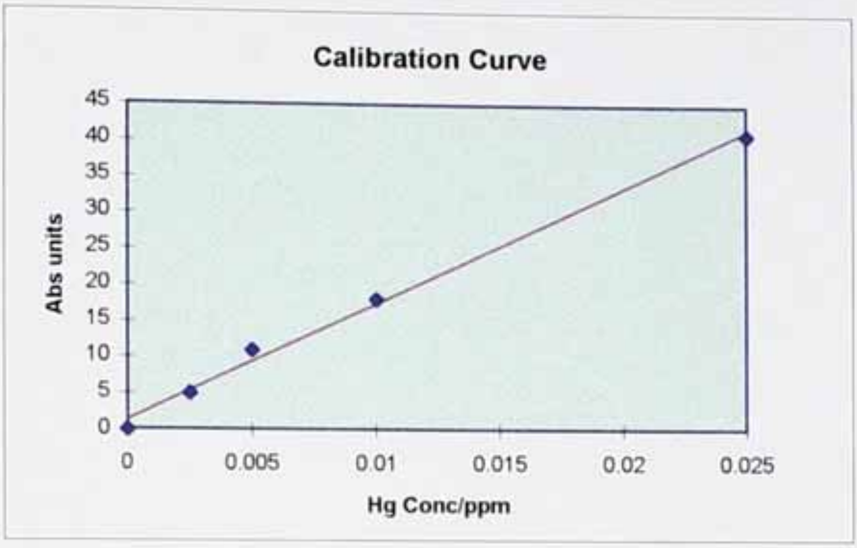
	Coefficients	*tandard Error*	*t Stat*	*P-value*
Intercept	0.46	0.23	2.00	0.14
Hg Conc/ppm	2463.29	18.78	131.20	9.76E-07

Regression Equation: $y = 2463.29x + 0.46$

Hair Calibration Curve and Data - d

Hair Calibration Data

Hg Conc/ppm	Abs units
0	0
0.0025	5
0.005	11
0.01	18
0.025	41



SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	0.99
Adjusted R Square	0.99
Standard Error	1.31
Observations	5

RESIDUAL OUTPUT

Observation	Predicted Abs	Residuals
1	1.34	-1.34
2	5.35	-0.35
3	9.37	1.63
4	17.41	0.59
5	41.53	-0.53

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1020.82	1020.82	591.53	0.0002
Residual	3	5.18	1.73		
Total	4	1026			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.34	0.81	1.64	0.20
Hg Conc/ppm	1607.59	66.10	24.32	0.0002

Regression Equation: y = 1607.59x + 1.33

Appendix XLVII

Hair Statistics

Hair Statistics

Difference between hair mercury levels for control and trial groups

Current selection: group = "C" or group = "T"

GROUP	Obs	Total	Mean	Variance	Std Dev
C	46	45	0.97	0.58	0.76
T	97	163	1.68	2.53	1.59
Difference			-0.71		

GROUP	Minimum	25%ile	Median	75%ile	Maximum	Mode
C	0.000	0.48	0.78	1.21	3.98	0.00
T	0.000	0.76	1.23	2.07	9.38	0.76

ANOVA (For normally distributed data only)

Variation	SS	df	MS	F statistic	p-value	t-value
Between	15.55	1	15.55	8.15	0.005	2.85
Within	269.06	141	1.91			
Total	284.62	142				

Bartlett's test for homogeneity of variance

Bartlett's chi square = 26.44 deg freedom = 1 p-value = 0.000

Bartlett's Test shows the variances in the samples to differ.

Use non-parametric results below rather than ANOVA.

Mann-Whitney or Wilcoxon Two-Sample Test (Kruskal-Wallis test for two groups)

Kruskal-Wallis H (equivalent to Chi square) = 9.94

Degrees of freedom = 1

p value = 0.0016

Difference between hair values for different occupations of trial group

Current selection: group = "T"

OCCUP	Obs	Total	Mean	Variance	Std Dev
ADMIN	38	70	1.84	1.51	1.23
CREMATOR	48	77	1.60	3.138	1.77
GROUNDS	11	16	1.47	3.857	1.96

OCCUP	Minimum	25%ile	Median	75%ile	Maximum	Mode
ADMIN	0.34	1.00	1.36	2.32	5.28	0.91
CREMATOR	0.00	0.70	0.99	1.69	9.38	0.76
GROUNDS	0.24	0.42	0.70	2.15	6.89	0.24

ANOVA (For normally distributed data only)

Variation	SS	df	MS	F statistic	p-value
Between	1.78	2	0.89	0.35	0.71
Within	241.32	94	2.57		
Total	243.10	96			

Bartlett's test for homogeneity of variance

Bartlett's chi square = 6.19 deg freedom = 2 p-value = 0.045

Bartlett's Test shows the variances in the samples to differ.

Use non-parametric results below rather than ANOVA.

Kruskal-Wallis One Way Analysis of Variance

Kruskal-Wallis H (equivalent to Chi square) = 7.47

Degrees of freedom = 2

p value = 0.024

Difference in number of fillings between control and trial groups

GROUP	Obs	Total	Mean	Variance	Std Dev	
C	46	260	5.65	25.34	5.03	
T	97	594	6.12	16.78	4.10	
Difference			-0.47			
GROUP	Minimum	25%ile	Median	75%ile	Maximum	Mode
C	0.00	0.00	5.50	10.00	21.00	0.00
T	0.00	3.00	6.00	10.00	17.00	0.00

ANOVA (For normally distributed data only)

Variation	SS	df	MS	F statistic	p-value	t-value
Between	6.94	1	6.94	0.36	0.56	0.60
Within	2750.95	141	19.51			
Total	2757.89	142				

Bartlett's test for homogeneity of variance

Bartlett's chi square = 2.70 deg freedom = 1 p-value = 0.10

The variances are homogeneous with 95% confidence.

If samples are also normally distributed, ANOVA results can be used.

Mann-Whitney or Wilcoxon Two-Sample Test (Kruskal-Wallis test for two groups)

Kruskal-Wallis H (equivalent to Chi square) = 0.56

Degrees of freedom = 1

p value = 0.457

Association between hair mercury levels and numbers of fillings

Control group selected

Correlation coefficient: $r = 0.10$

$r^2 = 0.01$

95% confidence limits: $-0.19 < R < 0.38$

Source	df	Sum of Squares	Mean Square	F-statistic
Regression	1	12.09	12.09	0.47
Residuals	44	1128.35	25.64	
Total	45	1140.43		

B Coefficients

		B	95% confidence			Partial
Variable	Mean	coefficient	Lower	Upper	Std Error	F-test
HAIR	0.97	0.68	-1.26	2.63	0.99	0.47
Y-Intercept		4.99				

Difference between hair mercury levels for EPA and non-EPA compliant crematoria

Current selection: group = "T"

EPA	Obs	Total	Mean	Variance	Std Dev
+	27	52	1.94	2.63	1.62
-	40	81	2.01	3.58	1.89
Difference			-0.07		

EPA	Minimum	25%ile	Median	75%ile	Maximum	Mode
+	0.47	0.76	1.45	2.16	6.59	0.76
-	0.44	0.90	1.33	2.25	9.38	0.88

ANOVA (For normally distributed data only)

Variation	SS	df	MS	F statistic	p-value	t-value
Between	0.09	1	0.09	0.03	0.86	0.17
Within	207.84	65	3.20			
Total	207.93	66				

Bartlett's test for homogeneity of variance

Bartlett's chi square = 0.71 deg freedom = 1 p-value = 0.40

The variances are homogeneous with 95% confidence.

If samples are also normally distributed, ANOVA results can be used.

Mann-Whitney or Wilcoxon Two-Sample Test (Kruskal-Wallis test for two groups)

Kruskal-Wallis H (equivalent to Chi square) = 0.00

Degrees of freedom = 1

p value = 0.99

Association between hair mercury levels and cremation load

Correlation coefficient: r = 0.01

r^2= 0.00

95% confidence limits: -0.23 < R < 0.25

Source	df	Sum of Squares	Mean Square	F-statistic
Regression	1	0.04	0.04	0.01
Residuals	65	207.89	3.19	
Total	66	207.93		

B Coefficients

		B	95% confidence			Partial
Variable	Mean	coefficient	Lower	Upper	Std Error	F-test
CREMNO	2007.54	0.000028	-0.00049	0.00055	0.00027	0.011
Y-Intercept		1.93				

Difference in hair mercury levels between crematoria with high or low outputs

Current selection: group = "T"

Criteria: Crematoria having more than 1600 cremations per year are defined as high

CREM	Obs	Total	Mean	Variance	Std Dev
Low	56	82	1.47	2.39	1.55
High	41	80	1.96	2.64	1.63
Difference			-0.49		

CREM	Minimum	25%ile	Median	75%ile	Maximum	Mode
Low	0.00	0.61	1.04	1.57	9.38	0.91
High	0.44	0.88	1.39	2.16	6.89	0.76

ANOVA (For normally distributed data only)

Variation	SS	df	MS	F statistic	p-value	t-value
Between	5.67	1	5.67	2.27	0.13	1.51
Within	237.42	95	2.5			
Total	243.10	96				

Bartlett's test for homogeneity of variance

Bartlett's chi square = 0.11 deg freedom = 1 p-value = 0.74

The variances are homogeneous with 95% confidence.

If samples are also normally distributed, ANOVA results can be used.

Mann-Whitney or Wilcoxon Two-Sample Test (Kruskal-Wallis test for two groups)

Kruskal-Wallis H (equivalent to Chi square) = 4.2

Degrees of freedom = 1

p value = 0.04

Appendix XLviii

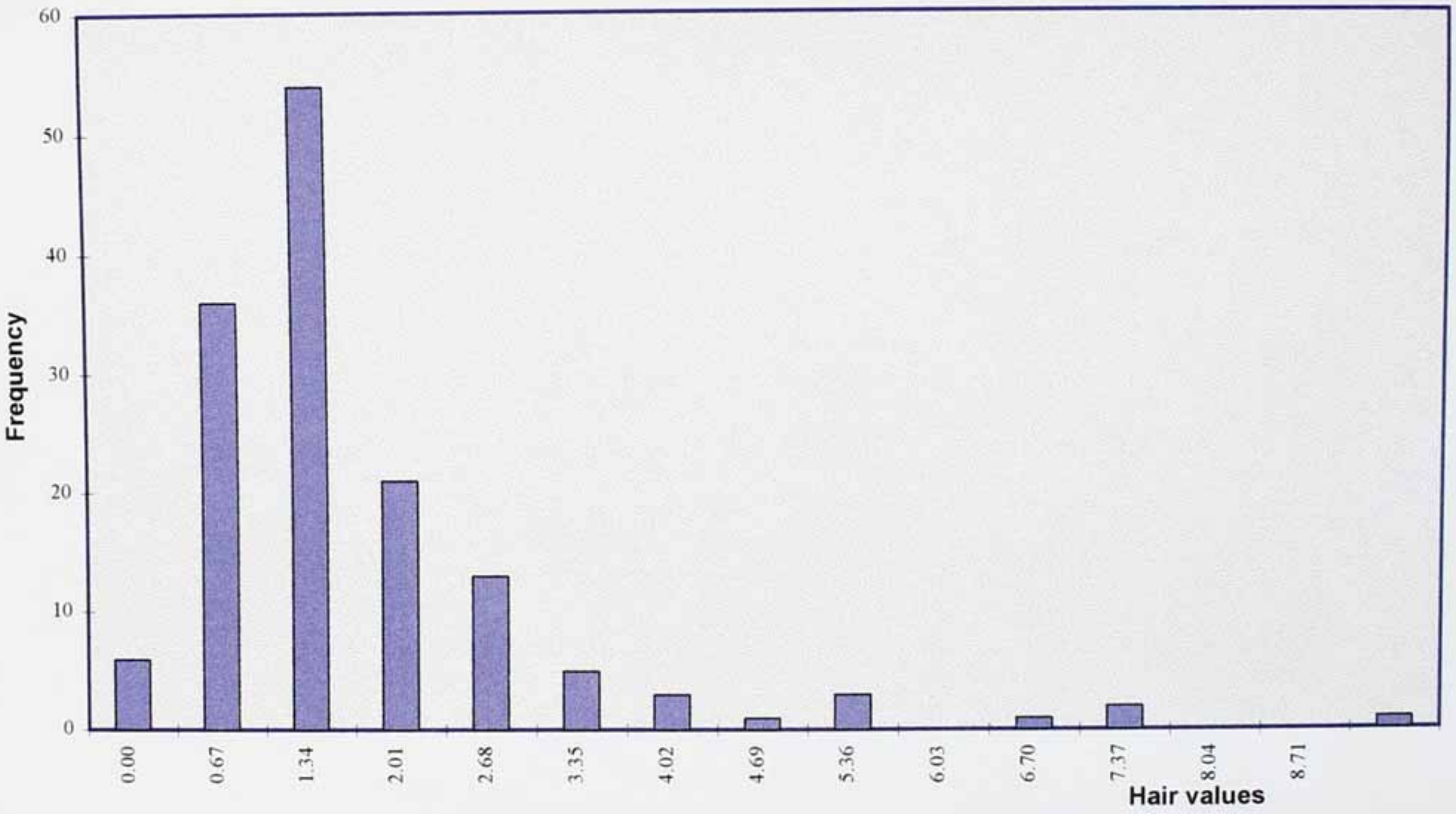
Mean Hair Mercury Levels for Different Crematoria

Mean Hair Mercury Levels for Different Crematoria

CREM	Obs	Total	Mean	Variance	Std Dev
Bath	9	8	0.916	0.438	0.662
Bedford	1	1	1.180	0.000	0.000
Blackley	1	1	1.270	0.000	0.000
Bretby	4	17	4.370	1.956	1.399
Burnley	1	1	0.760	0.000	0.000
Chesterfield	1	5	5.280	0.000	0.000
Colchester	2	4	1.900	0.387	0.622
Cornwall	1	1	0.760	0.000	0.000
Coventry	6	4	0.692	0.336	0.580
Crewe	3	5	1.807	1.167	1.080
Darlington	3	2	0.643	0.042	0.205
Douglasmuir	1	1	0.940	0.000	0.000
Dudley	2	8	3.830	15.235	3.903
Fylde	1	1	1.030	0.000	0.000
Glasgow	3	1	0.250	0.056	0.236
Guildford	1	1	1.390	0.000	0.000
Gwent	3	2	0.720	0.005	0.069
Harlow	2	10	4.955	39.161	6.258
Havering	10	27	2.698	3.731	1.932
Hyndburn	4	5	1.275	0.367	0.605
IBCA	1	2	2.320	0.000	0.000
Isle of Wt	4	4	1.107	0.146	0.382
Llwydcoed	3	7	2.250	0.123	0.351
Paisley	2	3	1.695	0.432	0.658
Perth	2	1	0.715	0.076	0.276
Poole	3	4	1.270	0.520	0.721
Rawdon	3	4	1.217	0.108	0.329
S Essex	2	2	1.135	0.061	0.247
SW Middles	1	2	2.070	0.000	0.000
Southport	5	10	1.970	2.587	1.608
Stafford	2	3	1.480	0.002	0.042
Stockport	4	4	0.963	0.160	0.400
Tameside	2	6	3.160	0.007	0.085
Walsall	2	2	0.960	0.274	0.523
Yeovil	2	1	0.735	0.031	0.177

Appendix XLIX

Histogram of Hair Values


Histogram of Hair Values