PaMSWaD (Pathways of Mercury in Solid Waste Disposal)

ORNL SAMPLING OPERATIONS SUMMARY AND PRELIMINARY DATA REPORT FOR PaMSWaD-I, BREVARD COUNTY LANDFILL[1]

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Background

In cooperation with the Florida Department of Environmental Protection we quantified the primary sources of Hg vapor releases to the atmosphere at two municipal landfill operations in south Florida in April, 1997 (Lindberg and Price, 1999). The results of that study indicated the need to address several remaining issues including the source of Hg in working face (WF) emissions, Hg speciation in landfill gas, the potential for losses of Hg from MSW prior to land filling, and the overall role of fluorescent bulbs. The objective of PaMSWaD is to reduce the uncertainties in the pathways and mass balance of mercury in the solid waste disposal process. This will entail a series of measurements of Hg emissions from the primary pathways of release at landfills, and during the storage and transport of MSW to the landfill. Because of the potential importance of fluorescent bulbs as a Hg source, emphasis is being placed on this material. We report here on Phase I.

Brevard Sampling Operations Schedule

For two weeks during November, 1998 the ORNL group collaborated with the UCF team to characterize Hg concentrations and fluxes at the Brevard County Landfill (BLF). A brief report of the results of the waste sorting activities by UCF is available (UCF, 1999). Table 1 summarizes the operation plan and sampling schedule followed during PaMSWaD-I. Since we returned, the preliminary data analysis has proceeded, and all data are now in hand. These will be more fully

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Table 1. ORNL SAMPLING OPERATIONS SUMMARY, Brevard County Landfill

Site	Dates and Times	Sampling Activities
ORNL	11/5 to 11/6/98	Final tests and packing
——	11/7 to 11/8	Travel to Cocoa, FL and Project meeting
BVD Landfill	11/9 @ 0730 - 1000	Tekran setup and tests
Shredder Bld	@ 1000 - 1700	Measure Hg levels in 8 dumpsters (headspace) in shade and sun
"	"	Break single fluorescent bulb in D5 and begin flux tests
"	"	Design method to directly measure Hg fluxes in dumpsters
Shredder Bld	11/10 @ 0800 - 1800	Measure Hg fluxes in naturally contaminated dumpster (D8)
"	"	Measure Hg fluxes in bulb-spiked dumpster (D5)
"	"	Measure Hg in headspace of 2 commercial dumpsters
Shredder Bld	11/11 @ 0800 - 1100	Measure Hg fluxes in bulb-spiked dumpster (D5)
"	"	Measure Hg in headspace of final commercial dumpster
Transfer Station	@ 1200 - 1700	Monitor "headspace" Hg levels over working pit under normal operating conditions
"	"	Spike working pit with single and multiple fluorescent bulbs to determine strength of spike signal, and Hg losses in transfer process
"	"	Spiked labeled transfer truck with 77 fluorescent bulbs for subsequent transport to the BLF working face for measurements during unloading operations
Shredder Bld	@ 1900 - 2200	Measure Hg in bulb drum headspace, decontaminate Tekran, set up for overnight standard additions and bias tests
Working Face	11/12 @ 0800 - 1130	Setup of meteorological tower and sampling site downwind of working face
Working Face	@ 1130 - 2300	Continuous monitoring of Hg concentrations downwind of WF and logging of WF activities, including samples during and after daily cover applied, station located below and west of WF
"	@ 1505 - 1515	Spiked labeled transfer truck with 77 fluorescent bulbs
"	@ 2300 - 13th @ 0700	Overnight monitoring adjacent to WF
Working Face	11/13 @ 0700 - 1800	Continuous monitoring of Hg concentrations downwind of WF and logging of WF activities, station level with and east of WF
Leachate Sta. 3	@ 1700 - 1800	Setup of Tekran #15 for simultaneous monitoring of background Hg levels in ambient air upwind of WF
WF & "	@ 2300 - 13th @ 0700	Overnight monitoring up- and downwind of WF @ 2 sites
Working Face	11/14 @ 0900 -1400	Monitoring upwind and downwind of WF, downwind site located above and to northeast of WF
Shredder Bld	@ 1400 - 1600	Tekran calibration and spike tests, flux measurements in D5
Hotel	11/15 @ 0800 - 1800	Tekran tests, spikes, and calibrations; flux chamber blank tests

Table 1. Continued.

Site	Dates and Times	Samples
Shredder Bld	11/16 @ 0800 - 1100	Measure headspace Hg signals in sorted waste from dumpsters and measure fluxes in spiked dumpsters (D8 & D5)
Working Face	@ 1200 - 1400	Measure fluxes on working face using ORNL flux chamber and select areas for waste excavation and sorting
"	@ 1400 - 1800	Monitoring downwind of WF, downwind site located below and to west of WF
Flair Station	11/17 @ 0800 - 1700	Sample LFG for Hg^0, TGM, and organic Hg (~45 samples)
Shredder Bld	@ 1100 - 1800	Measure headspace Hg signals in sorted waste from WF and flux From D5
Shredder Bld	11/18 @ 0800 - 1200	Measure headspace Hg signals in sorted waste from dumpsters and measure fluxes in spiked dumpsters
Working Face	@ 1300 - 1500	Spatial scaling measurements downwind of WF to determine approximate physical dimensions of Hg "plume" from WF
Landfill cover	@ 1600 - 19 @ 1300	Measure surface fluxes over old cover after location of hot spots using a real-time methane sensor
Shredder Bld	11/19 @ 1400 - 1800	Tekran tests, calibration, flux chamber blanks, and final measurements of headspace Hg signals in sorted waste and fluxes in spiked dumpster (D5)
Shredder Bld	11/20 @ 0700 - 0900	Pack van and hit the road
——	11/20 to 11/21	Travel to Oak Ridge

interpreted in the coming months. The remainder of this report will be in the form of highlights based on a preliminary semi-quantitative analysis of the Tekran measurement data, and a more complete quantitative analysis of the landfill gas data.

Preliminary Data Summary

Identifying Mercury Sources:

- *Waste transported to the BLF in dumpsters contains numerous sources of Hg*, including batteries and Hg-containing bulbs. We measured significant Hg signals over background (>20 ng/m^3; background ~ 2) in dumpster headspace in 2 of 12 dumpsters tested (Table 2,

one residential, one commercial). The source was identified in the sorted waste from one as electric blanket controls which must have been contaminated externally by a diffuse source such as a broken fluorescent bulb or thermometer. This source yielded a head space Hg level > 90 ng/m³. The source was unidentifiable in the second dumpster, but misc. isolated material showed a headspace Hg ~100 ng/m³ (after sealing in a 0.1 m³ container).

- *Broken fluorescent bulbs were not posttively identified in dumpsters or excavated waste, but several whole and partially broken bulbs were spotted during unloading of transfer trailers on the WF.* UCF discovered 16 unbroken high-intensity Sylvania Metalarc metal halide lamps in one dumpster. Although these lamps contained Hg vapor, there was no measurable Hg signal from the intact lamps.

Table 2. Concentrations of Hg° in headspace gases of dumpsters transported to the Brevard County landfill and sampled using the ORNL Tekran system. Ambient air Hg° in this area was ~1.5-2.0 ng/m³.

Sample	Waste Source	Head Space Hg° (ng/m³)
D 1	new, blank	1.6
D 2	residential	2.7
D 3	"	3.4
D 4	"	4.0
D 5*	used, but empty, control	2.7
D 6	commercial	8.2
D 7	residential	2.4
D 8	"	28.6
D 9	industrial	3.4
D 10	commercial	34.0
D 11	"	2.3
D 12	"	4.7

* D5 was later spiked with broken fluorescent bulbs and sampled as a dynamic flux chamber

Numerous *hot spots of Hg emissions were measured over the working face* with the ORNL flux system. Fluxes ranged from 3 to 150 ng m^{-2} h^{-1} at 7 different sites (Table 3). This was a clearly elevated flux, with a mean value (70±60) well above that for background soils (~5). The Hg source was not the cover mulch (~3 ng m^{-2} h^{-1}), but originated from the waste below (Table 3). The three sites with fluxes >100 ng m^{-2} h^{-1} were excavated (~ 1 m^3) and sorted by

Table 3. Preliminary fluxes of Hg^0 measured over recently placed waste (~1 d) on the working face of the Brevard County landfill. Fluxes were measured with the ORNL/Tekran flux system (Lindberg and Price, 1999). Background soil fluxes in Florida range from ~1 to 10 ng m^{-2} h^{-1}.

Sample	Surface Appearance	Hg^0 Flux (ng m^{-2} h^{-1})
Plot 1	50/50 % waste/mulch	16
Plot 2	90% mulch	10
Plot 3	100% waste	150
Plot 4	100% mulch	3
Plot 5	100% waste	120
Plot 6	50% waste	80
Plot 7	100% waste	120

UCF. Much to the surprise of this PI, several potential Hg sources were identified by the UCF students, which later demonstrated clearly measurable levels of Hg in headspace gas (range from ~600 to 700 ng m^{-3}). The PI assisted the students to further separate the potential Hg sources from the sorted waste into "most likely" and "least likely" Hg sources, and subsequent sampling in small closed containers indicated some success in the sorting.

mean headspace Hg^0 in "most likely" = 4400 ± 450 ng m^{-3}
mean headspace Hg^0 in "least likely" = 1400 ± 1800 ng m^{-3}

The "most likely" samples contained 13 crushed and 11 whole batteries of various sizes and scallop processing waste (see below). The "least likely" samples contained electrical components, syringes, misc. tools, a telephone, magnetic tape, and a butane lighter. Since it is unlikely that these latter materials originally contained Hg, they may have been contaminated with a diffuse source such as fluorescent bulb dust, which would be unidentifiable in aged samples.

Quantifying Mercury Sources:

- *Broken fluorescent bulbs* are *potentially significant sources of Hg emissions to the air* because they contain mg quantities of Hg. Since we had hypothesized important long term Hg^0 losses from broken bulbs, several studies were performed to partially quantify this source. These included measuring a time series of Hg headspace concentrations in and near closed dumpsters containing a broken bulb under different storage conditions, measuring concentrations over bulbs broken in the pit at the transfer station, and measuring concentrations during unloading activities on the WF, including from a bulb-spiked truck. In addition, we developed a method of treating spiked dumpsters as flux chambers to estimate the magnitude and duration of Hg emissions from broken bulbs in dumpsters. Once the first bulb was broken it became clear that the Tekran readings would be over range (>1000 ng m^{-3}) for many of these experiments, and we devised a dilution/mixing system using the Tekran standard additions unit which allowed us to quantitatively dilute our samples automatically by up to up to a factor of 30 with zero gas.

- *Airborne mercury concentrations in containers with broken bulbs are in the $\mu g/m^3$ range.* The headspace Hg concentrations over broken bulbs reached very high levels which persisted for at least 1 week. This was true for dumpsters which were ventilated and for those which remained sealed. Within 20 min. of breakage, Hg^0 reached levels of 2400 to 3800 ng m^{-3} in the filtered headspace air of D5. Following 10-min of forced ventilation (and mixing) with ambient air at a flow of ~20 m^3/h, the Hg concentration actually increased to ~8200 ng m^{-3} in filtered headspace samples, suggesting there was a strong vertical gradient in Hg above the floor of the dumpster after initial bulb breakage (headspace measurements were taken ~10 cm below the lid, which was ~1.2m above the floor). Assuming a well mixed system at this point, this suggests there was ~12 µg of gas phase Hg^0 in D5 at this

time, or only about 0.1% of the potentially available Hg in a typical bulb. The filtered samples and low Tekran blanks confirm that this material is in the gas phase.

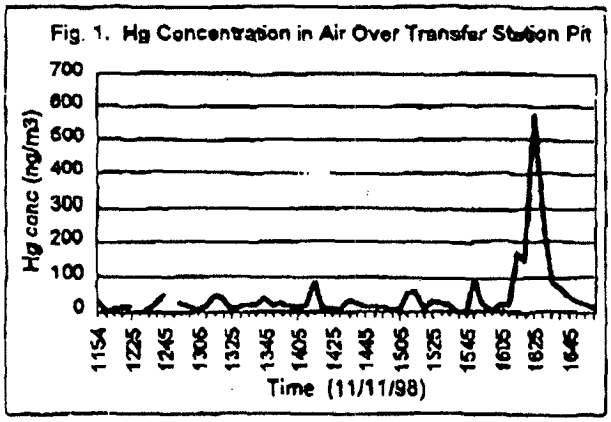
- *Mercury is strongly and persistently emitted from dumpsters containing broken fluorescent bulbs.* Our preliminary flux data suggests initial loss rates on the order of ~25 µg/h from a single bulb in a closed dumpster. This rate persisted for over a week, almost unchanged, and was recorded at ~50 µg/h 8 days after breakage. Some simple assumptions suggest that the single bulb could have lost as much as 20 - 80% of its initial Hg by volatilization over ~1 week. The USEPA, however, assumes that only a small percentage of Hg in bulbs is ever emitted to the air (primarily that fraction which is initially present as gaseous Hg°). This ignores the possibility for continued loss of Hg resulting from desorption or reduction of various Hg species associated with lamp dust. The ease with which bulb dust could be dispersed from waste containers during handling and transport of MSW supports the need to understand the behavior of this material.

- *Mercury is continuously emitted during normal operations at the transfer station.* We sampled filtered "ambient" air ~ 10 m above the floor of the active pit of the transfer station during normal dumping operations, and while bulbs were manually loaded into the pit (Table 4). The background levels of Hg at the station during nonactive periods (>10 ng m^3) suggest

Table 4. Levels of Hg° in air measured ~10 m above the floor of the ram pit at the Brevard County transfer station on 11/11/98. Measurements were taken over a 5-h period of routine operations and while fluorescent bulbs were manually loaded into the pit. The truck tagged with 62 bulbs at 1615 was tracked to the working face the following day, and Hg levels were measured downwind during unloading. Background levels of Hg° outside of the transfer station ranged from ~2-4 ng m^3.

Time	Activity in Ram Pit	Hg° (ng m^{-3})
1200 - 1300	ambient air in station	10 - 20
1300 - 1400	trucks unloaded	~20 - 40
1415	bulb broken on pit floor	90
1440	", at far end	23
1510	2 bulbs broken	56

1535 - 1545	inactivity (quiet time)	8 - 15
1550	dump truck unloaded	95



1615	truck tagging, 11bulbs	173
1620	truck tagging, 11bulbs	150
1625	truck tagging, 40 bulbs	577
1635	ram activated	93
1645	pit empty, debris visible	53
1655	inactivity (quiet time)	24
1700	ambient air in station	16

some level of past contamination. During routine truck unloading, however, spikes in Hg concentration were commonly seen, ranging from ~30 to 90 ng m^3 (Fig. 1). Bulbs were only occasionally detected in the dumped waste (<5% of vehicles). Manual addition of bulbs to the pit during dumping and compacting also yielded strong Hg concentration spikes, some exceeding 500 ng m^{-3}, depending on number of bulbs. There seems little doubt that Hg is lost to air air during routine transfer station operations. during routine transfer station operations.

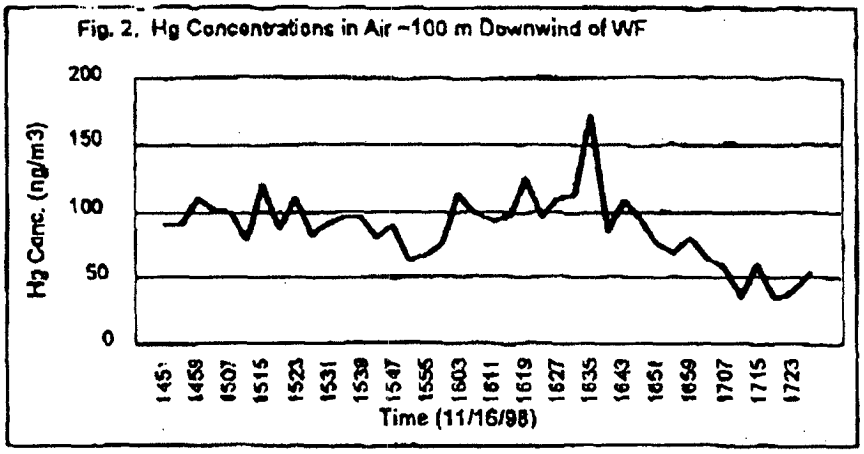
Measuring Mercury Emissions:

- As noted in our previous study, *Hg emissions through the final cover of the closed portions of the landfill are small.* This was also true at the BLF. Several hot spots of methane release were detected with a real-time sensor and Hg fluxes measured over the areas of

highest methane release (CH_4 concentration > 600 ppm in air 5 cm above the ground, compared to background levels of <5 ppm). However, Hg did not appear to be released at significantly elevated rates over these areas. The mean daytime flux over one background site was ~9 ng m^{-2} h^{-1}, while that over the primary hot spot ranged from 2 at night to 11 ng m^{-2} h^{-1} during the day. All of these fluxes are well within the range for background soils (e.g. Carpi and Lindberg, 1998). The existence of a strong diel cycle over the hotspot suggests that we are measuring typical Hg fluxes from the surface soil cover, not transport of Hg from the subsurface waste deposits through the cover. Background soil fluxes are strongly influenced by diel cycles in solar radiation and soil temperature (Carpi and Lindberg, 1998).

- *Increased emphasis was placed on quantifying Hg emissions at the working face.* In an effort to improve our earlier data base on fugitive emissions from the Martin County (MC) landfill, we sampled ambient air up- and downwind of the BLF WF over several days. In this study, we were able to make several additional important measurements which should reduce the uncertainties in modeling such losses. These include simultaneous data for Hg^0 in air up- and downwind of the WF, a longer period of measurement (~61 h), samples from three different downwind locations (above, below, and level with the WF), continuous logging and videotaping of WF activities by UCF students, continuous operation of a complete meteorological measurement tower adjacent to the WF, and measurements of the physical extent of the downwind Hg plume.

– *Important quantities of Hg are lost to the atmosphere during routine operations on the working face.* During nearly all WF operations, the levels of Hg° downwind significantly exceeded those measured upwind, often by an average of 30 to 40-fold (Table 5). In general, the concentrations of Hg° downwind of the WF were far higher than measured at MC in April, 1997, despite a comparable site layout and similar winds. It was not uncommon to see Hg° spikes which exceeded 100 ng/m^3 (e.g. Fig. 2). Background levels were comparable between sites, but both the mean and hourly maxima downwind concentrations were far higher at BLF compared to MC, where the peak concentration was <40 ng/m^3 (Lindberg and Price, 1999). During working hours, ~50% of the atmospheric Hg concentrations at BLF exceeded 50 ng/m^3, and ~10% exceeded 100. Concentrations decreased somewhat after the daily cover was applied and were generally lower and more stable at night (in Fig. 2 the daily cover was applied beginning at 1700). Some of the more interesting semi-quantitative observations at the WF included observation of consistent spikes in Hg air concentrations during unloading of scallop processing waste on different days, and observation of a spike signal upon unloading of the bulb-tagged transfer trailer



(Table 5). [the scallop waste was "investigated" by the PI and found to include significant quantities of "dredge spoil", and

Table 5: Concentrations of Hg° in air measured ~3 m above the ground on a meteorological tower located downwind of the Brevard County landfill working face (WF) over several days. The transfer trailer truck tagged with 62 bulbs discussed in Table 4 arrived at 1500 on 11/12.

Date/Time	Activity or Data Set	Hg^{o} ($ng\ m^{-3}$)
11/12, 1000 - 1800	mean downwind of WF	38 ± 29
"	maximum downwind	110
1510, 1515, 1520	bulb-tagged transfer trailer	60, 100, 40
1700, 1705, 1710	scallop waste @ 1705	80, 110, 90
11/12 to 11/13, night	mean downwind	15 ± 7
" day/night	mean background (upwind)	2.0 ± 0.7
11/13, 0800 - 1800	mean downwind of WF	78 ± 39
"	maximum downwind	162
1700, 1705, 1710	scallop waste @ 1705	60, 100, 70
11/13 to 11/14, night	mean downwind	51 ± 31
" day/night	mean background (upwind)	2.0 ± 0.5
11/14, 0900 - 1400	mean downwind of WF	27 ± 16
"	maximum downwind	70
" day	mean background (upwind)	1.9 ± 0.2
11/16, 1400 - 1800	mean downwind of WF	88 ± 26
"	maximum downwind	170
" day	mean background (upwind)	2.1 ± 1.4

we suspect degassing of Hg^{o} from reduced sediments is a possible explanation]. The spike from the "bulb truck" was smaller than expected, but surface winds were unfavorable at that time for us to capture the primary plume. The overall waste loading and meteorological data are still being processed, and will allow more quantitative estimates of the rates and mechanisms of fugitive Hg losses. However, we can make a very crude estimate of the flux from the WF on 11/16/98 between ~1500 - 1730. Our measurements of the plume dimensions suggest a more-or-less normal distribution in concentrations over ~80m, with a uniform peak concentration covering ~30m. We will assume a conservative plume dimension of 5x30 m (~10x50 m was used at MC). This yields a mean Hg emission of ~120

mg/h (± a factor of 2), or ~0.3 g over this brief period. The modeled hourly mean fluxes at the MC landfill were much smaller (~5 to 60 mg/h, Lindberg and Price 1999).

- *Concentrations of Hg° in landfill gas at BLF are comparable to levels in coal-fired utility flue gas.* During our earlier studies at two landfills in south Florida, we found highly elevated concentrations of total gaseous mercury (TGM) in landfill gas (LFG), and discussed the possibility that methylated forms also existed in these samples (Lindberg and Price 1999). However, these were determined by indirect (difference) methods based on a very limited sampling scheme (in both time and space), and direct identification of gas-phase organic Hg was not possible. At BLF we expanded our sampling to include multiple replicate samples at two in-line vent ports upstream of the single flair which processed all LFG produced at this site. We also used a number of different methods to sample various species: gold traps for TGM (efficiency for organic Hg not well characterized), charcoal traps for TGM (which collect all forms of gaseous Hg), carbotraps for dimethyl mercury, and a single cold trap scrubber for monomethyl mercury in LFG condensate (located upstream of the carbotraps). Finally, we extended our sampling to include the complete cycle of daytime operations (the data in our previous study were limited to a few ~10-min grab samples). Table 6 summarizes these data, which showed a highly consistent level of TGM over the day. The mean concentration of TGM in LFG at this site (~7200 ± 0.3 ng/m^3) significantly exceeded those we measured at the Martin and West Palm Beach County landfills (~500-600 ng/m^3, maximum 1800). Concentrations of TGM in industrial flue gas are typically in the range of 1-10 μg/m^3 (e.g. Lindberg 1980). Despite the potential problems with sampling this potentially corrosive (H_2S in CH_4) and water-saturated atmosphere, the gold traps once again performed well. Although we accumulated as much as ~40 ng Hg/trap,

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Table 6. Summary of Hg concentrations and speciation measured in landfill gas upstream of the Brevard County landfill flair station on 11/17/98. Samples ranged from 5 - 30 min in duration, and were collected over a 7-h period (~1000 - 1700). Charcoal, TGM, and carbotrap organic Hg results are from D. Walschlager and R. Burnett at Frontier Geosciences.

Hg Species and Sample Type	Mean Hg (ng m^{-3})	SD Hg (ng m^{-3})
TGM (charcoal)	7190	330

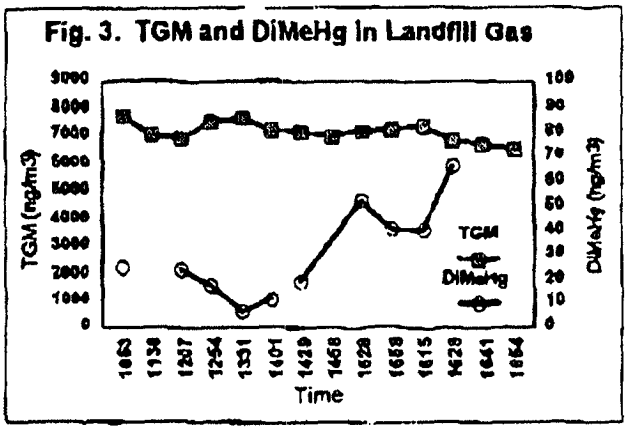
Hg Species and Sample Type	Mean Hg (ng m^{-3})	SD Hg (ng m^{-3})
TGM (gold, front trap)	8400	770
TGM (gold, backup trap)	4	4
Ratio (gold/charcoal)	1.2	0.1
Dimethyl mercury	30	18
Ratio (DiMethyl/TGM)	0.42%	0.26%
Monomethyl mercury	6	—*

*N=1 sample (MMHg was analyzed in a single 7-h cold condensation trap operated upstream of the carbotraps)

there was essentially no breakthrough onto the backup traps (mean back/front ratio <0.05%), increasing the confidence we have in these first-of-a-kind measurements. There was also a reasonably good (±20%) agreement between the gold and charcoal traps, with the gold traps biased high. However, the gold trap results are subject to some uncertainty because the loading was far beyond the normal calibration range of our CVAFS (we originally selected sampling times based on the lower Hg values we expected from our previous study).

- *Landfill gas contains important levels of methylated forms of Hg.* **It must be emphasized that these are preliminary data** (because of the unique nature of these samples there was only one opportunity/trap for analysis, and due to a varying instrument sensitivity over the period of analysis, several of the organic Hg results may be low by a factor of ~2, D Walschlager, pers. comm.). We know that gold traps quantitatively collect Hg°, and that charcoal traps collect all gaseous Hg forms, but the fate of organic Hg on gold traps is not well characterized. In our earlier study, we reported consistently higher Hg on charcoal than gold traps, and speculated that the difference of ~40-300 ng/m could

represent organic Hg (Lindberg and Price 1999). Although this Hg could not be identified, we did measure significant levels of MeHg in the LFG condensate (~20 ng/L at one site). Because of the need to confirm the formation and emission of gaseous methylated Hg species in LFG, a major objective at the BLF was to directly sample for organic Hg using published methods (Bloom and Fitzgerald 1988) in collaboration with D. Walschlager at Frontier Geosciences. We report here for the first time the positive identification of dimethyl mercury in LFG at concentrations orders of magnitude above background air. Both monomethyl (MMHg) and dimethyl mercury (DiMHg) were identified in the LFG samples. The primary species appears to be DiMHg which exhibited a mean concentration of ~30 ng/m³ (Table 6). MMHg was detected in the single LFG condensate sample we collected in a cold trap at a liquid concentration of 330 ng/L. Using Henry's Law, the gas phase concentration was estimated to be ~6 ng/m³ (Walschlager, pers. comm.). These forms of Hg have been identified in ambient air in Seattle at levels on the order of <0.01 ng/m³ for DMHg and <0.001 ng/m³ for MMHg (Prestbo et al. 1996). DMHg appeared to exhibit a trend of increasing concentrations over the day, although TGM remained quite



stable (Fig. 3). TGM varied by ~15% over 7 h, while DMHg increased from a minimum of ~7 to a peak ~70 ng/m³ over 3 h. DMHg averaged ~0.4% of TGM, but represented nearly 1% of TGM at its peak. These ratios are higher than those in ambient air measured in Seattle. Unlike at previously sampled sites, there are only crude estimates of total LFG flows at the BLF, with rates between ~400 and 800 scfm (~700 - 1300 m³/h) having been estimated at various times. Using this range, we estimate that the landfill flare releases TGM at a rate of ~3-6 mg/h, compared to a maximum of ~2 mg/h measured at our other sites. In addition, this landfill appears to generate methylated forms of Hg at a rate of about

0.01-0.02 mg/h. However, the >1500° F flare will assure that only inorganic Hg is released to the air at this site. Sites which generate raw LFG without flaring or other treatment could be important sources of airborne organic Hg.

Concluding Points

There now seems little doubt that not all landfills are comparable regarding internal levels of Hg and their contribution to the regional atmospheric Hg burden. This site is characterized by considerably higher levels of Hg than we reported earlier (Lindberg and Price 1999), and our estimates of Hg releases from landfills will increase once these data have been completely analyzed. However, it is clear from this brief summary of data from our third site that Hg is indeed lost to the air from various sources prior to the landfill process, during storage, transfer, and unloading/compacting activities. We plan an effort to quantify these losses. In addition, it is clear that broken fluorescent bulbs are strong sources of Hg^0 emissions, which appear to persist for at least several days. We now have the first evidence, of which we are aware, that methyl and dimethyl mercury are produced in landfill gas at levels far above ambient air, and may be emitted to the atmosphere from unflared sites. We are now planning Phase II of PaMSWaD which will take place at one of the larger landfill sites in Florida in 1999.

Acknowledgements

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