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Estimated Quantities and Trends of Cadmium, Lead, and Mercury in US Municipal Solid Waste Based on Analysis of Incinerator Ash

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Abstract

Heavy metals are present in a variety of products and can be released during product life cycles. The concentration of metals in municipal solid waste (MSW) reflects the amount of metals in products and is directly related to the amount of metals transferred to disposal sites. Measured monthly mean concentrations of cadmium, lead, and mercury in the ash from May 1995 through October 2007 at the Essex County, NJ incinerator and from May 2004 through November 2007 at the Warren County, NJ incinerator were used, along with air emissions data for mercury, to estimate the content of these metals in MSW. Estimated mean concentration and 95% confidence limits for cadmium in MSW at the Essex and Warren facilities, respectively, were 17.4±0.1 and 10.1±1.2 ppm. For lead, the corresponding values were 408±41 and 239±42 ppm, and for mercury, they were 2.6±0.2 and 0.9±0.2 ppm. A trend of increasing cadmium concentrations was found at both facilities. No change vs. time was observed in lead concentrations. Mercury concentration was found to be decreasing over time at the Essex facility.

Introduction

Many heavy metals have well-known toxic effects on living systems, and their use and disposal are regulated in a variety of ways. Nevertheless, because of useful physical and chemical properties, some heavy metals are intentionally added to consumer and industrial products.

Mercury was formerly included in some pharmaceutical products, agricultural chemicals, dry cell batteries, and paints and continues to be used in chloralkali production, switches and electrical apparatus, fluorescent light bulbs, and dental amalgam.[1] These ongoing uses of mercury are declining.[2] Cadmium was at one time extensively used in electroplating processes to coat iron and steel. In recent years, cadmium has been used increasingly for the production of rechargeable batteries, and this is now the dominant use of the metal. Lead was once widely added to gasoline in the form of tetraethyl lead and was also an important component in paints. The principal use of lead today is in the production of lead-acid batteries for automobiles and as power sources for information and telecommunication devices. Global lead consumption has been increasing along with the growth of information technology and the increase in use of automobiles and telecommunication networks.[3]

In some cases, at least partial releases of heavy metals to the environment during the normal life cycle of the product occur; in other cases, releases occur at disposal sites, although available data suggest that modern disposal facilities contain heavy metals relatively well.[4]

Since approximately 7% of MSW is incinerated in the US,[5] incinerator emissions and ash represent an issue of environmental concern.[6] MSW composition varies as a function of socioeconomic status, geographic location, season, collection patterns, and recycling practices;[7] therefore, representative sampling for heavy metals and pollutants in the waste stream is extremely difficult.[8]

A method used in the past to estimate the quantity of mercury in MSW was based on a survey of products containing the metal and the likely disposal rate of these products.[9] Other studies have attempted to quantify trends in heavy metal emissions from MSW incinerators through indirect measurement or estimation. Another method used to determine the metal content of MSW is direct output assessment. When refuse is incinerated organic substances are broken down and any heavy metals which become volatile at the high temperatures of incineration are released. A large percentage of volatilized metals is captured in pollution control systems and a small fraction escapes to the atmosphere. A portion remains in the bottom ash. The combined ash, containing both bottom ash and the residue from the control system, can then be analyzed. Any significant quantity of metals released to the air can be added in, and the input value of the incinerated product can be determined.[10]

In this study, the direct output assessment method was used to determine the content of cadmium, lead, and

mercury in MSW disposed at two of New Jersey's five MSW incinerators. These data were examined over time to determine if trends in the concentrations of these metals in MSW ash mirror the increasing use of cadmium and decreasing use of mercury and lead in products.

Materials and Methods

Residual ash and solid waste data were obtained from monthly reports of two MSW incinerators in New Jersey. These MSW incinerators are located in Essex and Warren counties. Data from these incinerators were reviewed. Total MSW (short tons), percent ash moisture, total ash residue (short tons), and total concentrations of cadmium, lead, and mercury (mg/kg) were tabulated on a monthly basis for the period 1995 to 2007 for the Essex County incinerator and from 2004 to 2007 for the Warren County incinerator.

Sample collection, preservation, and storage were carried out according to the methods specified in the NJDEP Field Sample Protocol Manual (http://www.nj.gov/dep/srp/guidance/fspm). Residual ash from facility operations was sampled monthly for total metals. The facility collected one sample every hour from the residue conveyor; the sample contained both bottom ash and fly ash in a mixed ratio representative of the combined ash residue generated for disposal or reuse. Daily composite samples were then prepared by combining all samples collected during each day. The resulting daily composite samples were then further combined into a monthly composite sample.

Chemical analysis of the monthly composite sample was carried out using appropriate USEPA methods suggested for each metal (http://www.epa.gov/epaoswer/hazwaste/test/ 3_series.htm). Total mercury was determined by USEPA SW-846 Method 7471A. With this method, prior to analysis, 0.2 g of the untreated sample was acid digested, and a sample solution was prepared according to the procedures described in the above-said method. The sample solution was analyzed by atomic absorption spectrometry. The absorbance at 253.7 nm wavelength was measured, which is a function of the concentration of mercury in the sample solution. Determinations of lead and cadmium were carried out by USEPA Method 3051/6020. According to this method, 0.5 g of the sample was subjected to microwave-assisted acid digestion. The sample was diluted, added with internal standards, and analyzed by inductively coupled plasma-mass spectroscopy. Concentrations of lead and cadmium were obtained from a linear regression calculation performed by the instrument software.

Data submitted as part of the monthly reports also included total tons of ash produced, total tons of MSW incinerated, and ash percent moisture. Mean monthly total content of cadmium, lead, and mercury of the ash was determined by multiplying the reported monthly concentration by the total amount of ash generated as adjusted to exclude the percent that was moisture.

This total was then compared with the total amount of waste incinerated to arrive at the estimated metals content of the waste. It was assumed that essentially all of the cadmium and lead in the waste ended up in the ash, which included both bottom and fly ash. In the case of mercury, an additional data source, quarterly stack tests of the mercury emissions to the air from the facilities, which are routinely reported to NJDEP, was used. The quantity of mercury in the air releases was added to the quantity of mercury in the ash to arrive at the total amount of mercury in the incinerated waste.

Results and Discussion

Plots of estimated monthly concentration of the three metals in MSW incinerated at each of the incinerators are shown in Figs. 1, 2, 3, 4, 5, 6.

Estimated mean concentration and 95% confidence limits for cadmium in MSW at the Essex and Warren facilities, respectively, were 17.4±0.1 and 10.1±1.2 ppm. For lead, the corresponding values were 408±41 and 239±42 ppm, respectively, and for mercury, the estimated MSW concentrations were 2.6±0.2 and 0.9±0.2 ppm, respectively.

Estimated cadmium concentrations in MSW were found to be increasing at both facilities, with ANOVA analysis showing a p value of <0.0001 for the trend in MSW disposed at the Essex County incinerator and a p value of 0.0257 for the trend in MSW disposed at the Warren County incinerator. No change over time was observed in estimated lead concentrations in MSW at either facility. A decrease over time was found in the estimated mercury content of MSW disposed at the Essex facility, with a p value of <0.0001.

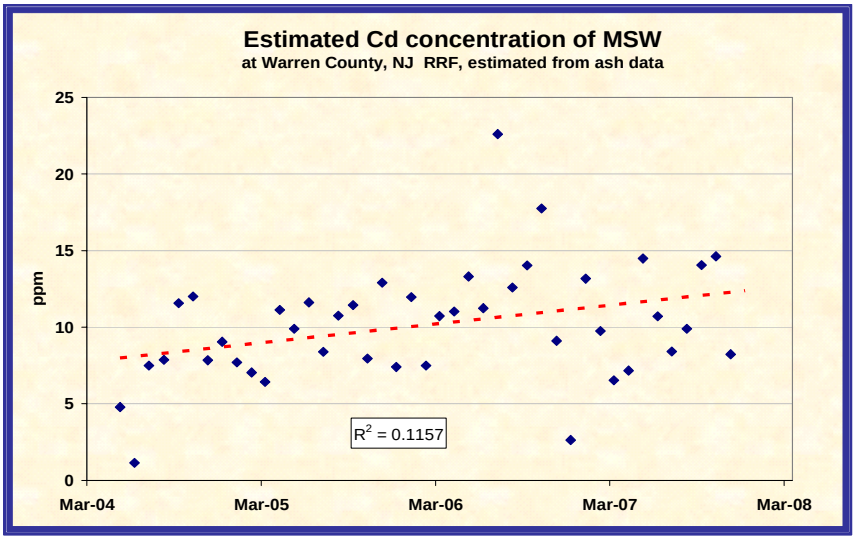

Fig. 1 Estimated cadmium concentration of MSW at Warren County, NJ RRF ,estimated from ash data

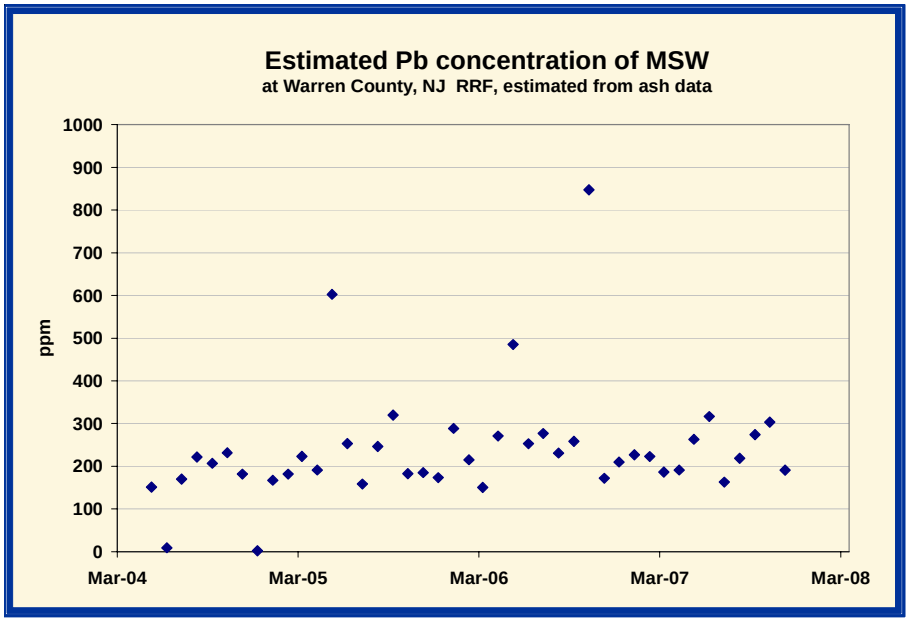

Fig. 2 Estimated lead concentration of MSW at Warren County, NJ RRF, estimated from ash data

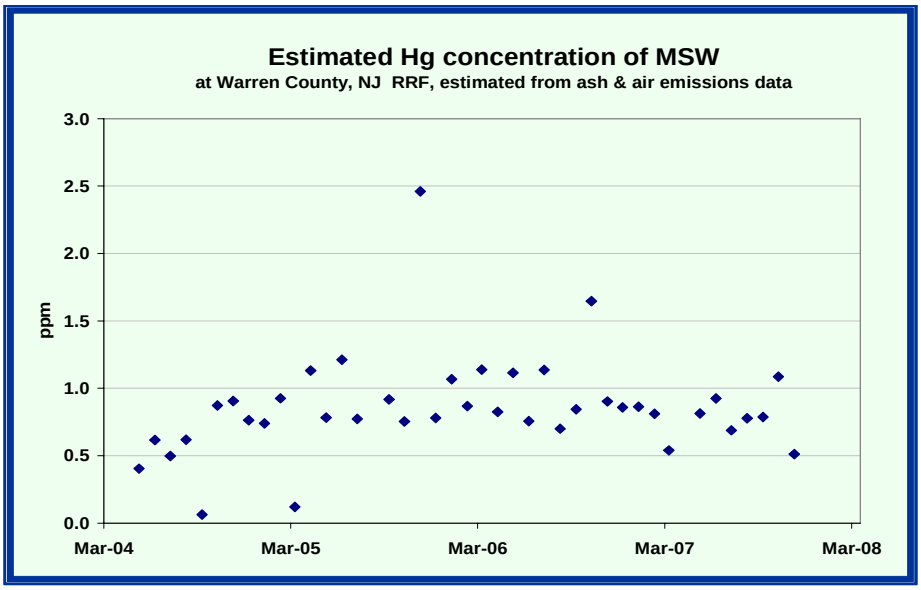

Fig. 3 Estimated mercury concentration of MSW at Warren County, NJ RRF, estimated from ash and air emission data

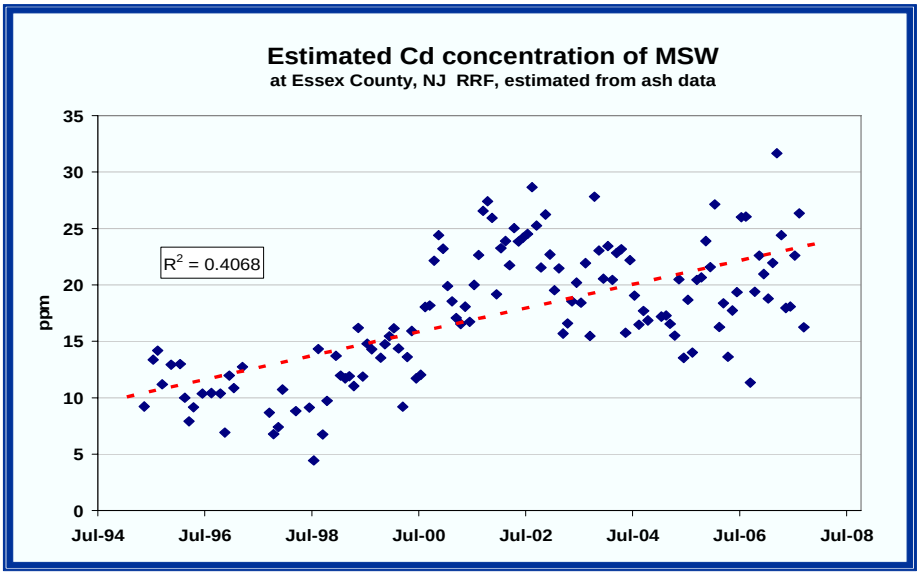

Fig. 4 Estimated cadmium concentration of MSW at Essex County, NJ RRF, estimated from ash data

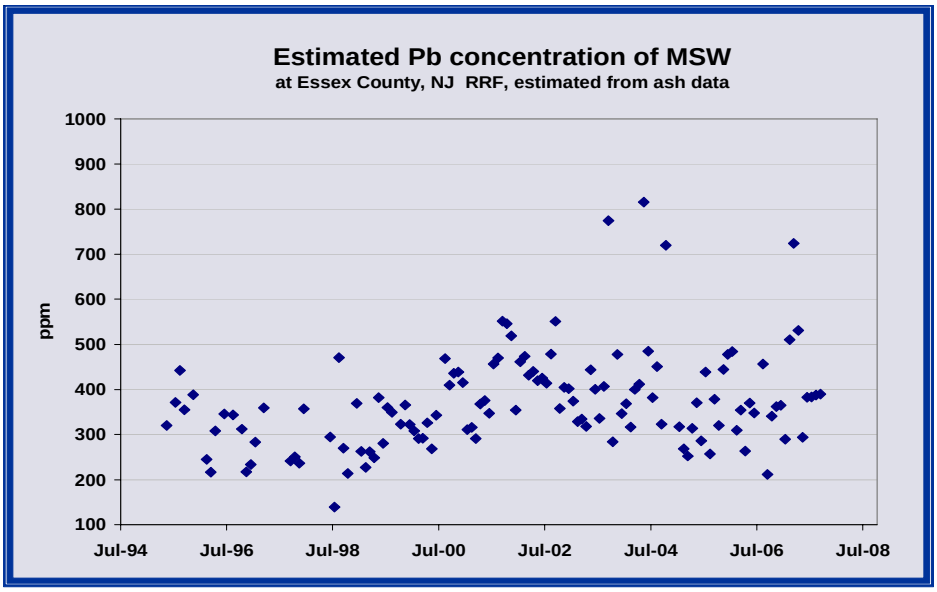

Fig. 5 Estimated lead concentration of MSW at Essex County, NJ RRF, estimated from ash data

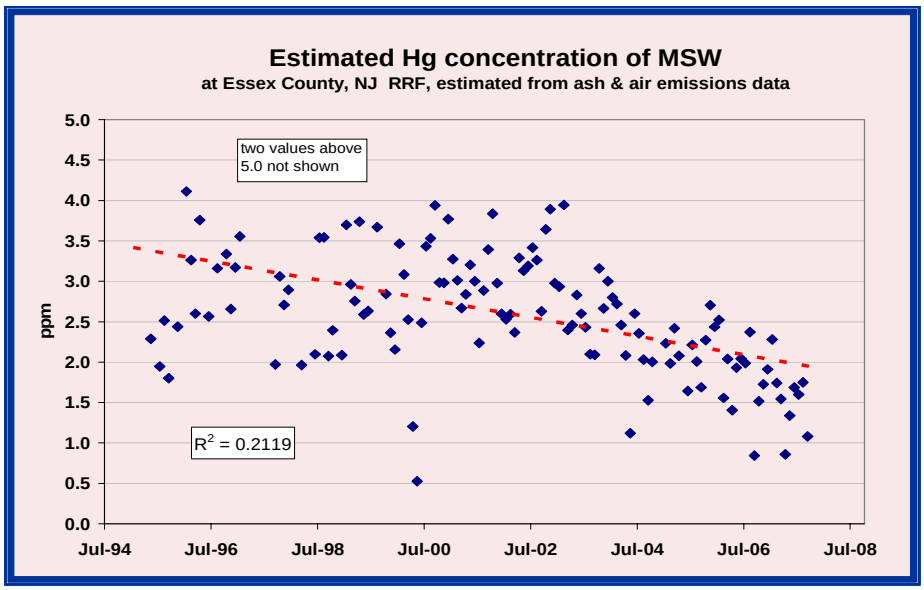

Fig. 6 Estimated mercury concentration of MSW at Essex County, NJ RRF, estimated from ash and air emission data

Conclusion

The increasing cadmium concentration in MSW at both facilities likely reflects the increased use of nickel-cadmium batteries in relatively inexpensive electronic items, as has been discussed elsewhere.[11] The decline in mercury concentration is consistent with the decrease in the overall quantity of mercury used in the US as discussed in recent reports.[12] [13] There is no trend in lead concentrations evident at either facility.

Available data and models suggest that modern landfills, which receive both MSW and ash from combustion of MSW, contain heavy metals relatively well.[14] Nevertheless, the monitoring history of today's disposal facilities is short compared to the geological time periods through which heavy metals and other disposed substances are expected to be sequestered. A trend of increasing quantity of heavy metals in the waste stream, as is evident with cadmium in this study, highlights the need for continued long-term monitoring of releases of heavy metals from landfills.

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