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Effects of Mercury Release from Amalgam Dental Restorations During Cremation on Soil Mercury Levels of Three New Zealand Crematoria

A. K. Nieschmidt,[1] N. D. Kim[2]

[1]Department of Earth Sciences and [2]Department of Chemistry, University of Waikato, Private Bag 3105, Hamilton, New Zealand

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A vast amount of research has been undertaken in the last 15-20 years on the corrosion reactions occurring in dental amalgam, release of mercury from amalgam restorations, and the toxic effects of this released mercury on the human body (Vimy and Lorscheider 1985; Lusso 1987; Eley and Cox 1988; Hanson and Pleva 1991; Fung and Molvar 1992; Huggins 1992; Mackay 1993). However, one environmental aspect of amalgam dental restorations that has not received a great deal of attention is the release of mercury during cremation. Mercury is liberated during cremation both because dental amalgams are unstable at cremation temperatures (650-700 °C) and because the free mercury metal is highly volatile (Phillips et al. 1994). In New Zealand, 58% of deaths are followed by cremation (International Cremation Statistics 1992) and this figure is likely to rise in the future. This increasing use of cremation as the method of corpse disposal, coupled with the fact that each amalgam restoration is approximately 50% mercury, implies that a significant amount of mercury may be emitted into the environment every year.

A handful of reports have been published giving estimates on the amount of mercury released into the atmosphere by crematoria and the concentration of soil mercury found around crematoria in the USA and England (Mills 1990; Kunzler and Andree 1991; Basu et al. 1991; Burton 1991; Hogland 1994; Phillips et al. 1994). However, prior to this work, no such studies had been carried out in New Zealand.

MATERIALS AND METHODS

Three crematoria were selected for soil mercury analysis, these being the Hamilton Crematorium, the South Auckland Crematorium and the Purewa Crematorium (situated in Remuera, Auckland, New Zealand). Details of operating conditions, number of cremations, and years in operation for each site are given in Table 1.

Correspondence to: N. D. Kim

Table 1. Crematorium statistics

Site	Year opened	cremations per year	total	Time for cremation	Temp of furnace	Model cremator	Fuel type
1#	1964	960	28800	60 min	500-800 °C	D & M *	Diesel
2#	1982	800	9600	60 min	800-850 °C	D & M *	Gas
3#	1957	1740	66200	60-80 min	500-900 °C	D & M *	Gas

Site 1: Hamilton, Site 2: South Auckland, Site 3: Purewa
* Dowson and Mason twin reflux

Soil samples were collected to 5 cm using a soil corer, from five sites around the Hamilton and Purewa crematoria, and three sites around the South Auckland crematorium (ground containing ashes was not disturbed). Samples were digested and analysed for mercury within 24 hr. Three separate samples were taken from each of sampling point, and each one of these samples was analysed in duplicate.

For two crematoria (Hamilton and Purewa) the sampling points were selected in such a way that, as much as possible, they encircled the crematorium (depending on the presence of unavoidable features such as driveways and walls). For both sites, one sampling sequence (Site 3) was further extended both downward (0-5 cm, 5-15 cm, and 15-30 cm) and at 5 m intervals leading in a straight line away from the chimney and along the prevailing wind direction.

Background mercury levels were determined on the same soil types as those at each crematorium, and are based on samples collected at least 500 m away from each site. The soil type around the Hamilton Crematorium is Horotiu silt loam, which is a free-draining allophanic soil. The soil type around the other two crematoria is Central yellow-brown loam, which is a soil developed on sediments derived largely from volcanic ashes but in places partly from marine rocks (DSIR 1968).

After sampling, soils were immediately returned to the laboratory where representative, homogeneous samples were taken for analysis. In order to avoid potential losses of mercury, samples were not oven-dried prior to sampling, but were digested in their field-moist state, with a later correction being applied to account for the measured water content. About 5 g soil was accurately weighed into a 100 mL round-bottom flask, and refluxed gently for 3 hr with 30 mL *aqua regia.* Cooled samples were filtered through acid-washed (Whatman 541) filter paper into 100 mL volumetric flasks, and made up to the mark with deionised water. Apparatus used was cleaned by acid-washing before and between digestions. Mercury standards were prepared in the same acid matrix as

the samples. Samples were analysed for mercury at 253.5 nm (with deuterium background correction) by Cold Vapour Atomic Absorption Spectrophotometry (CVAAS), using a GBC HG3000 hydride generation unit coupled to a GBC 909 AAS. Reduction of mercury in the flow-through cell was achieved using the stannous chloride procedure.

Certified reference materials were digested and analysed with some sample batches as a cross-check on accuracy. Certified soil (GBW 07401, Laboratory of the Government Chemist, England, 1990) containing (32 ± 3) ngHg g^{-1} and certified stream sediment (GBW 07311, Laboratory of the Government Chemist, England, 1986) containing (72 ± 6) ngHg g^{-1} represented the lower end of the range, and certified dogfish muscle (DORM-1, National Research Council, Canada, 1993) containing (0.798 ± 0.074) mgHg kg^{-1} represented the higher end. The latter material was used despite the fact that the matrix of DORM-1 is quite different to soil, and was necessary because certified soil samples containing as much mercury as found around some crematoria were not readily available. Overall, recoveries ranged from 75.2 % to 97.5 %, with a mean value of 83.9% ± 4.5 % of the mean certified values. These figures were seen to be acceptable accuracy given the trace nature of the analysis and the fact that the *aqua regia* extraction is a pseudo-total digestion.

RESULTS AND DISCUSSION

A site plan for Hamilton Crematorium with the average mercury concentrations for each sampling point is provided in Figure 1.

The Hamilton Crematorium is situated in a rural environment and the area surrounding the crematorium is flat, relatively unobstructed lawn, with only a small number of trees and shrubs present on one side of the building (at the location of sampling site 1). Mercury concentrations in surface (0-5 cm) soil around the crematorium varied from 190 to 560 µg kg^{-1}, and averaged 386 µg kg^{-1}, or about twice the background value for this location (200 µg kg^{-1}). Concentrations in the transect leading away from the chimney along the prevailing wind direction increased to a maximum of about three times background levels at 15 m distance and then decreased again (Figure 1). This finding suggests that a measurable amount of the mercury vapour expelled from the crematorium chimney is redeposited within a 30 m radius of the crematorium, giving localised soil contamination. The depth-profile at sampling site 3a reveals that mercury enrichment is confined to the surface 5 cm. Concentrations at sampling site 5 were equivalent to background levels: this was the site furthest away from the chimney and is also situated upwind of the chimney relative to the usual wind direction. Taken together, these results demonstrate that the Hamilton Crematorium is acting as a measurably significant source of mercury to its immediate environment.

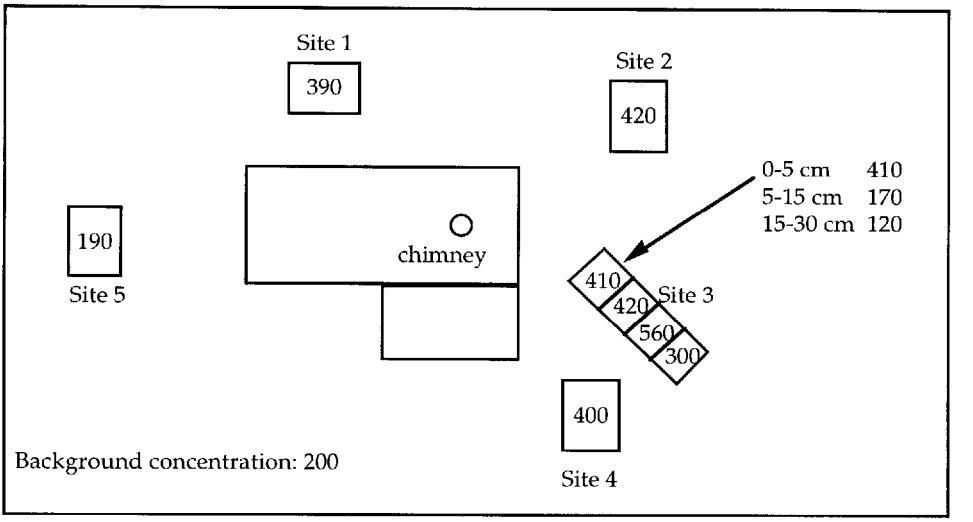

Figure 1. Site plan for Hamilton Crematorium showing average Hg concentrations in soil. All figures are in µg kg^{-1} (ppb). (Each number represents the average of 6 analyses).

The South Auckland Crematorium is located in a rural environment on an open, rolling landscape. There are only a small number of small trees and scrubs within a 30 m radius of the crematorium. This crematorium has only been in operation for 12 years with a total of 9600 cremations having taken place in that time, and was therefore chosen to investigate whether a noticeable increase in mercury levels, as compared to background levels, was detectable within this relatively short time period. Analysis of three separate sites showed an average increase of only 25 ppb Hg above background concentrations. Results obtained from analysis of soils from the South Auckland Crematorium are given in Table 2.

Table 2. Mercury concentrations in soil around the South Auckland Crematorium.

Sampling location	n	Mean mercury concn (µg kg^{-1})	Std. deviation (µg kg^{-1})	95% Conf. error (µg kg^{-1})
Background	6	90	7.1	± 9.8
Site 1	6	110	13.3	± 10.6
Site 2	6	120	13.8	± 11.0
Site 4	6	110	12.2	± 9.8

The Purewa Crematorium is situated in Remuera, Auckland, which is a residential area. A site plan with the average Hg concentrations at each of the sampling points is provided in Figure 2.

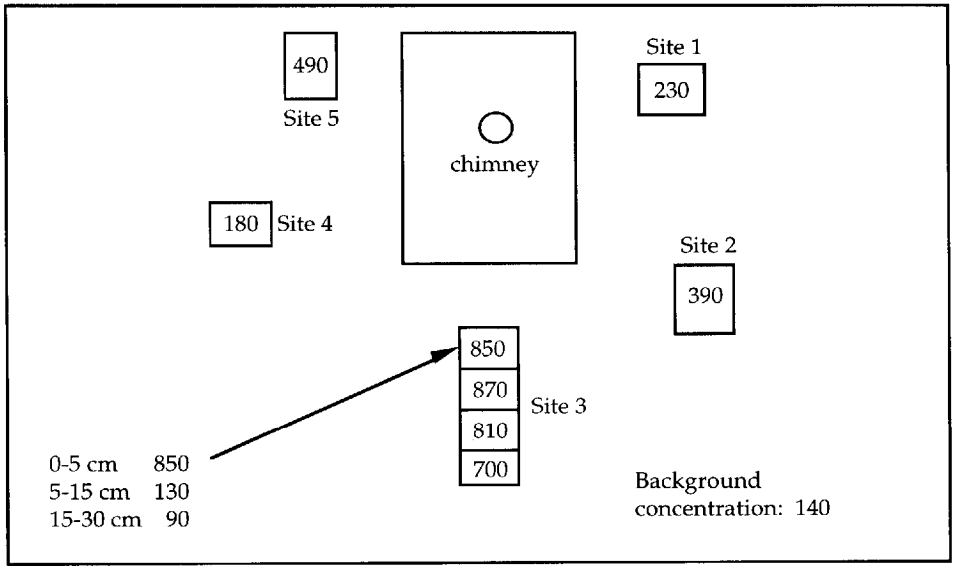

Figure 2. Site plan for Purewa Crematorium showing average Hg concentrations in soil. All figures are in µg kg^{-1} (ppb). (Each number represents the average of 6 analyses).

Unlike the Hamilton and South Auckland crematoria, the Purewa Crematorium is not surrounded by an open grass area. There are only small areas of grass around the crematorium, most of the area is concrete, either footpaths or driveways. There are also a lot of trees in the area. Sites 1 and 2 in particular, were areas where there were a number of trees present. Immediately adjacent to Site 4 was a small toilet block. The only open areas were Sites 3 and 5. The fact that there were a number of unavoidable objects in the immediate vicinity of the crematorium appears to be reflected in the mercury concentrations obtained. Whereas the mercury concentrations around the other two crematoria were reasonably similar at most of the sampled sites, mercury levels around Purewa varied considerably from site to site. Sampling sites 3 and 5 had the highest mercury concentrations, with Site 3, immediately downwind of the chimney, having up to six times more mercury than background concentrations. Site 2, being situated only slightly off the line of the dominant wind direction but amongst trees, had elevated levels, but only about half those of Site 3. Sites 1 and 4 had concentrations closer to background levels.

Similar trends to those evident at Hamilton regarding depth and distance mercury distribution also apply to Purewa. Along a downwind transect from the chimney, mercury concentrations increase with distance, then decrease again with further distance. The depth profile reveals that detectable mercury enrichment is once again confined to surface soil.

A summary of the increases in mercury concentrations above background levels at each crematorium (measured on the basis of geometric means) is presented in Table 3, along with other relevant statistics.

Table 3. Comparison of the three crematoria

Crematorium	Geo mean [Hg] above bkground	Years in operation	Cremations per year	Total cremations
Sth Auckland	25 µg kg^{-1}	12	800	9600
Hamilton	170 µg kg^{-1}	30	960	28800
Purewa	350 µg kg^{-1}	37	1740	66200

Of the three crematoria studied, Purewa is both the oldest (having opened in 1957) and has the highest cremation rate (1740 cremations per year on average). This is reflected in both the geometric mean mercury concentration (490 ppb as compared to 370 ppb at Hamilton and 115 ppb at South Auckland), and in the average annual increase rate (10 ppb as compared to 5.7 ppb at Hamilton and 2.1 ppb at South Auckland). Tentatively, mercury concentrations in soils around the crematoria appear to be best related to the total number of cremations performed, rather than either the yearly average number of cremations or the total years of operation. Although the number of pairs in our data set are insufficient for derivation of reliable correlation coefficients, the trend evident in the data would appear to suggest that an increase of 100 µg kg^{-1} in soil mercury concentrations might be expected for every 18000 cremations.

However, it is also evident by comparison of the estimated amount of mercury emitted from the source with the amount of mercury in soil around the crematoria, that most (99.95%) mercury either never reaches the local soil, or is deposited but re-volatilises. A upper-limit estimate of total mercury emitted from each crematorium can be made on the basis of dental statistics from an Adult Oral Health Survey carried out by Cutress et al. (1979) in conjunction with death statistics by age from the New Zealand Yearbook (1978), and figures for cremations performed at each location. From these figures, the approximate number of cremations carried out for each age bracket can be calculated. By multiplying this figure by the number of filled teeth for each group and the estimated amount of mercury in each of those fillings (taken as 0.6 grams), mercury emissions for each age bracket can be calculated. Full details of these calculations are available from the authors. A method for calculating mercury release from amalgams based on UK figures is also supplied in the literature (Mills 1990; modified by Burton 1991), and was applied for purposes of comparison. The results of these calculations are provided in Table 4.

Table 4. Upper limits for mercury released at source. Figures in brackets relate to the estimate on the basis of previous literature.

Crematorium	Yearly mercury release (kg)		Release over operating lifetime (kg)	
Sth Auckland	2.64	(2.61)	31.7	(31.3)
Hamilton	1.45	(1.44)	43.5	(43.2)
Purewa	1.22	(1.20)	45.1	(44.4)

Mercury emission values obtained using New Zealand statistics are in remarkably good agreement with figures obtained using a literature-method based on UK emissions (Mills 1990; modified by Burton 1991) (Table 4). This suggests similar emission values may apply to countries of similar socio-economic standards.

A lower boundary for mercury emitted from the crematoria can be estimated on the basis of the actual amount of extra mercury found to be present in the soil at each site. This calculation is based on a cylinder of soil of radius 30 m around each chimney and of depth 5 cm, and required measurement of the bulk density of each soil. Presented in Table 5 are calculations of the amount of extra mercury actually present in soil at the Hamilton and Purewa crematoria (mercury levels at the South Auckland site were considered too close to background levels for a reliable estimate to be made).

Table 5. Absolute amounts of mercury present in the soil around the Hamilton and Purewa crematoria.

Site Location	Volume of soil (m^3)	Soil bulk density ($kg\ m^{-3}$)	Geo. mean [Hg] ($mg\ kg^{-1}$)	Background [Hg] ($mg\ kg^{-1}$)	Extra over Background ($mg\ kg^{-1}$)	Total mass Hg (g)
Hamilton	141.37	880	370	200	170	21.15
Purewa	141.37	1080	490	140	350	53.44

From the soil receptor calculations it can be seen that soil in the immediate vicinity (30 m radius, 0.05 m depth) of each chimney retains only 21.2 g mercury in the case of Hamilton, and 53.4 g mercury in the case of Purewa (Table 5). These amounts equate to only 0.05% of the likely total mercury emissions for both crematoria (Table 4), a result which suggests that either (a) most mercury emitted from crematoria never reaches the local soil, or (b) emitted mercury is deposited in reasonable amounts in local soil, but is able to re-volatilise relatively efficiently. Volatilisation is known to be an important part of the global mercury cycle, accounting for the loss of significant amounts of the metal from soils (Fergusson 1990).

Using cremation data available from the International Cremation Statistics (1992) and the calculations of Burton (1991) it is possible to estimate that New Zealand emissions are likely to total about 22.8 kg Hg per year and that global annual mercury emissions would total 6962 kg. Globally, atmospheric mercury emissions from crematoria of this magnitude would account for about 0.8 % of total anthropogenic mercury emissions (based on the estimates of Nriagu and Pacyna 1988 and Nriagu 1989).

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